THE EARTH'S BEST DEFENSE

March 14, 2011

Via electronic mail

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Re: Comments on Tentative Order No. 2011-XX-DWQ

The Natural Resources Defense Council, on behalf of our over 100,000 California members and activists, appreciates the opportunity to comment on Tentative Order No. 2011-XX-DWQ, NPDES No. CAS000003, the Draft National Pollutant Discharge Elimination System (NPDES) Statewide Storm Water Permit Waste Discharge Requirements (WDRS) for State of California Department of Transportation ("Tentative Order"). We are concerned that, in critical aspects, the Tentative Order is inconsistent with state and federal law. In particular, the Tentative Order's approach to use of low impact development ("LID") is highly flawed; the Tentative Order's LID provisions are vague and ambiguous and fail to implement the federal maximum extent practicable standard. The flaws in the LID approach are even more apparent in contrast to recent adoptions by the Los Angeles, Santa Ana, San Diego, and San Francisco Regional Water Quality Control Board of LID provisions in Municipal Separate Storm Sewer ("MS4") permits which require onsite retention of the 85th percentile design storm. We strongly encourage the State Water Resources Control Board ("State Board") to revise the Tentative Order to address this and other issues discussed below.

I. Standards Governing the Adoption of the Tentative Order by the Regional Board

In considering the Tentative Order, the State Board must not only ensure compliance with substantive legal standards, but it must also ensure that it complies with well-settled standards that govern its administrative decision-making. The Tentative Order must be supported by evidence that justifies the State Board's decision to include, or not to include, specific requirements. The State Board would be abusing its discretion if the Tentative Order ultimately fails to contain findings that explain the reasons why certain control measures and standards have been selected and others omitted. Abuse of discretion is established if "the respondent has not proceeded in the manner required by law, the order or decision is not supported by the findings, or the findings are not supported by the evidence." (Cal. Code Civ. Proc. § 1094.5(b); *see also Zuniga v. Los Angeles County Civil Serv. Comm'n* (2006) 137 Cal.App.4th 1255, 1258 (applying same statutory standard); *Phelps v. State Water Resources Control Bd.* (2007) 157 Cal.App.4th 89, 98-99 ("abuse of discretion is established if the court determines that the findings are not supported by the weight of the evidence").)

The administrative decision must be accompanied by findings that allow the court reviewing the order or decision to "bridge the analytic gap between the raw evidence and ultimate decision or order." (*Topanga Ass'n for a Scenic Cmty. v. County of Los Angeles* (1974) 11 Cal.3d 506, 515.) This requirement "serves to conduce the administrative body to draw legally relevant sub-conclusions supportive of its ultimate decision … to facilitate orderly analysis and minimize the likelihood that the agency will randomly leap from evidence to conclusions." (*Id.* at 516.) "Absent such roadsigns, a reviewing court would be forced into unguided and resource-consuming explorations; it would have to grope through the record to determine whether some combination of credible evidentiary items which supported some line of factual and legal conclusions supported the ultimate order or decision of the agency." (*Id.* at 517 n.15.) Currently, the Tentative Order's provisions are not supported by the necessary evidence, as discussed below, and the State Board has failed to explain its decision not to adopt control measures and standards that have been adopted by other jurisdictions and proven by scientific studies to be more effective than the control measures and standards in the Tentative Order. The lack of substantial evidence to support the Tentative Order renders it unlawful. (*See, e.g., Bangor Hydro-Elec. Co. v. F.E.R.C.* (D.C. Cir. 1996) 78 F.3d 659, 664.)

II. The Tentative Order's Definition of Maximum Extent Practicable is Inadequate

Section 402(p) of the Clean Water Act ("CWA") establishes the maximum extent practicable ("MEP") standard as a requirement for pollution reduction in stormwater permits. The Act states that discharges from MS4 systems "shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants." The Tentative Order defines the maximum extent practicable standard as follows:

> The minimum required performance standard for implementation of municipal storm water management programs to reduce pollutants in storm water. . . . MEP is the cumulative effect of implementing, evaluating, and making corresponding changes to a variety of technically appropriate and economically feasible BMPs, ensuring that the most appropriate controls are implemented in the most effective manner. This process of implementing, evaluating, revising, or adding new BMPs is commonly referred to as the iterative process.

(Appendix C, at 5; see also Tentative Order, at Finding 7.) This vague pronouncement fails to adequately describe the requirements of the MEP standard. "[T]he phrase 'to the maximum extent practicable' does not permit unbridled discretion. It imposes a clear duty on the agency to fulfill the statutory command to the extent that it is feasible or possible." (*Defenders of Wildlife* *v. Babbitt* (D.D.C. 2001) 130 F.Supp.2d 121, 131 (internal citations omitted); *Friends of Boundary Waters Wilderness v. Thomas* (8th Cir. 1995) 53 F.3d 881, 885 ("feasible" means "physically possible").) Provisions that establish "what the discharger will do to reduce discharges to the 'maximum extent practicable,' cross[] the threshold from being an item of procedural correspondence to being a substantive component of a regulatory regime." (*Environmental Defense Center, Inc. v. U.S. EPA* (9th Cir. 2003) 344 F.3d 832, 853 (discussing requirements for implementing minimum measures in Phase II general MS4 permits).) Merely stating that the MEP standard creates a "minimum required performance standard" that is the "cumulative effect of implementing, evaluating, and making corresponding changes" to BMPs fails to adequately ensure the rigorous requirements of the MEP standard will be met.

The significance of this requirement has been recognized in a variety of jurisdictions. As one state hearing board held:

> [MEP] means to the fullest degree technologically feasible for the protection of water quality, except where costs are wholly disproportionate to the potential benefits . . . . This standard requires more of permittees than mere compliance with water quality standards or numeric effluent limitations designed to meet such standards . . . . The term "maximum extent practicable" in the stormwater context implies that the mitigation measures in a stormwater permit must be more than simply adopting standard practices. This definition applies particularly in areas where standard practices are already failing to protect water quality . . . .

(*North Carolina Wildlife Fed. Central Piedmont Group of the NC Sierra Club v. N.C. Division of Water Quality* (N.C.O.A.H. October 13, 2006) 2006 WL 3890348, Conclusions of Law 21-22 (internal citations omitted).) The North Carolina board further found that the permits in question violated the MEP standard both because commenters highlighted measures that would reduce pollution more effectively than the permits' requirements and because other controls, such as infiltration measures, "would [also] reduce discharges more than the measures contained in the permits." (*Id.* at Conclusions of Law 19.) The State Board should revise its proposed definition here, to ensure that the Tentative Order's governing performance standards properly implement federal requirements.

III. The Tentative Order's Project Planning and Design Section is Legally Inadequate

a. <u>LID is a Superior and Practicable Method of Addressing Stormwater</u>

As currently written, the Tentative Order does not require any specific level LID[1] implementation and would, as explained below, allow relatively ineffective conventional treat-

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[1] We advocate the implementation of LID practices because LID practices retain stormwater onsite through infiltration, harvesting and reuse, or evapotranspiration, thus ensuring that pollutant loads do not reach receiving waters. Others have advanced interpretations of "LID" that include the use of treat-and-discharge systems—these systems are not as effective as retention practices because the discharged water may still contain pollution, even if it is

and-discharge techniques to be used to address runoff in place of LID practices that retain runoff onsite. Indeed, the Tentative Order's LID provisions are entirely separated from the Tentative Order's numeric sizing criteria, and by the Fact Sheet's own admission, are generally "not required to be implemented but are listed in order of preference" for implementation.[2] The Tentative Order fails to meet the MEP standard as a result of its lack of any specific numeric metric for implementation of LID.

The Project Planning and Design section is critical for addressing the root causes of stormwater pollution. As the U.S. Environmental Protection Agency (U.S. EPA) has noted: "Most stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development. The addition of impervious surfaces, soil compaction, and tree and vegetation removal result in alterations to the movement of water through the environment. As interception, evapotranspiration, and infiltration are reduced and precipitation is converted to overland flow, these modifications affect not only the characteristics of the developed site but also the watershed in which the development is located. Stormwater has been identified as one of the leading sources of pollution for all waterbody types in the United States. Furthermore, the impacts of stormwater pollution are not static; they usually increase with more development and urbanization."[3] This is particularly the case with discharges from highway or road surfaces; concentrations of pollutants in highway runoff frequently exceed numeric limits designed to protect the health of receiving waters.[4]

LID has been established as a *superior and practicable* strategy[5] and, therefore, must be required. Accordingly, the U.S. EPA has called upon Regional Boards across California to prioritize the implementation of LID using numeric metrics. Notably, U.S. EPA threatened to "consider objecting to the [San Francisco Bay region's MS4] permit" if it did not include

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significantly attenuated. Our interpretation of "LID" is consistent with the U.S. EPA's: "LID comprises a set of approaches and practices that are designed to reduce runoff of water and pollutants from the site at which they are generated. By means of infiltration, evapotranspiration, and reuse of rainwater, LID techniques manage water and water pollutants at the source and thereby prevent or reduce the impact of development on rivers, streams, lakes, coastal waters, and ground water." U.S. Environmental Protection Agency (December 2007) *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*, at iii ("U.S. EPA LID Study").

[2] Tentative Fact Sheet, at 15-16.

[3] U.S. EPA LID Study, at v.

[4] See, e.g., California Department of Transportation ("Caltrans") (June 2003) *Caltrans Tahoe Highway Runoff Characterization and Sand Trap Effectiveness Studies*, CTSW-RT-03-054.36.02, at ES-2, *available at* http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-03-054.pdf.

[5] California Ocean Protection Council (May 15, 2008) *Resolution of the California Ocean Protection Council Regarding Low Impact Development*, at 2.

"additional, prescriptive requirements" for LID.[6] Along with the prioritization of LID implementation, "EPA's primary objective for incorporating LID into renewed MS4 permits, especially for those that represent the third or fourth generation of permits regulating these discharges, is that the permit must include clear, measurable, enforceable provisions for implementation of LID .... [P]ermit[s] should [also] include a clearly defined, enforceable process for requiring off-site mitigation for projects where use of LID design elements is infeasible."[7] In North Orange County, EPA likewise observed that the MS4 "permit must include clear, measurable, enforceable provisions for implementation of LID .... We would not support replacing [volume retention-based] approaches with qualitative provisions that do not include measurable goals."[8]

Other government agencies in California and around the U.S. have come to the same conclusions. The California Ocean Protection Council, for instance, strongly endorsed LID last year by "resolv[ing] to promote the policy that new developments and redevelopments should be designed consistent with LID principles" because "LID is a practicable and superior approach . . . to minimize and mitigate increases in runoff and runoff pollutants and the resulting impacts on downstream uses, coastal resources and communities."[9] In Washington State, the Pollution Control Hearings Board has found that LID techniques are technologically and economically feasible and must, therefore, be required in MS4 permits.[10] The National Academy of Sciences recently issued a comprehensive report with the same recommendation for stormwater management programs: "Municipal permittees would be required under general state regulations to make [LID] techniques top priorities for implementation in approving new developments and redevelopments, to be used unless they are formally and convincingly demonstrated to be infeasible."[11]

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[6] Letter from Douglas E. Eberhardt, EPA, to Dale Bowyer, San Francisco Bay Regional Water Quality Control Board (April 3, 2009), at 1.

[7] *Id.* at 1-2.

[8] Letter from Douglas E. Eberhardt, EPA, to Michael Adackapara, Santa Ana Regional Water Quality Control Board (February 13, 2009), at 2-3.

[9] California Ocean Protection Council (May 15, 2008) *Resolution of the California Ocean Protection Council Regarding Low Impact Development*, at 2.

[10] *Puget Soundkeeper Alliance et al. v. State of Washington, Dept. of Ecology, et al.* (2008) Pollution Control Hearings Board, State of Washington, No. 07-021, 07-026, 07-027, 07-028, 07-029, 07-030, 07-037, Phase I Final, at 6, 46, 57-58.

[11] National Academy of Sciences, Committee on Reducing Stormwater Discharge Contributions to Water Pollution, National Research Council (2008) *Urban Stormwater Management in the United States*, at 500.

Critically, as demonstrated in the EPA comments quoted above, the prioritization of LID practices is insufficient by itself to meet the MEP standard and *must* be paired with a measurable requirement for the implementation of LID. Since its inception, the MS4 permitting program has been seriously hampered by a pervasive absence of numeric performance standards for the implementation of best management practices ("BMPs") such as LID. For this reason, in December 2007, the State Water Resources Control Board commissioned a report which found that "[t]he important concept across all of [the] approaches [described in the report] is that the regulations established a *performance requirement to limit the volume of stormwater discharges*."[12] The report also noted that "[m]unicipal permits have the standard of Maximum Extent Practicable (MEP) which lends itself more naturally to specifying and enforcing a level of compliance for low impact development."[13] Another study, completed for the Ocean Protection Council, recommended the following standard: "Regulated development projects shall reduce the percentage of effective impervious area to less than five percent of total project area by draining stormwater into landscaped, pervious areas."[14]

While we appreciate the fact that the Tentative Order does require some undefined level of LID implementation, the Tentative Order remains legally insufficient due to the lack of a numeric performance requirement for LID, and the availability of all-encompassing waivers from treatment standards (discussed below). These problems with the Project Planning and Design Component need to be remedied before the Tentative Order will meet the Clean Water Act's MEP standard for pollutant reduction.

b. <u>The Tentative Order Does Not Contain—Nor Does it Justify the Lack of—Specific Standards for LID Implementation</u>

The Fact Sheet notes that "[t]he proper implementation of LID techniques not only results in water quality protection benefits and a reduction of land development and construction costs." However, the Fact Sheet's claim that "[t]he requirements of this Order facilitate the implementation of LID strategies to protect water quality, reduce runoff volume, and to promote sustainability" falls flat.[15] Instead, the Tentative Order's LID provisions represent a collection of largely hortatory provisions with no specific measurable outcome. Unfortunately, even the vast majority of the Tentative Order's LID provisions fall into this category, requiring only, for example, "*Conservation* of natural areas, *to the extent feasible*"; "*Minimization* of . . . impervious footprint"; "*Minimization*

[12] State Water Resources Control Board (December 2007) *A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption*, at 23 (emphasis added) (hereinafter "SWRCB LID Report").

[13] *Id.* at 4.

[14] Ocean Protection Council of California (January 2008) *State and Local Policies Encouraging or Requiring Low Impact Development in California*, at 27.

[15] Tentative Fact Sheet, at 15.

of disturbances to natural drainages"; "Use of climate-appropriate landscaping that *minimizes* irrigation and runoff [and] *promotes* surface infiltration . . . ." (Tentative Order ¶ E.2.d.(1).(d).(1)-(5).) Such vague provisions would not enable the State Board or Caltrans to measure the outcomes of, or to enforce, the Tentative Order's requirements since implementation could vary enormously.

i. The Tentative Order Must Establish Numeric Requirements for the Onsite Retention of Stormwater

The Tentative Order fails to set a specific numeric performance standard for the implementation of LID practices at Department and Non-Department Projects. As a result, provided that a project installs some *de minimis* LID features, it would comply with the Tentative Order. In effect, LID features would not have to be sized to accommodate any meaningful quantity of stormwater. This is completely contrary to the exhortations of expert agencies and scientists, as described above, or standards already adopted in numerous MS4 permits, ordinances, and regulations around the country. For example, the Regional Water Quality Control Boards for the Los Angeles, Santa Ana, and San Diego Regions have all recently adopted MS4 permits that effectively require new and redevelopment projects to retain onsite the 85th percentile storm through use of LID practices that infiltrate, harvest and reuse, or evapotranspire stormwater runoff, unless technically infeasible to do so.[16] The state of West Virginia has adopted a statewide Phase II MS4 permit that requires projects to retain onsite "the first one inch of rainfall from a 24-hour storm" event unless infeasible.[17] Federal buildings over 5,000 square feet must manage onsite (*i.e.*, prevent the offsite discharge of) the 95th percentile storm through infiltration, harvesting, and/or evapotranspiration.[18] And the City of Philadelphia requires projects to infiltrate the first one inch of rainfall from all impervious surfaces; if onsite infiltration is infeasible, the same performance must be achieved offsite.[19]

These jurisdictions have recognized the paramount importance of mandating onsite retention of a certain quantity of stormwater since onsite retention prevents *all* pollution in that

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[16] See, Los Angeles Regional Water Quality Control Board, Order No R4-2010-0108 (July 8, 2010) (Ventura County MS4 Permit. Through use of an Effective Impervious Area limitation, the Permit effectively requires retention of 95 percent of the 85th percentile storm); Santa Ana Regional Water Quality Control Board, Order No. RB8-2009-0030 (May 22, 2009) (North Orange County MS4 Permit); San Diego Regional Water Quality Control Board, Order No. R9-2009-0002 (December 16, 2009) (South Orange County MS4 Permit)

[17] State of West Virginia (June 22, 2009) Department of Environmental Protection, Division of Water and Waste Management, General National Pollution Discharge Elimination System Water Pollution Control Permit, NPDES Permit No. WV0116025 at 13-14.

[18] 42 U.S.C. § 17094; U.S. EPA (2009) Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects, at 12.

[19] City of Philadelphia, Stormwater Management Guidance Manual 2.0, at 1.1 (Jan. 29, 2008).

volume of rainfall from being discharged to receiving waters. Indeed, Caltrans itself has recognized this principle, stating that that "Infiltration basins and trenches [that retain water onsite] . . . provide the highest level of surface water quality protection. . . . [and] reduce the total amount of runoff, restoring some of the original hydrologic conditions of an undeveloped watershed."[20] Moreover, Caltrans has found that where use of infiltration BMPs was technically feasible, they "were among the most cost-effective BMPs tested."[21] By definition, Caltrans has found that, where technically feasible, retaining water onsite through this type of practice is MEP. Under the Clean Water Act, it must be required.

Yet nowhere under the Tentative Order's Low Impact Development provisions is there any requirement that establishes a level of implementation for LID practices. Instead, the LID requirements are noticeably divorced from the Project Planning and Design section's "Numeric Sizing Criteria for Storm Water Treatment Controls." Under this section, the Tentative order requires only that "projects shall infiltrate at least 90 percent of the storm water runoff from an 85th percentile 24-hour storm event[22] *or* meet at least one of the numeric sizing criteria below" through use of treatment control methods. (Tentative Order ¶ E.2.d.(1).(a).(ii).)[23] Thus, whether to use infiltration practices which by Caltrans' own admission "provide the highest level of surface water protection" and are "among the most cost-effective practices" is entirely discretionary. As treatment control BMPs can include conventional controls and engineered solutions that are demonstrably inferior to retention practices,[24] this requirement fails to meet the requirements of the MEP standard.

Moreover, the Tentative Order appears to ignore the use of practices such as evapotranspiration or harvesting and reuse that are mandated by numerous other MS4 permits in California as a means of meeting the 85th percentile storm retention requirement.[25] Where feasible, infiltration, as well as these other practices that retain runoff onsite, *must* be required by the Order. The Tentative Order's language leaving to Caltrans' discretion whether to infiltrate

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[20] Caltrans (January 2004) *BMP Retrofit Pilot Program, Final Report*, CTSW-RT-01-050, at viii.

[21] *Id.*, at ix.

[22] We are concerned that the standard articulated in the Tentative Order, requiring infiltration of 90 percent of the 85th percentile storm, would allow for discharge, untreated, of the remaining 10 percent of the 85th percentile volume, in apparent violation of the standard articulated in State Board WQ Order 2000-11.

[23] The Tentative Order defines Treatment Control BMPs as "Any engineered system designed to remove pollutants by simple gravity settling of particulate pollutants, filtration, biological uptake, media absorption or any other physical, biological, or chemical process, thus apparently including conventional engineered controls in addition to LID controls that retain runoff onsite.

[24] See, R. Horner (2007) *Initial Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Francisco Bay Area.*

[25] See note 16, *supra.*

runoff or utilize other treatment control methods amounts to no requirement at all for infiltration, and ignores other practices that result in the onsite retention of stormwater. To meet the MEP standard, the State Board must ensure that LID practices that retain stormwater onsite unless technically infeasible.

c. The Tentative Order's Allowance for Complete Waivers from Treatment Control Requirements violates the Clean Water Act

Federal regulations mandate that MS4 permits impose requirements to reduce the discharge of stormwater pollution from new development and redevelopment projects. (40 C.F.R. § 122.26.) The State Water Board—through the *Bellflower* decision—has gone further and established the SUSMP hydraulic sizing criteria as a compliance floor for all Priority Development Projects (or here, Department and Non-Department Projects).[26] A permit cannot meet the MEP standard if it does not impose these criteria to reduce stormwater pollution, yet these criteria are exactly what the Tentative Order would allow the Executive Officer to waive where the Officer finds that "a project will have minimal impact to water quality." (Tentative Order ¶ E.2.d.(1).(a).(i).(3).) The CWA requires that discharges from MS4 systems "shall require controls to reduce the discharge of pollutants to the maximum extent practicable," not only from projects with significant impacts to water quality, but from all projects. This section should be revised accordingly.

IV. The Tentative Order Fails to Include Provisions that Effectively Prohibit all Non-Stormwater Discharges, as Required by the Clean Water Act

Federal law requires that MS4 permits "shall include a requirement to *effectively prohibit* non-stormwater discharges into the storm sewers." (Tentative Order ¶ B.2.) The Tentative Order states that certain enumerated non-stormwater discharges "are conditionally exempt from [the] prohibition" against non-stormwater discharges into the MS4 system.[27] But federal regulations under the CWA are clear: when any of the categories of non-stormwater discharges identified as exempt in the Tentative Order are identified as sources of pollution, they are disallowed.[28] Caltrans' own data indicates that agricultural runoff is a source of pollutants, and

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[26] State Water Resources Control Board (2000) Water Quality Order No. 2000-11, at 15-18.

[27] Tentative Order, p. 18.

[28] 40 C.F.R. § 122.26(d)(2)(iv)(B)(1). While we focuse here on discharge sources identified as sources of pollution, Section 402(p)(3)(B)(ii) of the CWA requires that permits for discharge from municipal sewers "effectively prohibit non-stormwater discharges," and does not create any authorization for exemption of such discharges. The Clean Water Act's implementing regulations under 40 C.F.R. § 122.26(d)(2)(iv)(B)(1) set forth the circumstances under which the permittee must specifically design a program to "to detect and remove (or require the discharger to the municipal separate storm sewer to obtain a separate NPDES permit for) illicit discharges and improper disposal into the storm sewer" of specified non-storm water discharges or flows identified as sources of pollutants. Yet, the requirement of an enforcement program to "detect

so should be "removed" according to federal regulations.

The Fact Sheet states that "the CWA exempts agricultural irrigation water return flows from the NPDES program."[29] Yet Section 402(l)(1) of the CWA states only that, "The Administrator shall not require a permit under this section, for discharge composed *entirely* of return flows from irrigated agriculture." (Emphasis added.) Thus, unless there is absolutely no other component to discharge from Caltrans' MS4 systems, the fact that a component, or a portion of its discharge stems from agricultural return flow does not exempt Caltrans from effectively prohibiting the discharge of agricultural runoff to the MS4 system. Just as untenable is the State Board's position that if agricultural irrigation water is "regulated by WDRs or conditional waivers of WDRs" and if the Caltrans cooperates with organizations conducting monitoring of such discharges, the discharges are as a result not expected to be a source of pollutants and need not be prohibited. (Tentative Order ¶ B.2 n.3.)

State and Regional Water Board databases and reports similarly demonstrate significant, ongoing contamination associated with even "regulated" agricultural runoff. In November 2010, the Central Coast Regional Water Quality Control Board ("Central Coast Board") stated that agricultural discharges (pesticides, sediment, nutrients) are a "major cause of water pollution" in the Central Coast Region.[30] While agricultural runoff has been regulated by a conditional waiver for years, the Central Coast Board still finds agricultural discharges "continue to contribute to already significantly impaired water quality."[31] Similarly, the Central Valley Regional Water Quality Control Board ("Central Valley Board") has stated that agricultural discharge "can affect water quality by transporting constituents of concern" including pesticides, sediment, nutrients, salts, pathogens, and heavy metals from agricultural fields.[32] The Central Valley Board finds that many water bodies are impaired because of "pollutants from agricultural sources,"[33] and that over 60% of regional water quality exceedances occur during irrigation season.[34]

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and remove . . . illicit discharges," does not support the construction, seemingly implemented by the Tentative Order, that certain specified categories of non-stormwater discharges are "*exempt . . . unless*" they are identified as a source of pollution. Tentative Order ¶ B.2 (emphasis added).

[29] Tentative Fact Sheet, at 3.

[30] Regional Water Quality Control Board, Central Coast Region (2010) *Recommendations for Water Code Waiver for Agricultural Discharges*, at 7.

[31] *Id.*

[32] Regional Water Quality Control Board, Central Valley Region (2010) *Draft Program Environmental Impact Report*, at 1.

[33] *Id.*

[34] State Water Resources Control Board & Central Valley Regional Water Quality Control Board, "Report to the California State Legislature Joint Legislative Budget Committee on Reduction of Agricultural Pollution Runoff into the Sacramento-San Joaquin Delta," p. 2 (2011).

Agricultural irrigation run-off is not just a pervasive problem for regional boards; it is a problem for Caltrans, as demonstrated by their own data. In the Caltrans Characterization Study performed for the Tentative Order, monitoring results indicated that "conventional pollutants, trace metals, and nutrients were higher in agricultural" areas.[35] Caltrans's own monitoring sites "exhibited higher concentrations of most conventional pollutants (EC, DOC, TDS, TOC, TSS)" for agricultural areas than all other land uses.[36] Trace metals found in Caltrans's storm drains around agricultural areas showed "consistently higher concentrations" than for other land uses.[37] Nutrient pollution followed the same pattern, as total phosphorus, orthophosphate, and TKN were "significantly higher" in agricultural areas.[38] In sum, there is no basis to conclude that agricultural runoff is not a source of pollutants, or to exempt agricultural runoff from the prohibition against non-stormwater discharges to the MS4.[39]

Likewise, landscape irrigation, irrigation water and lawn watering, categories of non-stormwater discharges currently identified as exempt from the prohibition against non-stormwater discharges to the MS4, are known sources of pollution. For example, lawn irrigation has been identified as a "hot spot" for nutrient contamination in urban watersheds—lawns "contribute greater concentrations of Total N, Total P and dissolved phosphorus than other urban source areas … source research suggests that nutrient concentrations in lawn runoff can be as much as four times greater than other urban sources such as streets, rooftops or driveways."[40] These additional known sources of pollution must be prohibited from entering the MS4.

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[35] California Department of Transportation (2003) *Storm Water Monitoring & Data Management: Discharge Characterization Study Report*, at 67.

[36] *Id.* at 55.

[37] *Id.*

[38] *Id.*

[39] The San Diego Regional Water Quality Control Board has previously eliminated exemptions for both agricultural irrigation discharges and landscape irrigation discharges. In the case of agricultural discharges, the Board found them to be "significant sources of pollution." Water Quality Ordinances Update: Hearing Before the Board of Supervisors and Orange County Flood Control District, (2011), *available at* http://cams.ocgov.com/Web_Publisher/Agenda02_01_2011_files/images/A10-001604.HTM; see also, Memo from Catherine George Hagan, San Diego Regional Water Quality Control Board, to Chairman Wright and Members of the Regional Board (Nov. 5, 2009) re: Regulatory Authority for Imposing Numeric Effluent Limits on Dry Weather, Non-Storm Water Discharges, in Municipal Storm Water Permits, at 3-5.

[40] Center for Watershed Protection (March 2003) *Impacts of Impervious Cover on Aquatic Systems* at 69; see also H.S. Garn (2002) *Effects of lawn fertilizer on nutrient concentration in runoff from lakeshore lawns, Lauderdale Lakes, Wisconsin.* U.S. Geological Survey Water-Resources Investigations Report 02-4130 (In an investigation of runoff from lawns in Wisconsin,

V. Numeric Effluent Limitations Must be Established Where Feasible

The U.S. EPA recently stated that "where the NPDES authority determines that MS4 discharges . . . . have the reasonable potential to cause or contribute to water quality standards excursions, permits for MS4s . . . should contain numeric effluent limitations where feasible to do so."[41] Without providing any justification, the Tentative Order states that, outside of the Lake Tahoe area, "Storm water discharges from MS4s are highly variable in frequency, intensity, and duration, and it is difficult to characterize the amount of pollutants in the discharges," thus, numeric effluent limitations ("NELs") are not appropriate. Yet the fact that NELs are feasible for Lake Tahoe, an area with highly variable weather and use conditions, illustrates that the process is "feasible." The Tentative Order should be revised to incorporate NELs for all locations where it is feasible to do so, in accordance with U.S. EPA guidance.

VI. Conclusion

For the aforementioned reasons, the Tentative Order requires substantial revision and is unlawful under federal and state law, in particular to pass legal muster under the CWA's MEP standard. These changes are necessary to ensure the protection of the waters of this state, and we strongly urge the State Board to reject the Tentative Order as currently drafted, and to provide staff with clear direction on the modifications that are required, as discussed above.

Sincerely,

Noah Garrison
Project Attorney
Natural Resources Defense Council

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runoff from fertilized lawns contained elevated concentrations of phosphorous and dissolved phosphorous).

[41] Memorandum from James Hanlon, U.S. EPA Office of Wastewater Management and Denise Keehner, U.S. EPA Office of Wetlands, Oceans and Watersheds to Water Management Division Directors, Regions 1-10 (Nov, 12, 2010) re: Revisions to the November 22, 2002 Memorandum 'Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs, at 3. For adopted TMDLs that include wasteload allocations for stormwater discharges, "permits for . . . MS4 discharges must contain effluent limits and conditions consistent with the . . . WLAs in the TMDL." *Id.,* citing 40 CFR Sec. 122.44(d)(1)(vii)(B).

INITIAL INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR THE SAN FRANCISCO BAY AREA

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ABSTRACT

The Clean Water Act NPDES permit that regulates municipal separate storm sewer systems (MS4s) in the San Francisco Bay Area, California will be reissued in 2007. The draft permit includes general provisions related to low impact development practices (LID) for certain kinds of development and redevelopment projects. Using six representative development project case studies, based on California building records, the author investigated the practicability and relative benefits of LID options for the majority of the region having soils potentially suitable for infiltration either in their natural state or after amendment using well recognized LID techniques. The results showed that (1) LID site design and source control techniques are more effective than conventional best management practices (BMPs) in reducing runoff rates; and (2) in each of the case studies, LID methods would reduce site runoff volume and pollutant loading to zero in typical rainfall scenarios.

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INTRODUCTION

The Assessment in Relation to Municipal Permit Conditions

This purpose of this study is to investigate the relative water quality and water reuse benefits of three levels of storm water treatment best management practices (BMPs): (1) basic "treat-and-release" BMPs (e.g., drain inlet filters, CDS units), (2) commonly used BMPs that expose runoff to soils and vegetation (extended-detention basins and biofiltration swales and filter strips), and (3) low impact development (LID) practices. The factors considered in the investigation are runoff volume, pollutant loading, and the availability of water for infiltration or other reuse. In order to assess the differential impact of storm water reduction approaches on these factors, this study examines six case studies typical of development covered by the proposed Municipal Regional Urban Runoff Phase I NPDES Stormwater Permit (MRP).

This report covers locations in the Bay Area most amenable to soil infiltration of stormwater runoff, those areas having soils in Natural Resources Conservation Service (NRCS) Hydrologic Soil Groups A, B, or C as classified by the Natural Resources Conservation Service (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). Depending on site-specific conditions, A and B soils would generally effectively infiltrate water without modification, whereas C soils could require organic amendments according to now standard LID methods. This report does not cover locations with group D soils, which are generally not amenable to infiltration, again depending on the specific conditions on-site. A subsequent report will examine options in these locations, which include other LID techniques (e.g., roof runoff harvesting for irrigation or gray water supply) and state-of-the-art conventional stormwater management practices. A minority but still substantial fraction of the Bay Area has group D soils (39.3, 68.0, 18.3, and 50.1 percent of the mapped areas of Alameda, Contra Costa, San Mateo, and Santa Clara Counties, respectively). Regarding any mapped soil type, it is important to keep in mind that soils vary considerably within small distances. Characteristics at specific locations can deviate greatly from those of the major mapped unit, making infiltration potential either more or less than may be expected from the mapping.

Low impact development methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating storm flows before they can enter surface receiving waters, and treating flow remaining on the surface through contact with vegetation and soil, or a combination of these strategies. Soil-based LID practices often use soil enhancements such as compost, and thus improve upon the performance of more traditional basins and biofilters. The study encompassed vegetated swales (channels for conveyance at some depth and velocity), vegetated filter strips (surfaces for conveyance in thin sheet flow), and bioretention areas (shallow basins with a range of vegetation types in which runoff infiltrates through soil either to groundwater or a subdrain for eventual surface discharge). Application of these practices in a low impact site design mode requires either determination that existing site soils can support runoff reduction through infiltration or that soils will be amended using accepted LID techniques to attain this objective. Finally, the study further broadened implementation options to include water harvesting (collection and storage for use in, for example, irrigation or gray water systems), roof downspout infiltration trenches, and porous pavements.

The investigation also considered whether typical development patterns and local conditions in the Bay Area would enable LID implementation as required by a new standard proposed for the 2007 Ventura County Municipal Storm Water Permit. This standard requires management of effective impervious area (EIA), limiting it to 5%, as well as other impervious area (what might be termed Not-Connected Impervious Area, NCIA), and pervious areas.

Where treatment control BMPs are required to manage runoff from a site, Volume or Flow Hydraulic Design Bases commonly used in California were assumed to apply. The former basis applies to storage-type BMPs, like ponds, and requires capturing and treating either the runoff volume from the 85th percentile, 24-hour rainfall event for the location or the volume of annual runoff to achieve 80 percent or more volume treatment. The calculations in this analysis used the 85th percentile 24-hour rainfall event basis. The Flow basis applies to flow-through BMPs, like swales, and requires treating the runoff flow rate produced from a rain event equal to at least 0.2 inches per hour intensity (or one of two other approximately equivalent options).

Scope of the Assessment

With respect to each of the six development case studies, three assessments were undertaken: a baseline scenario incorporating no stormwater management controls; a second scenario employing conventional BMPs; and a third development scenario employing LID stormwater management strategies.

To establish a baseline for each case study, annual stormwater runoff volumes were estimated, as well as concentrations and mass loadings of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). These baseline estimates were based on the anticipated land use and cover with no stormwater management efforts.

Two sets of calculations were then conducted using the parameters defined for the six case studies. The first group of calculations estimated the extent to which basic BMPs reduce runoff volumes and pollutant concentrations and loadings, and what impact, if any, such BMPs have on recharge rates or water retention on-site.

The second group of calculations estimated the extent to which commonly used soil-based BMPs and LID site design strategies ameliorate runoff volumes and pollutant concentrations and loadings, and the effect such techniques have on recharge rates. When evaluating LID strategies in the context of the EIA concept employed in the draft Ventura County MS4 permit, it was presumed that EIA would be limited to three percent. It was also assumed that pervious surfaces on a site receiving runoff from other areas on the site would be sized and prepared to manage (through infiltration or storage) the volume directed there in addition to precipitation falling directly on those areas. The assessment of basins, biofiltration, and low impact design practices analyzed the expected infiltration capacity of the case study sites. It also considered related LID techniques and practices, such as source reduction strategies, that could work in concert with infiltration to serve the goals of: (1) preventing increase in annual runoff volume from the pre- to the post-developed state, (2) preventing increase in annual pollutant mass loadings between the two development states, and (3) avoiding exceedances of the Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan) criteria for copper and zinc.

The results of this analysis show that:

- A full-range of typical development categories common in the Bay Area, from single family residential to restaurants, housing developments, and commercial uses like office buildings, can feasibly implement standard LID techniques to achieve no stormwater discharge during rain events equal to, and in some cases greater than, design storm conditions. This conclusion is based on an analysis that used actual building records in California and annual rainfall records in two rainfall zones in the Bay Area to show that site conditions support this level of performance. In addition, site conditions typical at a wide range of development projects are more than sufficient to attain compliance with a three percent EIA limit, as is being contemplated in other MS4 re-issuance proceedings in California presently.

- Developments implementing no post-construction BMPs result in storm water runoff volume and pollutant loading that are substantially increased, and recharge rates that are substantially decreased, compared to pre-development conditions.

- Developments implementing basic post-construction treatment BMPs achieve reduced pollutant loading compared to developments with no BMPs, but stormwater runoff volume and recharge rates are similar to developments with no BMPs.

- Developments implementing traditional basins and biofilters, and even more so low impact post-construction BMPs, achieve significant reduction of pollutant loading and runoff volume as well as greatly enhanced recharge rates compared to both developments with no BMPs and developments with basic treatment BMPs.

This report covers the methods employed in the investigation, data sources, and references for both. It then presents the results, discusses their consequences, draws conclusions, and makes recommendations relative to the feasibility of utilizing low-impact development practices in Bay Area developments.

CASE STUDIES

Six case studies were selected to represent a range of urban development types considered to be representative of the Bay Area. These case studies involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), an office building (OFF), a relatively large (1000 homes) single-family residential development (Lg-SFR), and a single home (SINGLE).[1]

Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. Code requirements vary by jurisdiction, with the tendency now to drop below the traditional 200 sq ft average. About 180 sq ft is common, but various standards for full- and compact-car spaces, and for the mix of the two, can raise or lower the average.[2] The 176 sq ft size is considered to be a reasonable value for conventional practice.

Roadways and walkways assume a wide variety of patterns. Exclusive of the two SFR cases, simple, square parking lots with roadways around the four sides and square buildings with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively.

Single-family residences were assumed each to have a driveway 20 ft wide and 30 ft long. It was further assumed that each would have a sidewalk along the front of the lot, which was calculated to be 5749 sq ft in area. Assuming a square lot, the front dimension would be 76 ft. A 40-ft walkway was included within the property. Sidewalks and walkways were taken to be 4 ft wide. For each case study the total area for all of these impervious features was subtracted from the total site area to estimate the pervious area, which was assumed to have conventional landscaping cover (grass, small herbaceous decorative plants, bushes, and a few trees).

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[1] Building permit records from the City of San Marcos in San Diego County provided data on total site areas for the first four case studies, including numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. While the building permit records made no reference to features such as roadways, walkways, and landscaping normally associated with development projects, these features were taken into account in the case studies using assumptions described herein. Larger developments and redevelopment were not represented in the sampling of building permits from the San Marcos database. To take these types of projects into account in the subsequent analysis, the Lg-SFR scenario scaled up all land use estimates from the Sm-SFR case in the ratio of 1000:23. The single home case (SINGLE) was derived from Bay Area records obtained at http://www.ppic.org/content/other/706EHEP_web_only_appendix.pdf, which showed 8000 ft^2 as a rough average for a single home lot in the region. As with the other cases, these hypothetical developments were assumed to have roadways, walkways, and landscaping, as described herein.

[2] J. Gibbons, *Parking Lots*, NONPOINT EDUCATION FOR MUNICIPAL OFFICERS, Technical Paper No. 5 (1999) (http://nemo.uconn.edu/tools/publications/tech_papers/tech_paper_5.pdf).

Table 1 summarizes the characteristics of the six case studies. The table also provides the recorded or estimated areas in each land use and cover type.

Table 1. Case Study Characteristics and Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
No. buildings	11	23	1	1	1000	1
Total area (ft^2)	476,982	132,227	33,669	92,612	5,749,000	8,000
Roof area (ft^2)	184,338	34,949	3,220	7,500	1,519,522	2114
No. parking spaces	438	-	33	37	-	-
Parking area (ft^2)	77,088	-	5808	6512	-	-
Access road area (ft^2)	22,212	-	6097	6456	-	-
Walkway area (ft^2)	33,960	10,656	1362	2078	463,289	518
Driveway area (ft^2)	-	13,800	-	-	600,000	835
Landscape area (ft^2)	159,384	72,822	17,182	70,066	3,166,190	4533

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home

METHODS OF ANALYSIS

Annual Stormwater Runoff Volumes

Annual surface runoff volumes produced were estimated for both pre- and post-development conditions for each case study site. Runoff volume was computed as the product of annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to rainfall received). For impervious areas the following equation was used:

$$\mathbf{C = (0.009)\, \mathit{I} + 0.05}$$

where I is the impervious percentage. This equation was derived by Schueler (1987) from Nationwide Urban Runoff Program data (U.S. Environmental Protection Agency 1983). With I = 100 percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients was the Natural Resource Conservation Service's (NRCS) Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff as a function of precipitation and a variable representing land cover and soil, termed the curve number (CN). Larger events are forecast to produce a greater amount of runoff in relation to amount of rainfall because they more fully saturate the soil. Therefore, use of the model to estimate annual runoff requires selecting some event or group of events to represent the year. The 85th percentile, 24-hour rainfall event was used in the analysis here for the relative comparison between pre- and post-development and applied to deriving a runoff coefficient for annual estimates, recognizing that smaller storms would produce less and larger storms more runoff.

A memorandum titled Rainfall Data Analysis and Guidance for Sizing Treatment BMPs (http://www.cccleanwater.org/construction/Publications/CCCWPBasinSizingMemoFINAL_4-20-05.pdf) prepared for the Contra Costa Clean Water Program demonstrated a linear relationship between unit basin storage volume for 80 percent capture (which is related to the 85th percentile event) and mean annual precipitation. Rainfall for Bay Area 85th percentile, 24-hour events could thus be determined from locations where events have been established in direct proportion to mean annual rainfall.

In order to obtain appropriate regional estimates of annual precipitation, rainfall records were obtained from a number of sites in the four counties, plus the city of Vallejo, covered by the permit.[3] The mean annual range is from 13.73 to 24.30 inches, with quantities close to either 14 or 20 inches predominating. The study was performed for both of these rainfall totals. These figures were used in conjunction with 85th percentile, 24-hour event amounts of 0.75 for Los Angeles and 0.92 for Santa Rosa (http://ci.santa-rosa.ca.us/pworks/other/SW/SRSWManualFinalDraft.pdf), respectively, and mean annual totals of 12 and 31 inches for the respective cities to estimate 85 percentile, 24-hour event quantities of 0.77 and 0.82 inch for the 14 and 20-inch Bay Area rainfall zones, respectively.

Pre- and post-development runoff quantities were computed with selected CN values and the 0.77- and 0.82-inch rainfalls. The CN choices based on tabulated data in NRCS (1986) and professional judgment were 83 before development and 86 after land modification. Estimate runoff amounts were then divided by the rainfall totals to obtain runoff coefficients. The results were about the same for the two rainfall zones at 0.07 and 0.12 before and after development, respectively. Finally, total annual runoff volumes were estimated based on the two average annual precipitation figures.

Stormwater Runoff Pollutant Discharges

Annual pollutant mass discharges were estimated as the product of annual runoff volumes produced by the various land use and cover types and pollutant concentrations typical of those areas. Again, the 0.75-inch precipitation event was used as a basis for volumes. Stormwater pollutant data have typically been measured and reported for general land use types (e.g., single-family residential, commercial). However, an investigation of low impact development practices of the type this study sought to conduct demands data on specific land coverages. The literature offers few data on this basis. Those available and used herein were assembled by a consultant to the City of Seattle for a project in which the author participated. They appear in Attachment A (Herrera Environmental Consultants, Inc. undated).

Pollutant concentrations expected to occur typically in the mixed runoff from the several land use and cover types making up a development were estimated by mass balance; i.e., the concentrations from the different areas of the sites were combined in proportion to their contribution to the total runoff.

The Effect of Conventional Treatment BMPs on Runoff Volume, Pollutant Discharges, and Recharge Rates

The first question in analyzing how BMPs reduce runoff volumes and pollutant discharges was, What BMPs are being employed in Bay Area developments under the permit now in force? These county permits provide regulated entities with a large number of choices and few fixed requirements regarding the selection of stormwater BMPs. (See Contra Costa County NPDES Municipal Stormwater Permit, Order No. 99-058; see also Santa Clara County NPDES Municipal Stormwater Permit, Order No. 01-024, at C.3.a.). Clean Water Program Available options presumably include manufactured BMPs, such as drain inlet inserts (DIIs) and continuous deflective separation (CDS) units. Developments may also select such non-

[3] http://www.census.gov/stab/ccdb/cit7140a.txt,
http://www.acwd.org/dms_docs/76d0b026b60d97830492079a48b1cb88.pdf,
http://www.ci.berkely.ca.us/aboutberkeley/weather.html, http://www.usbr.gov/dataweb/dams/ca10168.htm,
http://www.redwoodcity.org/about/weather.html.

proprietary devices as extended-detention basins (EDBs) and biofiltration swales and filter strips. EDBs hold water for two to three days for solids settlement before releasing whatever does not infiltrate or evaporate. Biofiltration treats runoff through various processes mediated by vegetation and soil. In a swale, runoff flows at some depth in a channel, whereas a filter strip is a broad surface over which water sheet flows. Each of these BMP types was applied to each case study, although it is not clear that these BMPs, in actuality, have been implemented consistently within the Bay Area to date.

The principal basis for the analysis of BMP performance was the California Department of Transportation's (CalTrans, 2004) BMP Retrofit Pilot Program, performed in San Diego and Los Angeles Counties. One important result of the program was that BMPs with a natural surface infiltrate and evaporate (probably, mostly infiltrate) a substantial amount of runoff, even if conditions do not appear to be favorable for an infiltration basin. On average, the EDBs, swales, and filter strips lost 40, 50 and 30 percent, respectively, of the entering flow before the discharge point. DIIs and CDS units do not contact runoff with a natural surface, and therefore do not reduce runoff volume.

The CalTrans program further determined that BMP effluent concentrations were usually a function of the influent concentrations, and equations were developed for the functional relationships in these cases. BMPs generally reduced influent concentrations proportionately more when they were high. In relatively few situations influent concentrations were constant at an "irreducible minimum" level regardless of inflow concentrations.

In analyzing the effects of BMPs on the case study runoff, the first step was to reduce the runoff volumes estimated with no BMPs by the fractions observed to be lost in the pilot study. The next task was estimating the effluent concentrations from the relationships in the CalTrans report. The final step was calculating discharge pollutant loadings as the product of the reduced volumes and predicted effluent concentrations. As before, typical pollutant concentrations in the mixed runoff were established by mass balance.

Estimating Infiltration Capacity of the Case Study Sites

Infiltrating sufficient runoff to maintain pre-development hydrologic characteristics and prevent pollutant transport is the most effective way to protect surface receiving waters. Successfully applying infiltration requires soils and hydrogeological conditions that will pass water sufficiently rapidly to avoid overly-lengthy ponding, while not allowing percolating water to reach groundwater before the soil column captures pollutants.

The study assumed that infiltration would occur in surface facilities and not in below-ground trenches. The use of trenches is certainly possible, and was judged to be an approved BMP by CalTrans after the pilot study. However, the intent of this investigation was to determine the ability of pervious areas to manage the site runoff. This was accomplished by determining the infiltration capability of the pervious areas in their original condition for each development case study, and further assessing the pervious areas' infiltration capabilities if soils were modified according to low impact development practices.

The chief basis for this aspect of the work was an assessment of infiltration capacity and benefits for Los Angeles' San Fernando Valley (Chralowicz et al. 2001). The Chralowicz study posited providing 0.1-0.5 acre for infiltration basins to serve each 5 acres of contributing drainage area. At 2-3 ft deep, it was estimated that such basins could infiltrate 0.90-1.87 acre-ft/year of runoff in San Fernando Valley conditions. Soils there are generally various loam textures with infiltration rates of approximately 0.5-2.0 inches/hour. Loams are also common formations in the portion of the Bay Area covered by this report, those areas with Hydrologic

Soil Groups A, B, and C,[4] thus making the conclusions of the San Fernando Valley study applicable for these purposes. This information was used to estimate how much of each case study site's annual runoff would be infiltratable, and if the pervious portion would provide sufficient area for infiltration. For instance, if sufficient area were available, the infiltration configuration would not have to be in basin form but could be shallower and larger in surface area. This study's analyses assumed the use of bioretention areas rather than traditional infiltration basins.

Volume and Pollutant Source Reduction Strategies

As mentioned above, the essence of low impact development is reducing runoff problems before they can develop, at their sources, or exploiting the infiltration and treatment abilities of soils and vegetation. If a site's existing infiltration and treatment capabilities are inadequate to preserve pre-development hydrology and prevent runoff from causing or contributing to violations of water quality standards, then LID-based source reduction strategies can be implemented, infiltration and treatment capabilities can be upgraded, or both.

Source reduction can be accomplished through various LID techniques. Soil can be upgraded to store runoff until it can infiltrate, evaporate, or transpire from plants through compost addition. Soil amendment, as this practice is known, is a standard LID technique.

Upgraded soils are used in bioretention cells that hold runoff and effect its transfer to the subsurface zone. This standard LID tool can be used where sufficient space is available. This study analyzed whether the six development case study sites would have sufficient space to effectively reduce runoff using bioretention cells, assuming the soils and vegetation could be amended and enhanced where necessary.

Conventional pavements can be converted to porous asphalt or concrete or replaced with concrete or plastic unit pavers or grid systems. For such approaches to be most effective, the soils must be capable of infiltrating the runoff passing through, and may require renovation.

Source reduction can be enhanced by the LID practice of water harvesting, in which water from impervious surfaces is captured and stored for reuse in irrigation or gray water systems. For example, runoff from roofs and parking lots can be harvested, with the former being somewhat easier because of the possibility of avoiding pumping to use the water and fewer pollutants. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings.[5] Many successful systems of this type are in operation, such as the Natural Resources Defense Council office (Santa Monica, CA), the King County Administration Building (Seattle, WA), and two buildings on the Portland State University campus (Portland, OR). This investigation examined how water harvesting could contribute to stormwater management for case study sites where infiltration capacity, available space, or both appeared to be limited.

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4 http://gis.ca.gov/catalog/BrowseCatalog.epl?id=108, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

5 New Buildings Institute, Inc., *Advanced Buildings* (2005) (http://www.poweryourdesign.com/LEEDGuide.pdf).

RESULTS OF THE ANALYSIS

1. "Base Case" Analysis: Development without Stormwater Controls

Comparison of Pre- and Post-Development Runoff Volumes

Table 2 presents a comparison between the estimated runoff volumes generated by the respective case study sites in the pre- and post-development conditions, assuming implementation of no stormwater controls on the developed sites. On sites dominated by impervious land cover, most of the infiltration that would recharge groundwater in the undeveloped state is expected to be lost to surface runoff after development. This greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, raise flooding risk, and transport pollutants. Only the office building, the plan for which retained substantial pervious area, would lose less than 40 percent of the site's pre-development recharge.

Table 2. Pre- and Post-Development without BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater (annual volume in acre-ft)

Distribution	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Precipitation[b]	12.8	3.54	0.90	2.47	154	0.21
Pre-development runoff[c]	0.89	0.25	0.07	0.17	10	0.02
Pre-development recharge[d]	11.9	3.29	0.83	2.30	144	0.19
Post-development impervious runoff[c]	8.07	1.51	0.42	0.57	66	0.09
Post-development pervious runoff[c]	0.51	0.24	0.06	0.23	10	0.01
Post-development total runoff[c]	8.58	1.75	0.48	0.80	76	0.10
Post-development recharge[d]	4.22	1.79	0.42	1.67	78	0.11
Post-development recharge loss (% of pre-development)	7.68 (65%)	1.50 (46%)	0.41 (49%)	0.65 (27%)	66 (45%)	0.08 (41%)
20 Inches/Year Rainfall:						
Precipitation[b]	18.2	5.06	1.29	3.54	220	0.30
Pre-development runoff[c]	1.28	0.35	0.10	0.24	15	0.03
Pre-development recharge[d]	16.9	4.71	1.19	3.30	205	0.27
Post-development impervious runoff[c]	11.5	2.16	0.60	0.82	94	0.13
Post-development pervious runoff[c]	0.73	0.34	0.08	0.33	15	0.01
Post-development total runoff[c]	12.2	2.50	0.68	1.15	109	0.14
Post-development recharge[d]	6.0	2.56	0.61	2.39	111	0.16
Post-development recharge loss (% of pre-development)	10.9 (65%)	2.15 (46%)	0.58 (49%)	0.91 (27%)	94 (45%)	0.11 (41%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Pollutant Concentrations and Loadings

Table 3 presents the pollutant concentrations from the literature and loadings calculated as described for the various land use and cover types represented by the case studies. Landscaped areas are expected to release the highest TSS concentration, although relatively low TSS mass loading because of the low runoff coefficient. The highest copper concentrations and loadings are expected from parking lots. Roofs, especially commercial roofs, top the list for both zinc concentrations and loadings. Landscaping would issue by far the highest phosphorus, although access roads and driveways would contribute the highest mass loadings. With expected concentrations being equal in the two rainfall zones, mass loadings in the 20 inches/year zone would be higher than those in the 14 inches/year zone in the same proportion as the ratio of rainfall quantities.

Table 3. Pollutant Concentrations and Loadings for Case Study Land Use and Cover Types

Land Use	Concentrations				Loadings			
	TSS (mg/L)	TCu (mg/L)	TZn (mg/L)	TP (mg/L)	Lbs. TSS/ acre-year	Lbs. TCu/ acre-year	Lbs. TZn/ acre-year	Lbs. TP/ acre-year
14 Inches/Year Rainfall:								
Residential roof	25	0.013	0.159	0.11	75	0.039	0.477	0.330
Commercial roof	18	0.014	0.281	0.14	54	0.042	0.844	0.420
Access road/driveway	120	0.022	0.118	0.66	360	0.066	0.354	1.981
Parking	75	0.036	0.097	0.14	225	0.108	0.291	0.420
Walkway	25	0.013	0.059	0.11	75	0.039	0.177	0.330
Landscaping	213	0.013	0.059	2.04	81	0.005	0.022	0.774
20 Inches/Year Rainfall:								
Residential roof	25	0.013	0.159	0.11	107	0.056	0.683	0.472
Commercial roof	18	0.014	0.281	0.14	77	0.060	1.207	0.601
Access road/driveway	120	0.022	0.118	0.66	515	0.094	0.507	2.834
Parking	75	0.036	0.097	0.14	322	0.155	0.417	0.601
Walkway	25	0.013	0.059	0.11	107	0.056	0.253	0.472
Landscaping	213	0.013	0.059	2.04	135	0.008	0.037	1.291

The Basin Plan freshwater acute criteria for copper and zinc are 0.013 mg/L and 0.120 mg/L, respectively (http://www.swrcb.ca.gov/rwqcb2/basinplan/web/BP_CH3.html). All developed land uses are expected to discharge copper at or above the criterion, based on the mass balance calculations using concentrations from Table 3. Any surface release from the case study sites would just meet or violate the criterion at the point of discharge, although dilution by the receiving water would lower the concentration below the criterion at some point. Even if copper mass loadings are reduced by BMPs, any surface discharge would equal or exceed the criterion initially, but it would be easier to dilute below that level. In contrast, runoff from land covers other than roofs would not violate the acute zinc criterion. Because of this difference, the evaluation considered whether or not the zinc criterion would be exceeded in each analysis, whereas there was no point in this analysis for copper. There are no equivalent water quality criteria for TSS and TP; hence, their concentrations were not further analyzed in the different scenarios.

Table 4 shows the overall loadings, as well as zinc concentrations, expected to be delivered from the case study developments should they not be fitted with any BMPs. As Table 4 shows, all cases are forecast to exceed the 0.120 mg/L acute zinc criterion. Because of its size, the large residential development dominates the mass loading emissions.

Table 4. Case Study Pollutant Concentration and Loading Estimates without BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/ Year Rainfall:						
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.121
Lbs. TSS/year	1254	328	119	230	14249	20
Lbs. TCu/year	0:44	0.070	0.030	0.043	3.04	0.004
Lbs. TZn/year	2.94	0.576	0.165	0.286	25.04	0.034
Lbs. TP/year	6.24	2.27	0.68	1.69	98.55	0:14
20 Inches/ Year Rainfall:						
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.121
Lbs. TSS/year	1864	501	180	360	21781	30
Lbs. TCu/year	0.63	0.102	0.043	0.063	4.44	0.006
Lbs. TZn/year	4.22	0.833	0.238	0.417	36.2	0.050
Lbs. TP/year	9.60	3.55	1.05	2.71	154	0.22

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home

2. *"Conventional BMP" Analysis: Effect of Basic Treatment BMPs*

Effect of Basic Treatment BMPs on Post-Development Runoff Volumes

The current set of regional permits allows regulated parties to select from a range of BMPs in order to treat or infiltrate a given quantity of annual rainfall. The administrative draft of the proposed MRP is also non-specific regarding the role of LID in satisfying permit conditions. The range of BMPs includes drain inlet inserts, CDS units, and other manufactured BMPs, detention vaults, and sand filters, all of which isolate runoff from the soil; as well as basins and biofiltration BMPs built in soil and generally having vegetation. Treatment BMPs that do not permit any runoff contact with soils discharge as much stormwater runoff as equivalent sites with no BMPs, and hence yield zero savings in recharge. As mentioned above, the CalTrans (2004) study found that BMPs with a natural surface can reduce runoff by substantial margins (30-50 percent for extended-detention basins and biofiltration).

With such a wide range of BMPs in use, runoff reduction ranging from 0 to 50 percent, and a lack of clearly ascertainable requirements, it is not possible to make a single estimate of how much recharge savings are afforded by maximal implementation of the current permits or the Municipal Regional Permit (MRP), if issued as now proposed. We made the following assumptions regarding implementation of BMPs. Assuming natural-surface BMPs perform at the average of the three types tested by CalTrans (2004), i.e., 40 percent runoff reduction, the estimate can be bounded as shown in Table 5. The table demonstrates that allowing free choice of BMPs without regard to their ability to direct water into the ground forfeits substantial groundwater recharge benefits when hardened-surface BMPs are selected. Use of soil-based conventional BMPs could cut recharge losses from half or more of the full potential to about one-quarter to one-third or less, except with the highly impervious commercial development. This analysis shows the wisdom of draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way. But as subsequent analyses showed, soil amendment can gain considerably greater benefits.

Table 5. Pre- and Post-Development with Conventional BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater (annual volume in acre-ft)

Distribution	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Precipitation[b]	12.8	3.54	0.90	2.47	154	0.21
Pre-development runoff[c]	0.89	0.25	0.07	0.17	10	0.02
Pre-development recharge[d]	11.9	3.29	0.83	2.30	144	0.19
Post-development impervious runoff[e]	4.84-8.07	0.90-1.51	0.25-0.42	0.34-0.57	39-66	0.05-0.09
Post-development pervious runoff[e]	0.30-0.51	0.14-0.24	0.04-0.06	0.13-0.23	6.3-10	0.006-0.01
Post-development total runoff[e]	5.15-8.58	1.05-1.75	0.29-0.48	0.48-0.80	46-76	0.06-0.10
Post-development recharge[d, e]	4.22-7.60	1.79-2.49	0.42-0.62	1.67-2.00	78-108	0.11-0.15
Post-development recharge loss (% of pre-development) [e]	4.29-7.68 (36-65%)	0.80-1.50 (24-46%)	0.80-0.41 (26-49%)	0.30-0.65 (13-27%)	34-66 (24-45%)	0.05-0.08 (24-41%)
20 Inches/Year Rainfall:						
Precipitation[b]	18.2	5.06	1.29	3.54	220	0.30
Pre-development runoff[c]	1.28	0.35	0.10	0.24	15	0.03
Pre-development recharge[d]	16.9	4.71	1.19	3.30	205	0.27
Post-development impervious runoff[e]	6.92-11.5	1.29-2.16	0.35-0.60	0.49-0.82	56-94	0.08-0.13
Post-development pervious runoff[e]	0.44-0.73	0.20-0.34	0.05-0.08	0.19-0.33	9.0-15	0.006-0.01
Post-development total runoff[e]	7.36-12.2	1.50-2.50	0.41-0.68	0.68-1.15	65-109	0.08-0.14
Post-development recharge[d, e]	6.0-10.8	2.56-3.56	0.61-0.88	2.39-2.86	111-155	0.16-0.22
Post-development recharge loss (% of pre-development) [e]	6.1-10.9 (36-65%)	1.14-2.15 (24-46%)	0.31-0.58 (26-49%)	0.44-0.91 (13-27%)	49-94 (24-45%)	0.07-0.11 (24-41%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home. Ranges represent 40 percent runoff volume reduction, with full site coverage by BMPs having a natural surface, to no reduction, with BMPs isolating runoff from soil.
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff [e] Ranging from the quantity with hardened bed BMPs to the quantity with soil-based BMPs

Effect of Basic Treatment BMPs on Pollutant Discharges

Table 6 presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from four types of conventional treatment BMPs. The loading reduction results show the CDS units always performing below 50 percent reduction for all pollutants analyzed, and most often in the vicinity of 20 percent, with zero copper reduction.

Table 6. Pollutant Concentration and Mass Loading Reduction Estimates with Conventional BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Effluent Concentrations:						
CDS TZn (mg/L)[a]	0.095	0.095	0.098	0.102	0.095	0.094
EDB TZn (mg/L)[a]	0.085	0.086	0.084	0.084	0.086	0.084
Swale TZn (mg/L)	0.055	0.054	0.055	0.056	0.054	0.053
Filter strip TZn (mg/L)	0.039	0.039	0.039	0.041	0.039	0.038
Mass Loading Reductions—14 Inches/Year Rainfall:						
CDS TSS reduction	15.7%	19.9%	22.0%	24.0%	19.9%	20.2%
CDS TCu reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CDS TZn reduction	22.7%	22.4%	22.9%	23.1%	22.4%	22.5%
CDS TP reduction	30.6%	41.5%	40.7%	45.9%	41.5%	42.0%
EDB TSS reduction	68.1%	73.7%	79.0%	81.1%	73.7%	74.3%
EDB TCu reduction	61.9%	55.7%	66.2%	63.0%	55.7%	55.8%
EDB TZn reduction	59.7%	59.6%	60.4%	61.9%	59.6%	59.8%
EDB TP reduction	61.9%	69.7%	69.1%	72.9%	69.7%	70.1%
Swale TSS reduction	68.8%	71.1%	73.1%	73.9%	71.1%	71.3%
Swale TCu reduction	72.5%	68.5%	78.2%	73.3%	68.5%	68.5%
Swale TZn reduction	78.4%	78.1%	84.3%	78.8%	78.1%	78.2%
Swale TP reduction	66.3%	70.7%	67.2%	76.2%	70.7%	71.1%
Filter strip TSS reduction	69.9%	75.4%	80.6%	82.6%	75.4%	76.0%
Filter strip TCu reduction	74.4%	69.1%	78.2%	75.4%	69.1%	69.1%
Filter strip TZn reduction	78.3%	77.9%	78.4%	78.7%	77.9%	78.1%
Filter strip TP reduction	48.4%	53.1%	63.7%	59.8%	53.1%	53.5%

Table 6 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Mass Loading Reductions—20 Inches/Year Rainfall:						
CDS TSS reduction	18.8%	25.0%	26.3%	30.5%	25.0%	25.4%
CDS TCu reduction	0.7%	1.9%	1.1%	3.0%	1.9%	2.0%
CDS TZn reduction	23.1%	23.3%	23.6%	24.7%	23.3%	23.4%
CDS TP reduction	35.4%	46.6%	44.8%	51.8%	46.6%	47.1%
EDB TSS reduction	68.8%	74.6%	79.6%	81.6%	74.6%	75.1%
EDB TCu reduction	61.8%	55.6%	66.0%	62.7%	55.6%	55.7%
EDB TZn reduction	59.6%	59.3%	60.2%	61.5%	59.3%	59.6%
EDB TP reduction	63.0%	70.4%	69.7%	73.4%	70.4%	70.7%
Swale TSS reduction	69.1%	71.4%	73.6%	74.1%	71.4%	71.6%
Swale TCu reduction	72.5%	68.4%	77.9%	73.1%	68.4%	68.5%
Swale TZn reduction	78.3%	78.0%	84.1%	78.6%	78.0%	78.1%
Swale TP reduction	67.6%	71.9%	68.2%	77.1%	71.9%	72.3%
Filter strip TSS reduction	70.6%	76.3%	81.2%	83.1%	76.3%	76.8%
Filter strip TCu reduction	74.4%	69.0%	78.0%	75.1%	69.0%	69.1%
Filter strip TZn reduction	78.2%	77.8%	78.3%	78.5%	77.8%	77.9%
Filter strip TP reduction	49.9%	54.6%	66.3%	61.0%	54.6%	55.0%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home; CDS— continuous deflective separation unit; EDB—extended-detention basin

When treated with extended-detention basins, swales, or filter strips, effluents from each development case study site are expected to fall below the Basin Plan acute zinc criterion. These natural-surface BMPs, if fully implemented and well maintained, are predicted to prevent the pollutant masses generated on the six case study development sites from reaching a receiving water in both rainfall zones, which do not differ appreciably. Only total phosphorus reduction falls below 50 percent for three case studies. Otherwise, mass loading reductions range from about 60 to above 80 percent for the EDB, swale, and filter strip. These data indicate that draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way, pays water quality as well as hydrologic dividends.

3. LID Analysis

(a) Hydrologic Analysis

The LID analysis repeats the analysis above, focusing here on the performance of LID techniques in reducing or eliminating runoff from the six development case studies. In addition to assessing the total runoff that would be expected, the analysis also considered whether LID techniques would be sufficient to attain compliance with a performance standard being considered by the Los Angeles Regional Water Quality Control Board for Ventura County, California. This standard limits EIA (Effective Impervious Area) to five percent (but our analysis further assumed EIA would be ultimately reduced to three percent). All runoff from NCIA (Not-Connected Impervious Area) was assumed to drain to vegetated surfaces.

One goal of this exercise was to identify methods that reduce runoff production in the first place. It was hypothesized that implementation of source reduction techniques could allow all of the case study sites to infiltrate substantial proportions, or all, of the developed site runoff, advancing the hydromodification mitigation objective of the Draft Permit. When runoff is dispersed into the soil instead of being rapidly collected and conveyed away, it recharges groundwater, supplementing a resource that maintains dry season stream flow and wetlands. An increased water balance can be tapped by humans for potable, irrigation, and process water supply. Additionally, runoff volume reduction would commensurately decrease pollutant mass loadings.

Accordingly, the analysis considered the practicability of more than one scenario. In one option, all roof runoff is harvested and stored for some beneficial use. A second option disperses runoff into the soil via roof downspout infiltration trenches. The former option is probably best suited to cases like large commercial and office buildings, while distribution in the soil would fit best with residences and relatively small commercial developments. The analysis was repeated with the assumptions of harvesting OFF roof runoff for some beneficial use and dispersing roof runoff from the remaining four cases in roof downspout infiltration systems.

Expected Infiltration Capacities of the Case Study Sites

The first inquiry on this subject sought to determine how much of the total annual runoff each property is expected to infiltrate, since infiltration is a basic (although not exclusive) LID technique. Based on the findings of Chralowicz et al. (2001), it was assumed that an infiltration zone of 0.1-0.5 acres in area and 2-3 ft deep would serve a drainage catchment area in the size range 0-5 acres and infiltrate 0.9-1.9 acre-ft/year. The conclusions of Chralowicz et al. (2001) were extrapolated to conservatively assume that 0.5 acre would be required to serve each additional five acres of catchment, and would infiltrate an incremental 1.4 acre-ft/year (the midpoint of the 0.9-1.9 acre-ft/year range). According to these assumptions, the following schedule of estimates applies:

Pervious Area Available for Infiltration	Catchment Served acres	Infiltration Capacity
0.5 acres	0-5 acres	1.4 acre-ft/year
1.0 acres	5-10 acres	2.8 acre-ft/year
1.5 acres	10-15 acres	4.2 acre-ft/year
(Etc.)	...	...

As a formula, infiltration capacity ≈ 2.8 x available pervious area. To apply the formula conservatively, the available area was reduced to the next lower 0.5-acre increment before multiplying by 2.8.

As shown in Table 7, in both rainfall zones all six of the sites have adequate or greater capacity to infiltrate the full annual runoff volume expected from NCIA and pervious areas where EIA is limited to three percent of the total site area. Indeed, five of the six development types have sufficient pervious area to infiltrate *all* runoff, including runoff from EIA areas. These results are based on infiltrating in the native soils with no soil amendment. For any development project at which infiltration-oriented BMPs are considered, it is important that infiltration potential be carefully assessed using site-specific soils and hydrogeologic data. In the event such an investigation reveals a marginal condition (e.g., hydraulic conductivity, spacing to groundwater) for infiltration basins, soils could be enhanced to produce bioretention zones to assist infiltration. Notably, the five case studies with far greater than necessary infiltration capacity would offer substantial flexibility in designing infiltration, allowing ponding at less than 2-3 ft depth.

Table 7. Infiltration and Runoff Volume (With 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.36	0.10	0.03	0.07	4.4	0.01
NCIA + pervious area runoff (acre-ft/year)	**8.20**	**1.64**	**0.45**	**0.73**	**71.3**	**0.08**
Total runoff (acre-ft/year)	8.56	1.74	0.48	0.80	75.7	0.09
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration potential[c]	>100%	>100%	>100%	>100%	>100%	>100%
20 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.52	0.14	0.04	0.10	6.2	0.01
NCIA + pervious area runoff (acre-ft/year)	**11.7**	**2.34**	**0.64**	**1.04**	**101.7**	**0.14**
Total runoff (acre-ft/year)	12.2	2.48	0.68	1.14	108.0	0.15
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration potential[c]	84%	>100%	>100%	>100%	>100%	>100%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Compare runoff production from NCIA + pervious area (**row 3**) with estimated infiltration capacity (**row 6**)

As Table 7 shows, each of the six case study sites have the capacity to infiltrate *all* or substantially all of the runoff produced onsite annually by draining impervious surfaces to pervious areas on native soils or, in some soil regimes, soils amended with organic matter. If these sites were designed as envisioned in this analysis, no runoff discharge is expected in storms as large as, and probably larger than, the design storm event—using infiltration only. Discharge would be anticipated only with exceptionally intense, large, or prolonged rainfall that saturates the ground at a faster rate than water can infiltrate or evaporate. Even runoff from the area assumed to be EIA could be infiltrated in most cases based on the amount of pervious area available in typical development projects. Therefore, this analysis shows that the EIA performance standard being considered for Ventura County, California, or one more stringent, can be met readily in development projects occurring on A, B, and C soils in the San Francisco Bay Area.

Additional Source Reduction Capabilities of the Case Study Sites: Water Harvesting Example

As noted, infiltration is one of a wide variety of LID-based source reduction techniques. Where site conditions such as soil quality or available area limit a site's infiltration capacity, other source LID measures can enhance a site's runoff retention capability. For example, soil amendment, which improves infiltration, is a standard LID technique. Water harvesting is another. Such practices can also be used where infiltration capacity is adequate, but the developer desires greater flexibility for land use on-site. Table 8 shows the added LID implementation flexibility created by subtracting roof runoff by harvesting it or efficiently directing it into the soil through downspout dispersion systems, further demonstrating the feasibility and robust performance of LID options for reducing or eliminating runoff in most expected conditions. Specifically, all development types studied could readily infiltrate and/or retain all expected annual precipitation.

Table 8. Infiltration and Runoff Volume Reduction Analysis Including Roof Runoff Harvesting or Disposal in Infiltration Trenches (Assuming 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.36	0.10	0.03	0.07	4.4	0.01
Roof runoff (acre-ft/year)	4.68	0.89	0.08	0.19	38.5	0.05
Other NCIA + pervious area runoff (acre-ft/year)	**3.52**	**0.75**	**0.37**	**0.54**	**32.7**	**0.04**
Total runoff (acre-ft/year)	8.56	1.74	0.48	0.80	75.6	0.10
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration capacity[c]	>100%	>100%	>100%	>100%	>100%	>100%
20 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.52	0.14	0.04	0.10	6.2	0.01
Roof runoff (acre-ft/year)	6.67	1.27	0.12	0.28	55.1	0.08
Other NCIA + pervious area runoff (acre-ft/year)	**5.03**	**1.07**	**0.52**	**0.76**	**46.7**	**0.06**
Total runoff (acre-ft/year)	12.2	2.48	0.68	1.14	108.0	0.15
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10

Table 8 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration capacity[c]	>100%	>100%	>100%	>100%	>100%	>100%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Comparison of runoff production from NCIA + pervious area **(row 3)** with estimated infiltration capacity **(row 6)**

Effect of Full LID Approach on Recharge

Table 9 shows the recharge benefits of preventing roofs from generating runoff and infiltrating as much as possible of the runoff from the remainder of the case study sites. The data show that LID methods offer significant benefits relative to the baseline (no stormwater controls) in all cases. These benefits are particularly impressive in developments with relatively high site imperviousness, such as in the MFR case.

Table 9. Comparison of Water Captured Annually (in acre-ft) from Development Sites for Beneficial Use with a Full LID Approach Compared to Development With No BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Pre-development recharge[b] (acre-ft)	11.9	3.29	0.83	2.30	144	0.19
No BMPs—						
Post-development recharge[b] (acre-ft)	4.22	1.79	0.42	1.67	78	0.11
Post-development recharge lost (acre-ft)	7.68	1.50	0.41	0.65	66	0.08
Post-development % recharge lost	65%	46%	49%	27%	45%	41%
Full LID approach—						
Post-development runoff capture (acre-ft)[c]	11.9	3.29	0.83	2.30	144	0.19
Post-development recharge lost (acre-ft)	0	0	0	0	0	0
Post-development % recharge lost	0%	0%	0%	0%	0%	0%

Table 9 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
20 Inches/Year Rainfall:						
Pre-development recharge[b] (acre-ft)	16.9	4.71	1.19	3.30	205	0.27
No BMPs—						
Post-development recharge[b] (acre-ft)	6.0	2.56	0.61	2.39	111	0.16
Post-development recharge lost (acre-ft)	10.9	2.15	0.58	0.91	94	0.11
Post-development % recharge lost	65%	46%	49%	27%	45%	41%
Full LID approach—						
Post-development runoff capture (acre-ft)[c]	16.9	4.71	1.19	3.30	205	0.27
Post-development recharge lost (acre-ft)	0	0	0	0	0	0
Post-development % recharge lost	0%	0%	0%	0%	0%	0%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—Single family home
[b] Quantity of water infiltrating the soil; the difference between precipitation and runoff
[c] Water either entirely infiltrated in BMPs and recharged to groundwater or partially harvested from roofs and partially infiltrated in BMPs. EIA was not distinguished from the remainder of the development, because these sites have the potential to capture all runoff.

(b) Water Quality Analysis

It was assumed that any site discharges would be subject to treatment control. For purposes of the analysis, treatment control was assumed to be provided by conventional sand filtration. This choice is appropriate for study purposes for two reasons. First, sand filters can be installed below grade, and land above can be put to other uses. Pervious area should be reserved for receiving NCIA drainage, and using sand filters would not draw land away from that service or other site uses. A second reason for the choice is that sand filter performance data equivalent to the data used in analyzing other conventional BMPs are available from the CalTrans (2004) work. Sand filters may or may not expose water to soil, depending on whether or not they have a hard bed. This analysis assumed a hard bed, meaning that no infiltration would occur and thus there would be no additional recharge in sand filters. Performance would be even better than shown in the analytical results if sand filters were built in earth.

Pollutant Discharge Reduction Through LID Techniques

The preceding analyses demonstrated that in each of the six case studies, *all* stormwater discharges could be eliminated at least under most meteorological conditions by dispersing runoff from impervious surfaces to pervious areas. Therefore, pollutant additions to receiving waters would also be eliminated.

SUMMARY AND CONCLUSIONS

This paper demonstrated that common Bay Area residential and commercial development types subject to the Municipal NPDES Permit are likely, without stormwater management, to reduce groundwater recharge from the pre-development state by approximately half in most cases to a much higher fraction with a large ratio of impervious to pervious area. With no treatment, runoff from these developments is expected to exceed Basin Plan acute copper and zinc criteria at the point of discharge and to deliver large pollutant mass loadings to receiving waters.

Conventional soil-based BMP solutions that promote and are component parts of low impact development approaches, by contrast, regain about 30-50 percent of the recharge lost in development without stormwater management in Bay Area locations having NRCS Hydrologic Soil Groups A, B, and C. It is expected the soil-based BMPs generally would release effluent that meets the acute zinc criterion at the point of discharge, although it would still exceed or just barely meet the copper limit. Excepting phosphorus, it was found that these BMPs would capture and prevent the movement to receiving waters of the majority of the pollutant loadings considered in the analysis.

It was found that by draining all site runoff to pervious areas with A, B, or C soil types, runoff can be eliminated entirely in most development categories. It follows that a three percent Effective Impervious Area standard can be met in typical developments, as well. This result was reached assuming the use of native soils or well recognized soil enhancement techniques (typically, with compost). Draining impervious surfaces onto these soils, in connection with limiting directly connected impervious area to three percent of the site total area, should eliminate storm runoff from some development types and greatly reduce it from more highly impervious types. Adding roof runoff elimination to the LID approach (by harvesting or directing it to downspout infiltration trenches) provides an additional tool, increasing flexibility and confidence that no discharge in most meteorological conditions is a feasible performance expectation. Even in the development scenarios involving the highest relative proportion of impervious surface, losses of rainfall capture for beneficial uses could be reduced from the untreated scenario when draining to pervious areas was supplemented with water harvesting. These results demonstrate the basic soundness of the concept of using LID techniques to reduce stormwater pollution in the Bay Area, and further show that limiting directly connected impervious area and draining the remainder over pervious surfaces, as contemplated by some Regional Water Boards in California, is also feasible.

REFERENCES

California Department of Transportation. 2004. BMP Retrofit Pilot Program Final Report. California Department of Transportation, Sacramento, CA.

Chralowicz, D., T. Goff, M. Mascali, and E. Taylor. 2001. Infiltration of Urban Stormwater Runoff to Recharge Groundwater Used for Drinking Water: A Study of the San Fernando Valley, California. Master of Environmental Science and Management Report, University of California at Santa Barbara, Santa Barbara, California.

Herrera Environmental Consultants, Inc. Undated. Pollutant Concentrations for Urban Source Areas, unpublished data table.

Natural Resource Conservation Service. 1986. Urban Hydrology for Small Watersheds, Technical Release-55. U.S. Department of Agriculture, Washington, D.C.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, D.C.

U.S. Environmental Protection Agency. 1983. Results of the Nationwide Urban Runoff Program: Volume 1 - Final Report, Report No. 832R83112. Office of Water, Washington, D.C.

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ATTACHMENT A

POLLUTANT CONCENTRATIONS FOR URBAN SOURCE AREAS (HERRERA ENVIRONMENTAL CONSULTANTS, INC. UNDATED)

Source Area	Study	Location	Sample Size (n)	TSS (mg/L)	TCu (ug/L)	TPb (ug/L)	TZn (ug/L)	TP (mg/L)	Notes
Roofs									
Residential	Steuer, et al. 1997	MI	12	36	7	25	201	0.06	2
Residential	Bannerman, et al. 1993	WI	~48	27	15	21	149	0.15	3
Residential	Waschbusch, et al. 2000	WI	25	15	n.a.	n.a.	n.a.	0.07	3
Residential	FAR 2003	NY		*19*	*20*	*21*	*312*	*0.11*	4
Residential	Gromaire, et al. 2001	France		*29*	*37*	*493*	*3422*	*n.a.*	5
Representative Residential Roof Values				**25**	**13**	**22**	**159**	**0.11**	
Commercial	Steuer, et al. 1997	MI	12	24	20	48	215	0.09	2
Commercial	Bannerman, et al. 1993	WI	~16	15	9	9	330	0.20	3
Commercial	Waschbusch, et al. 2000	WI	25	18	n.a.	n.a.	n.a.	0.13	3
Representative Commercial Roof Values				**18**	**14**	**26**	**281**	**0.14**	
Parking Areas									
Res. Driveways	Steuer, et al. 1997	MI	12	157	34	52	148	0.35	2
Res. Driveways	Bannerman, et al. 1993	WI	~32	173	17	17	107	1.16	3
Res. Driveways	Waschbusch, et al. 2000	WI	25	34	n.a.	n.a.	n.a.	0.18	3
Driveway	FAR 2003	NY		*173*	*17*		*107*	*0.56*	4
Representative Residential Driveway Values				**120**	**22**	**27**	**118**	**0.66**	
Comm./ Inst. Park. Areas	Pitt, et al. 1995	AL	16	110	116	46	110	n.a.	1
Comm. Park. Areas	Steuer, et al. 1997	MI	12	110	22	40	178	0.2	2
Com. Park. Lot	Bannerman, et al. 1993	WI	5	58	15	22	178	0.19	3
Parking Lot	Waschbusch, et al. 2000	WI	25	51	n.a.	n.a.	n.a.	0.1	3
Parking Lot	Tiefenthaler, et al. 2001	CA	5	36	28	45	293	n.a.	6
Loading Docks	Pitt, et al. 1995	AL	3	40	22	55	55	n.a.	1
Highway Rest Areas	CalTrans 2003	CA	53	*63*	*16*	*8*	*142*	*0.47*	7
Park and Ride Facilities	CalTrans 2003	CA	179	*69*	*17*	*10*	*154*	*0.33*	7
Comm./ Res. Parking	FAR 2003	NY		*27*	*51*	*28*	*139*	*0.15*	4
Representative Parking Area/Lot Values				**75**	**36**	**26**	**97**	**0.14**	

Landscaping/Lawns									
Landscaped Areas	Pitt, et al. 1995	AL	6	33	81	24	230	n.a.	1
Landscaping	FAR 2003	NY		*37*	*94*	*29*	*263*	n.a.	4
Representative Landscaping Values				**33**	**81**	**24**	**230**	**n.a.**	
Lawns - Residential	Steuer, et al. 1997	MI	12	262	n.a.	n.a.	n.a.	2.33	2
Lawns - Residential	Bannerman, et al. 1993	WI	~30	397	13	n.a.	59	2.67	3
Lawns	Waschbusch, et al. 2000	WI	25	59	n.a.	n.a.	n.a.	0.79	3
Lawns	Waschbusch, et al. 2000	WI	25	122	n.a.	n.a.	n.a.	1.61	3
Lawns - Fertilized	USGS 2002	WI	58	n.a.	n.a.	n.a.	n.a.	2.57	3
Lawns - Non-P Fertilized	USGS 2002	WI	38	n.a.	n.a.	n.a.	n.a.	1.89	3
Lawns - Unfertilized	USGS 2002	WI	19	n.a.	n.a.	n.a.	n.a.	1.73	3
Lawns	FAR 2003	NY	3	*602*	*17*	*17*	*50*	*2.1*	4
Representative Lawn Values				**213**	**13**	**n.a.**	**59**	**2.04**	

Notes:

Representative values are weighted means of collected data. Italicized values were omitted from these calculations.

1 - Grab samples from residential, commercial/institutional, and industrial rooftops. Values represent mean of DETECTED concentrations

2 - Flow-weighted composite samples, geometric mean concentrations

3 - Geometric mean concentrations

4 - Citation appears to be erroneous - original source of data is unknown. Not used to calculate representative value

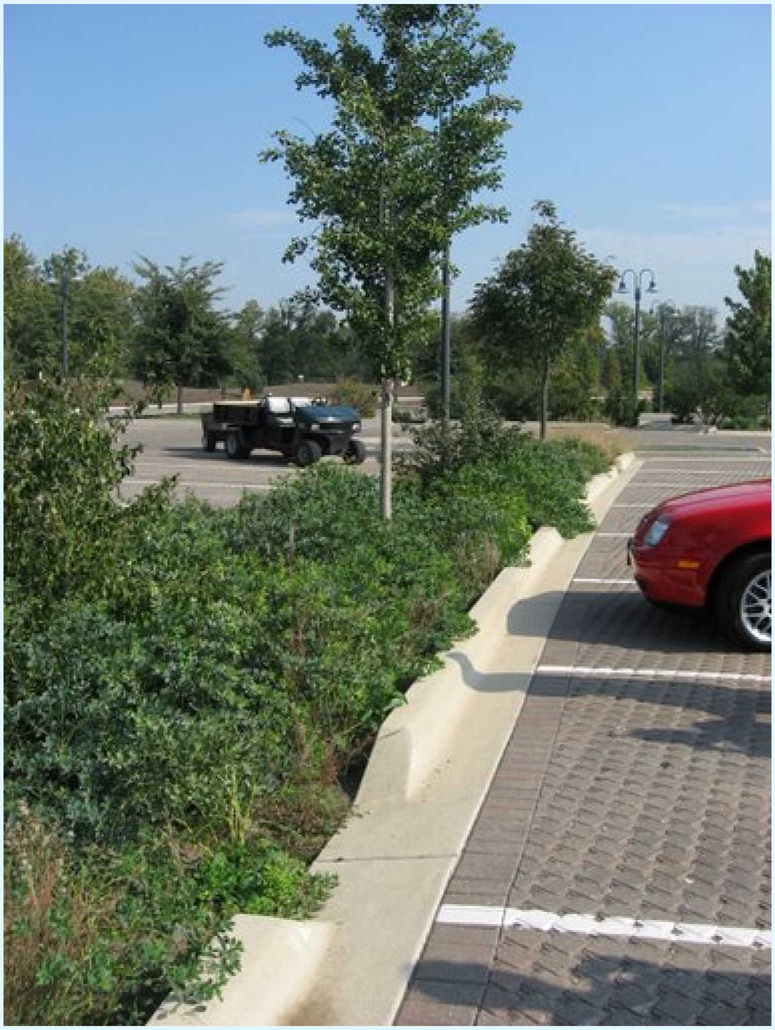
5 - Median concentrations. Not used to calculate representative values due to site location and variation from other values.

6 - Mean concentrations from simulated rainfall study

7 - Mean concentrations. Not used to calculate representative values due to transportation nature of land use.

United States Environmental Protection Agency
Office of Water (4503T) Washington, DC 20460
EPA 841-B-09-001 December 2009 www.epa.gov/owow/nps/lid/section438

Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act



Foreword

Stormwater runoff in urban and developing areas is one of the leading sources of water pollution in the United States. In recognition of this issue, Congress enacted Section 438 of the Energy Independence and Security Act of 2007 (EISA) to require federal agencies to reduce stormwater runoff from federal development projects to protect water resources. More recently, the President signed Executive Order 13514 on "Federal Leadership in Environmental, Energy, and Economic Performance" calling upon all federal agencies to "lead by example" to address a wide range of environmental issues, including stormwater runoff. The Executive Order required the U.S. Environmental Protection Agency (EPA), in coordination with other federal agencies, to publish this Technical Guidance.

EPA worked closely with many federal agencies to develop this Technical Guidance to help federal agencies in implementing EISA Section 438. The guidance provides a step-by-step framework that will help federal agencies maintain pre-development site hydrology by retaining rainfall on-site through infiltration, evaporation/transpiration, and re-use to the same extent as occurred prior to development. The Technical Guidance provides background information, key definitions, case studies, and guidance on meeting the new requirements.

Federal agencies can comply with Section 438 by using a variety of stormwater management practices often referred to as "green infrastructure" or "low impact development" practices, including, for example, reducing impervious surfaces, using vegetative practices, porous pavements, cisterns and green roofs.

One of the most exciting new trends in water quality management today is the movement by many cities, counties, states, and private sector developers toward the increased use of this next generation stormwater management practices to help protect and restore water quality. Many federal agencies, including EPA, are already using a full spectrum of stormwater management practices to reduce the impact of federal facilities on local watersheds. These projects have produced results such as reductions in site runoff volumes and increased stormwater quality, which ultimately lead to more sustainable facilities.

EPA enjoyed the opportunity to work with a number of federal agencies to develop this state-of-the art, technical guidance and appreciate all their input. We look forward to continuing the dialogue as we all work to implement this guidance.

Peter S. Silva
Assistant Administrator
Office of Water
U.S. Environmental Protection Agency

Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act

INTRODUCTION

In December 2007, Congress enacted the Energy Independence and Security Act of 2007. Section 438 of that legislation establishes strict stormwater runoff requirements for federal development and redevelopment projects. The provision reads as follows:

> **"Storm water runoff requirements for federal development projects.** The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow."

The intent of Section 438 of the Energy Independence and Security Act of 2007 (EISA) is to require federal agencies to develop and redevelop applicable facilities in a manner that maintains or restores stormwater runoff to the maximum extent technically feasible. Until recently, stormwater programs established to address water quality objectives have been designed to control traditional pollutants that are commonly associated with municipal and industrial discharges, e.g., nutrients, sediment, and metals. Increases in runoff volume and peak discharge rates have been regulated through state and local flood control programs. Although these programs have merit, knowledge accumulated during the past 20 years has led stormwater experts to the conclusion that conventional approaches to control runoff are not fully adequate to protect the nation's water resources (National Research Council, 2008).

Implementation of Section 438 of the EISA can be achieved through the use of the green infrastructure/low impact development (GI/LID) infrastructure tools described in this guidance. The intention of the statute is to maintain or restore the pre-development site hydrology during the development or redevelopment process. To be more specific, this requirement is intended to ensure that receiving waters are not negatively impacted by changes in runoff temperature, volumes, durations and rates resulting from federal projects. It should also be noted that a performance-based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site.

Section 14 of the Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance

On October 5, 2009, President Barack Obama signed Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance." Section 14 of the Executive Order provides:

> Stormwater Guidance for Federal Facilities. Within 60 days of the date of this order, the Environmental Protection Agency, in coordination with other Federal agencies as

> appropriate, shall issue guidance on the implementation of section 438 of the Energy Independence and Security Act of 2007 (42 U.S.C. 17094).

This provision contains two significant elements. First, for the first time, EPA is formally assigned the responsibility to write and issue the Section 438 guidance, in coordination with other federal agencies. Second, it establishes a deadline for EPA to do so by December 5, 2009.

Purpose and Organization of this Guidance

The purpose of this document is to provide technical guidance and background information to assist federal agencies in implementing EISA Section 438. Each agency or department is responsible for ensuring compliance with EISA Section 438. The document contains guidance on how compliance with Section 438 can be achieved, measured and evaluated. In addition, information detailing the rationale for the stormwater management approach contained herein has been included.

This document is intended solely as guidance. This document is not a regulation nor does it substitute for statutory provisions or regulations. This guidance does not impose any legally binding requirements on federal agencies and does not confer any legal rights or impose legal obligations upon any member of the public. This document does not create a cause of action against the EPA, other federal agencies, or the United States.

The following information is presented within this document:

Part I: Implementation Framework

A. Background
B. Benefits and outcomes of the new stormwater performance requirements
C. Applicability and definitions
D. Tools to implement the requirements of Section 438
E. Calculating the 95^{th} percentile rainfall event

Part II: Case Studies on Capturing the 95^{th} Percentile Storm Using Onsite Management Practices

Case studies representing typical federal installations have been included. The case studies were selected to demonstrate the feasibility of providing adequate stormwater control for a range of site conditions and building designs. To the maximum extent technically feasible, each case study includes a description of a method that can be used to determine the design objectives of the project based on retaining the 95^{th} percentile storm. Examples of onsite technologies and practices have also been provided. The case studies are intended to provide examples of modeling procedures that can be used to quantify treatment system performance and processes for assessing sites and determining appropriate control techniques to the maximum extent technically feasible.

Part I: Implementation Framework

A. BACKGROUND

This section contains background on the causes and consequences of stormwater discharges, solutions that can be used to address the causes and consequences of stormwater discharges and how to implement those solutions to comply with Section 438 of EISA.

Alterations to Natural Hydrology and the Impact on Stormwater Runoff
In the natural, undisturbed environment rain that falls is quickly absorbed by trees, other vegetation, and the ground. Most rainfall that is not intercepted by leaves infiltrates into the ground or is returned to the atmosphere by the process of evapotranspiration. Very little rainfall becomes stormwater runoff in permeable soil, and runoff generally only occurs with larger precipitation events. Traditional development practices cover large areas of the ground with impervious surfaces such as roads, driveways, sidewalks, and buildings. Under developed conditions runoff occurs even during small precipitation events that would normally be absorbed by the soil and vegetation. The collective force of the increased runoff scours streambeds, erodes stream banks, and causes large quantities of sediment and other entrained pollutants to enter the water body each time it rains (Shaver, et al., 2007; Booth testimony, 2008).

As watersheds are developed and impervious surfaces increase in area, the hydrology of the watersheds fundamentally changes over time which results in degraded aquatic ecosystems. In recognition of these problems, stormwater managers employed extended detention approaches to mitigate the impacts of increased peak runoff rates. However, wet ponds and similar practices are not fully adequate to protect downstream hydrology because of the following inherent limitations of these conventional practices (National Research Council, 2008; Shaver, et al., 2007):

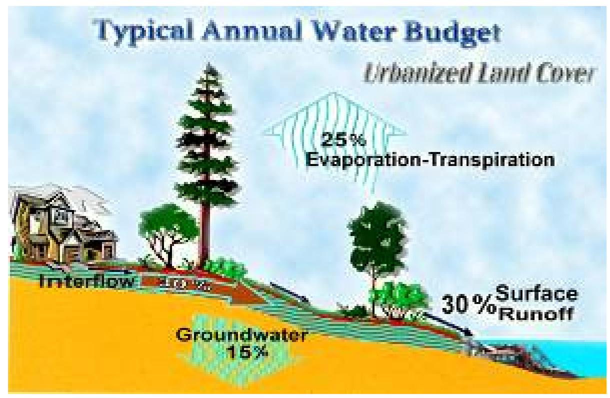
- Poor peak control for small, frequently-occurring storms;
- Negligible volume reduction; and
- Increased duration of peak flow.

Detention storage targets relatively large, infrequent storms, such as the two and 10-year/24-hour storms for peak flow rate control. As a result of this design limitation, flow rates from smaller, frequently-occurring storms typically exceed those that existed onsite before land development occurred and these increases in runoff volumes and velocities typically result in flows erosive to stream channel stability (Shaver, et al., 2007). Section 438 is intended to address the inadequacies of the historical detention approach to managing stormwater and promote more sustainable practices that have been selected to maintain or restore predevelopment site hydrology.

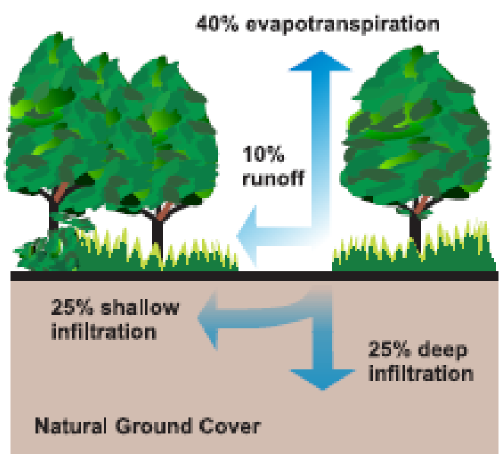
A 2008 National Research Council report on urban stormwater confirmed that current stormwater control efforts are not fully adequate. Three of the report's findings on stormwater management approaches are particularly relevant (National Research Council, 2008).

1. Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds;
2. Stormwater control measures such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from new development; and
3. Stormwater control measures that harvest, infiltrate, and evapotranspire stormwater are critical to reducing the volume and pollutant loading of small storms.

Pre-development Hydrology. *Courtesy of C. May, University of Washington.*



Post-Development Hydrology. *Courtesy of C. May, University of Washington.*



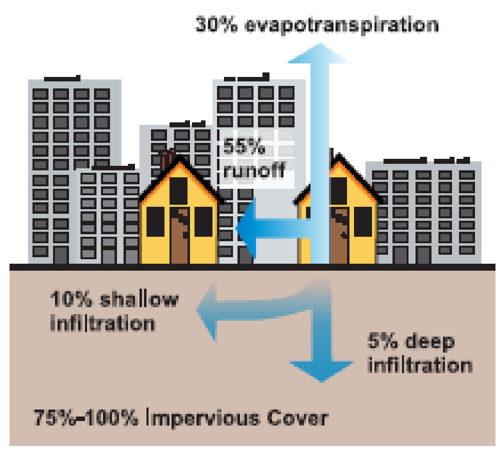


Figure 1. Pre-Development and Post-Development Hydrology. (USDA).

Figure 1 contains two sets of diagrams depicting the water balances at undeveloped and developed sites. Runoff patterns will vary based on factors such as geographic location, local meteorological conditions, vegetative cover and soils. The first set of figures represents conditions in the Pacific Northwest where storms have a long duration and low intensity, i.e., the volume of rain in an individual storm is small. The second set of figures from the U.S. Department of Agriculture represents a more generalized set of conditions, but was included to illustrate that heavily urbanized areas typically cause large increases in runoff.

Land cover changes that result from site development include increased imperviousness, soil compaction, loss of vegetation, and loss of natural drainage patterns, which result in increased runoff volumes and peak runoff rates. The cumulative impacts of the land cover changes result in alterations of the natural hydrology of a site, which disrupts the natural water balance and changes water flow paths. The consequences of these impacts include:

1. *Increased volume of runoff*. With decreased area for infiltration and evapotranspiration due to development, a greater amount of rainfall is converted to overland runoff which results in larger stormwater discharges.
2. *Increased peak flow of runoff*. Increased impervious surface area and higher connectivity of impervious surfaces and stormwater conveyance systems increase the flow rate of stormwater discharges and increase the energy and velocity of discharges into the stream channel.
3. *Increased duration of discharge*. Detention systems generate greater flow volumes and rates. These prolonged higher discharge rates can undermine the stability of the stream channel and induce erosion, channel incision and bank cutting.
4. *Increased pollutant loadings*. Impervious areas are a collection site for pollutants. When rainfall occurs these pollutants are mobilized and transported directly to stormwater conveyances and receiving streams via these impervious surfaces.
5. *Increased temperature of runoff*. Impervious surfaces absorb and store heat and transfer it to stormwater runoff. Higher runoff temperatures may have deleterious effects on receiving streams. Detention basins magnify this problem by trapping and discharging runoff that is heated by solar radiation (Galli, 1991; Schueler and Helfrich, 1988).

The resulting increases in volume, peak flow, and duration are illustrated in the hydrograph in Figure 2, which is a representation of a site's stormwater discharge with respect to time. The hydrograph illustrates the impacts of development on runoff volume and timing of the runoff. Individual points on the curve represent the rate of stormwater discharge at a given time. The graph illustrates that development and corresponding changes in land cover result in greater discharge rates, greater volumes, and shorter discharge periods. In a natural condition, runoff rates are slower than those on developed sites and the discharges occur over a longer time period. The predevelopment peak discharge rate is also much lower than the post-development peak discharge rate due to attenuation and absorption by soils and vegetation. In the post-development condition there is generally a much shorter time before runoff begins because of increased impervious surface area, a higher degree of connectivity of these areas and the loss of soils and vegetative cover that slow or reduce runoff.

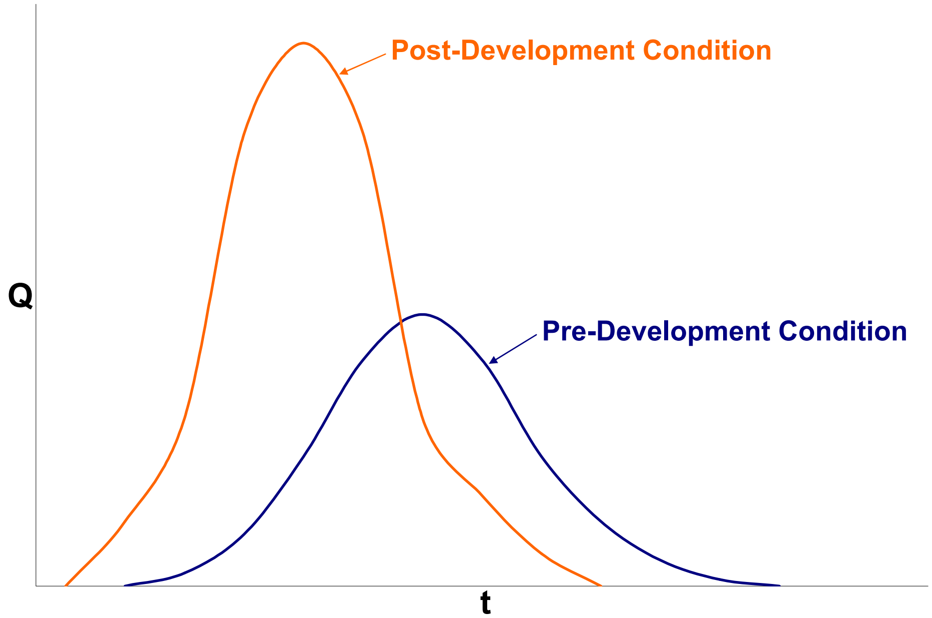


Figure 2. Post-Development Hydrograph.
(Q = volumetric flow rate; t = time)

Figure 3. Stream Displaying the Effects of Stormwater Runoff and Channel Downcutting.

The Solution: Preserving and Restoring Hydrology
A new approach has evolved in recent years to eliminate or reduce the amount of water and pollutants that run off a site and ultimately are discharged into adjacent water bodies.

The fundamental principle is to employ systems and practices that use or mimic natural processes to: 1) infiltrate and recharge, 2) evapotranspire, and/or 3) harvest and use precipitation near to where it falls to earth.

GI/LID practices include a wide variety of practices that utilize these mechanisms. These practices can be used at the site, neighborhood and watershed/regional scales. In this document the focus is on site-level practices, which is most consistent with the terms used in Section 438: "project," "facility," and "property." Although these performance requirements apply at the project site-level, flexibility exists to utilize nearby areas or areas directly adjacent to the facility to manage the runoff, i.e., evapotranspirate, infiltrate or harvest and use. Where justifiable, it also may be appropriate to evapotranspirate, infiltrate or harvest and use an equivalent or greater amount of runoff offsite as long as the runoff is discharged or used in the same receiving subwatershed or watershed.

The purpose of EISA Section 438 is to replicate the pre-development hydrology to protect and preserve both the water resources onsite and those downstream. For example, if prior to development, twenty five (25) percent of the annual rainfall runs directly into the stream and the remainder infiltrates into the ground or is evapotranspired into the air, then the post-development goal should be to limit runoff to twenty five (25) percent of the annual precipitation while maintaining the correct aquifer recharge rate. This has the benefit, in most cases, of delivering water to the stream at approximately the same rate, volume, duration and temperature as the stream had naturally evolved to receive prior to development. The result will be to eliminate or minimize the erosion of streambeds and streambanks, significantly reduce the delivery of many pollutants to water bodies, and retain historical instream temperatures.

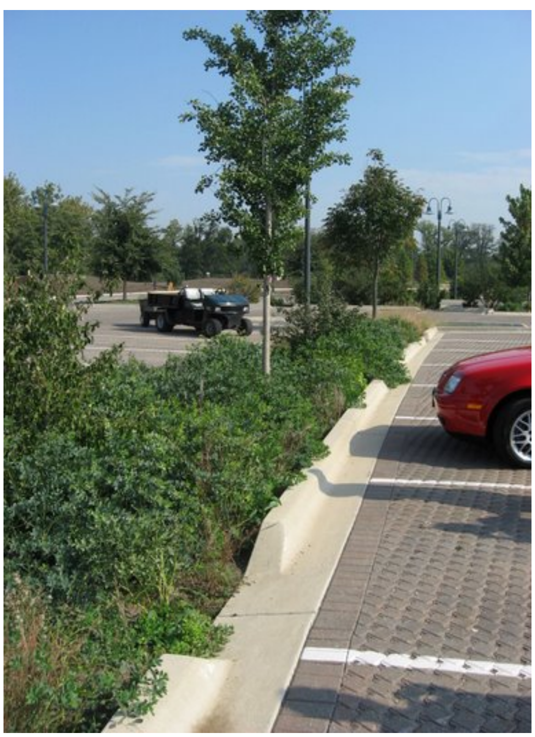


Figure 4. Parking lot bioswale and permeable pavers in Chicago.

Restoring or maintaining pre-development hydrology has emerged as a control approach for several reasons. Most importantly, this approach is intended to directly address the root cause of impairment. Current control approaches have been selected in an attempt to control the symptoms (peak flow, and excess pollutants), but this strategy is not fully adequate because of the scale of the problem, the cumulative impacts of multiple developments and the need to manage both site and watershed level impacts. With current approaches, it is also difficult to adequately protect and improve water quality because the measures employed are not addressing the main problem which is a hydrologic imbalance.

Designing facilities based on the goal of maintaining or restoring pre-development hydrology provides a site specific basis and an objective methodology with which to determine appropriate practices to protect the receiving environment.

Using pre-development hydrology as the guiding control principal also allows the designer to consider climatic and geologic variability and tailor the solutions to the project location. Thus the need for a one size fits all approach is rendered unnecessary since the design objective is dictated by the pre-development site conditions and other technicalities of the project site and facility. Instead of prescribed approaches dictating discharge volumes or flow rates, site assessments of historical infiltration and runoff rates will inform the designer and provide the basis for a suitable design. The use of this approach will minimize compliance complications that may arise from prescriptive design approaches which do not account for the variability of precipitation frequencies, rainfall intensities and pre-development land cover and soil conditions that influence infiltration and runoff.

B. Benefits and Outcomes of the New Stormwater Performance Requirements

Implementation of these new stormwater performance requirements in EISA Section 438 provides numerous environmental and economic benefits in addition to reducing the volume of stormwater runoff:

Benefits to Water Resources:

- *Cleaner Water.* The use of plants, soils and water harvesting and use practices can reduce stormwater runoff volumes and pollutant loadings and the frequency and magnitude of combined sewer overflows (volume and pollutant loading reductions). These practices are part of a larger set of practices called green infrastructure/low impact development.
- *Clean and Adequate Water Supplies.* GI/LID approaches using soil based vegetated infiltration systems can be used to recharge ground water and maintain stream base flow. By recharging ground water aquifers, aquatic ecosystem health is maintained and base flows are increased which helps ensure more constant flows for drinking water withdrawals. Harvesting and reusing rainwater also reduces the need to use potable water for all uses and can reduce both the infrastructure and energy needed to treat and transport both drinking water and stormwater.
- *Source Water Protection.* GI/LID practices provide pollutant removal benefits, thereby providing some protection for both ground water and surface water sources of drinking water. In addition, GI/LID provides ground water recharge benefits.

GI/LID approaches are a set of management approaches and technologies that utilize and/or mimic the natural hydrologic cycle processes of infiltration, evapotranspiration and use. GI/LID practices include green roofs, trees and tree boxes, rain gardens, vegetated swales, pocket wetlands, infiltration planters, porous and permeable pavements, vegetated median strips, reforestation and revegetation and protection of riparian buffers and floodplains. These practices can be used almost anywhere soil and vegetation can be worked into the urban or suburban landscape. They include decentralized harvesting approaches such as rain barrels and cisterns that can be used to capture and re-use rainfall for watering plants or flushing toilets.

Other Social and Environmental Benefits:

- *Cleaner Air.* Trees and vegetation improve air quality by filtering many airborne pollutants and can help reduce the amount of respiratory illness (Vingarzan and Taylor, 2003).
- *Reduced Urban Temperatures.* Summer city temperatures can average 10ºF higher than nearby suburban temperatures (Casey Trees, 2007). High temperatures are also linked to higher ground level ozone concentrations. Vegetation creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air (Grant, et al., 2003). Reductions in impervious surface and the use of light colored pervious surfaces (e.g., permeable concrete) also can mitigate urban temperatures.
- *Moderate the Impacts of Climate Change.* Climate change impacts and effects vary regionally, but GI/LID techniques can provide adaptation benefits for a wide array of circumstances. They can be used to conserve, harvest and use water, to recharge ground waters and to reduce surface water discharges that could contribute to flooding. In addition, there are mitigation benefits such as reduced energy demand and carbon sequestration by vegetation.
- *Increased Energy Efficiency.* Green space helps lower ambient temperatures and, when incorporated on and around buildings, helps shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. Diverting stormwater from wastewater collection, conveyance and treatment systems can reduce the amount of energy needed to pump and treat the water. Energy efficiency not only reduces costs, but also reduces generation of greenhouse gases.
- *Community Benefits.* Trees and plants improve urban aesthetics and community livability by providing recreational and wildlife areas. Studies show that property values are higher when trees and other vegetation are present. Increased green space also has public health benefits and has been shown to reduce crime and the associated stresses of urban living.

Figure 5. Rain water cistern.

C. Applicability and Definitions

Applicability

1. Who is a "**Sponsor**" of a project?

Section 438 applies to the "**sponsor** of any development or redevelopment project involving a Federal facility . . ." Section 438 requires that the "sponsor . . . shall use . . . strategies for the property to maintain or restore . . . the predevelopment hydrology. . ." The "sponsor" should generally be regarded as the federal department or agency that owns, operates, occupies or is the primary user of the facility and has initiated the development or redevelopment project. If the federal agency hires another entity to perform activities such as site construction or maintenance, the agency should nonetheless be regarded as the sponsor and be responsible to assure compliance with the requirements of Section 438. The agency sponsor is free to contract out various duties and responsibilities that are associated with achieving compliance.

2. What is a "**Federal facility**"?

Section 438 provides that its requirements apply to the "sponsor of any development or redevelopment project involving a **Federal facility** . . ." Section 401(8) of EISA states: "The term `Federal facility' means any building that is constructed, renovated, leased, or purchased in part or in whole for use by the Federal Government."

3. What is a **"footprint**"?

Section 438 applies to a federal facility "with a **footprint** that exceeds 5,000 square feet." For the purposes of this guidance, any project involving a federal facility that disturbs 5,000 square feet or more of ground area is covered by this guidance. Existing facilities that have an overall **footprint** of 5,000 square feet or greater that disturb less than 5,000 square feet of land area as part of any single development or redevelopment project are not subject to Section 438 requirements. Consistent with the purpose of Section 438 to preserve or restore pre-development hydrology, the term "footprint" includes all land areas that are disturbed as part of the project.

4. What is "**the property**"?

Section 438 provides that the project sponsor "shall use site planning, design, construction, and maintenance strategies for the **property** to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the **property."** This clause has been interpreted to mean that the land surrounding the project site is available to implement the appropriate GI/LID practices where optimal.

Although the performance requirements of EISA Section 438 apply only to the project footprint, the flexibility exists to utilize the entire federal property in implementing the stormwater strategies for the project.

Definitions

95^{th} percentile rainfall event. The 95^{th} percentile rainfall event represents a precipitation amount which 95 percent of all rainfall events for the period of record do not exceed. In more technical terms, the 95^{th} percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the 95^{th} percentile rainfall depth based on the range of all daily event occurrences during this period.

The 24-hour period is typically defined as 12:00:00 am to 11:59:59 pm. In general, at least a 20-30 year period of rainfall record is recommended for such an analysis. This raw data is readily available and collected by most airports across the county. Small rainfall events that are 0.1 of an inch or less are excluded from the percentile analysis because this rainfall generally does not result in any measureable runoff due to absorption, interception and evaporation by permeable, impermeable and vegetated surfaces. Many stormwater modelers and hydrologists typically exclude rainfall events that are 0.1 inch or less from calculations of rainfall events of any storm from their modeling analyses of rainfall event frequencies. See, for example, the Center for Watershed Protection's Urban Subwatershed Restoration Manual 3 (available at www.cwp.org).

Federal facility. The term "federal facility" means any buildings that are constructed, renovated, leased, or purchased in part or in whole for use by the federal government as defined in section 401(8) of the Energy Independence and Security Act.

Development or re-development. For the purposes of this provision this term applies to any action that results in the alteration of the landscape during construction of buildings or other infrastructure such as parking lots, roads, etc, (e.g., grading, removal of vegetation, soil compaction, etc.) such that the changes affect runoff volumes, rates, temperature, and duration of flow. Examples of projects that would fall under "re-development" include structures or other infrastructure that are being reconstructed or replaced and the landscape is altered. Typical patching or resurfacing of parking lots or other travel areas would not fall under this requirement.

D. TOOLS TO IMPLEMENT THE REQUIREMENTS OF SECTION 438

Section 438 of the Energy Independence and Security Act of 2007 reads as follows:

> **Section 438. Storm water runoff requirements for federal development projects.** The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

The intention of EISA Section 438 is to preserve or restore the hydrology of the site during the development or redevelopment process. To be more specific, this requirement is intended to ensure that aquatic biota, stream channel stability, and historical aquifer recharge rates of receiving waters are not negatively impacted by changes in runoff temperature, volumes, durations and rates resulting from federal projects. A performance based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site.

To meet these performance objectives, technically feasible stormwater control practices that are effective in reducing the volume of stormwater discharge should be used. To implement EISA Section 438, this guidance recommends that the federal facility use all known, available and reasonable methods of stormwater retention and/or use to the maximum extent technically feasible (METF). Tools to implement the requirements of Section 438 are described below and illustrated in Figure 8.

Establishing Section 438 Performance Design Objectives

Described below are options site designers can use to comply with Section 438. There may be situations where Option 1 (retaining the 95th percentile rainfall event) is not protective enough to maintain or restore the predevelopment hydrology of the project (for example, in some headwater streams). In these cases, Option 2 (site-specific hydrologic analysis) could be used to determine the types of stormwater practices necessary to preserve predevelopment runoff conditions. Option 2 could also be used if predevelopment runoff conditions can be maintained by retaining less than the 95th percentile rainfall event. Because a performance based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site, Option 2 was provided in recognition that there are established methodologies that can be utilized to estimate the volume of infiltration and evapotranspiration based on site-specific hydrology and thus establish the predevelopment hydrology performance design objectives.

Option 1: Retain the 95th Percentile Rainfall Event

One approach to establishing the performance design objectives is to design, construct, and maintain stormwater management practices that manage rainfall onsite, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event to the maximum extent technically feasible (METF). This objective should be accomplished by the use of practices that infiltrate, evapotranspire and/or harvest and use rainwater. The 95th percentile rainfall event is the event whose precipitation total is greater than or equal to 95 percent of all storm events over a given period of record. For example, to determine what the 95th percentile storm event is in a specific location, all 24 hour storms that have recorded values over a 30 year period would be tabulated and a 95th percentile storm would be determined from this record, i.e., 5% of the storms would be greater than the number determined to be the 95th percentile storm. Thus the 95th percentile storm would be represented by a number such as 1.5 inches, and this would be the design storm (example 95th percentile storm events for selected cities are presented in Table 1). The designer would then select a system of practices, to the METF, that infiltrate, evapotranspire or harvest and use this volume multiplied by the total area of the facility/project footprint. Methods and data used to estimate the 95th percentile event are discussed in Part II of this document.

For the purposes of this guidance, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites. This 95th percentile approach was identified and recommended because this storm size represents the volume that appears to best represent the volume that is fully infiltrated in a natural condition and thus should be managed onsite to restore and maintain this pre-development hydrology for duration, rate and volume of stormwater flows. In general, only large storms generate significant runoff. In addition, this approach was identified because it employs natural treatment and flow attenuation methods that are presumed to have existed on the site before construction of infrastructure (e.g., building, roads, parking lots, driveways,) and is intended to infiltrate or evapotranspirate the full volume of the 95th percentile storm. Because this approach necessitates the use of practices that generally preclude extended detention, it will also typically address the issue of maintaining predevelopment temperatures. However, in cases where there are discharges to cool water streams or other sensitive receiving waters, additional strategies may be needed to ensure that stormwater discharges do not result in greater thermal impacts than would occur in pre-development conditions (Schueler and Helfrich, 1988).

Where technically feasible, the goal of Option 1 is that one hundred percent (100%) of the volume of water from storms less than or equal to the 95th percentile event over the footprint of the project should not be discharged to surface waters. In some cases, runoff can be harvested and used and ultimately may be discharged to surface waters or a sanitary treatment system; such direct or indirect discharges must be authorized or allowed by the regulatory authority. For example, if runoff is captured for nonpotable uses such as toilet flushing or other uses that are not irrigation related, these waters potentially could be discharged into the sanitary sewer system. Preferred mechanisms for retaining discharges from storms greater than the 95th percentile event are through overflow or diversion for the volume that exceeds the 95th percentile amount. Because standard underdrains typically discharge from smaller storms as well, underdrain designs, if employed, should ensure adequate retention capacity for the 95th percentile event volume. For structures such as roofs and paved surfaces that can increase the temperature of stormwater runoff, materials that minimize temperature increases (e.g., concrete vs. asphalt; vegetated roofs) should be considered and used as appropriate.

Retaining 100 percent of all rainfall events equal to or less than the 95th percentile rainfall event was identified as Option 1 because small, frequently-occurring storms account for a large proportion of the annual precipitation volume, and the runoff from those storm events also significantly alters the discharge frequency, rate and temperature of the runoff.

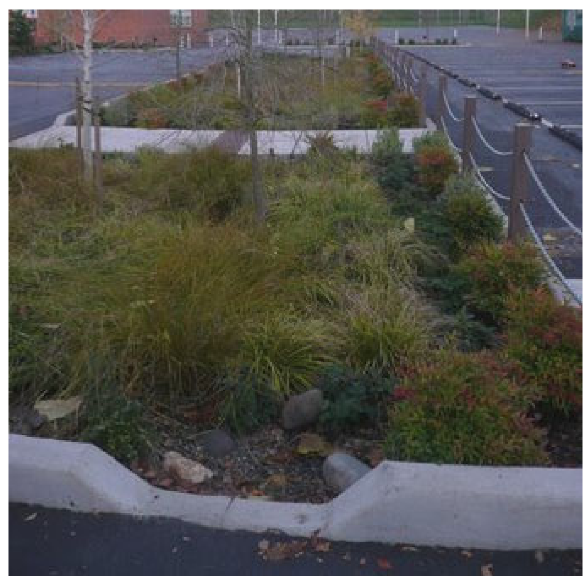


Figure 6. Bioretention facility in Oregon.

The runoff produced by these small storms and the initial portion of larger storms has a strong negative cumulative impact on receiving water hydrology and water quality. In areas that have been developed, runoff is generated from almost all storms, both small and large, due to the impervious surfaces associated with development and the loss of soils and vegetation. In contrast, natural or undeveloped areas discharge little or no runoff from small storms because the rain is absorbed by the landscape and vegetation. Studies have shown that increases in runoff event frequency, volume and rate can be diminished or eliminated through the use of GI/LID designs and practices, which infiltrate, evapotranspire and capture and use stormwater.

Option 1 was identified because it is a simplified approach to meet the intent of Section 438 in contrast to Option 2 which requires the designer to conduct a hydrologic analysis of the site based on site-specific conditions.

Table 1. Example 95th Percentile Storm Events for Select U.S. Cities (adapted from Hirschman and Kosco, 2008).

City	95th Percentile Event Rainfall Total (in)	City	95th Percentile Event Rainfall Total (in)
Atlanta, GA	1.8	Kansas City, MO	1.7
Baltimore, MD	1.6	Knoxville, TN	1.5
Boston, MA	1.5	Louisville, KY	1.5
Buffalo, NY	1.1	Minneapolis, MN	1.4
Burlington, VT	1.1	New York, NY	1.7
Charleston, WV	1.2	Salt Lake City, UT	0.8
Coeur D'Alene, ID	0.7	Phoenix, AZ	1.0
Cincinnati, OH	1.5	Portland, OR	1.0
Columbus, OH	1.3	Seattle, WA	1.6
Concord, NH	1.3	Washington, DC	1.7
Denver, CO	1.1		

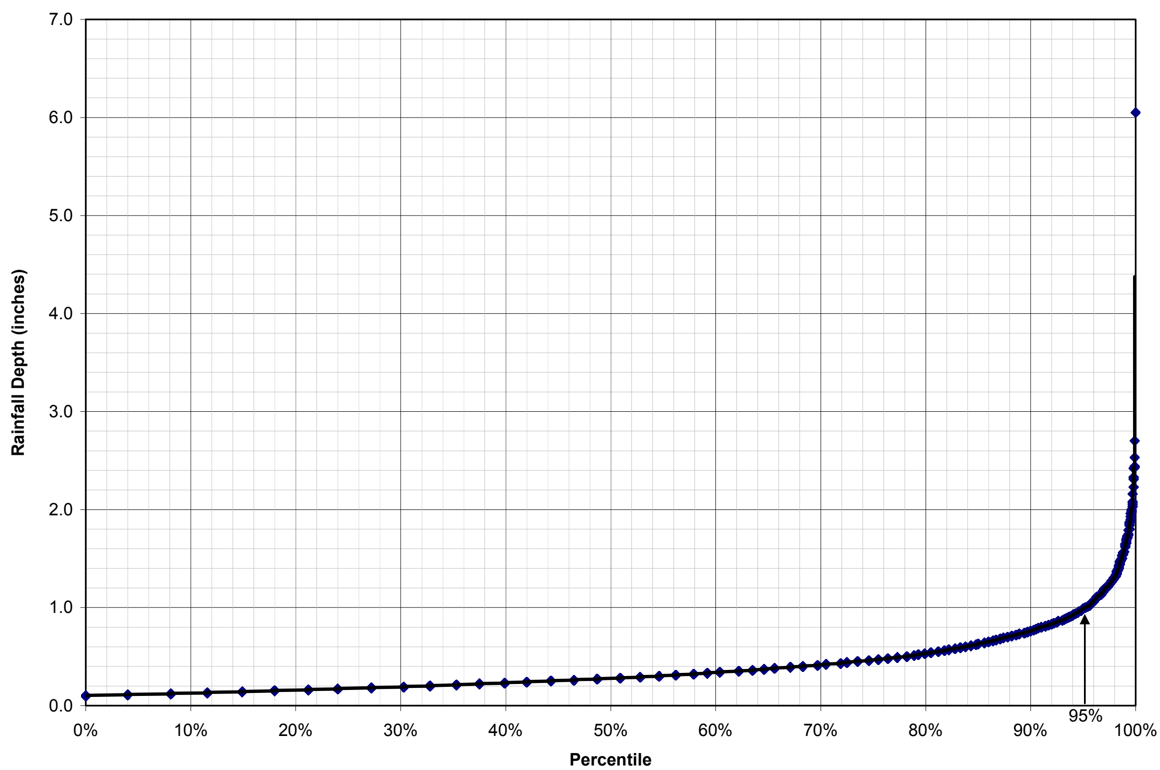


Figure 7. Rainfall Frequency Spectrum showing the 95th percentile rainfall event for Portland, OR (~1.0 inches)

Calculating the 95th Percentile Rainfall Event

Section E of this guidance contains information on how to calculate the 95th percentile rainfall event for a specific area. A long-term record of daily rainfall amounts (ideally, at least 30 years) is needed to calculate the 95th percentile rainfall.

Designers opting to use Option 1 need to do the following:

1) calculate or verify the precipitation amount from the 95th percentile storm event (this number would be typically expressed in inches, e.g., 1.5", and

2) employ onsite stormwater management controls to the METF that infiltrate, evapotranspire or harvest and use the appropriate design volume.

The 95th percentile event can be calculated by using the following procedures below (summarized from Hirschman and Kosco, 2008, *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*, Center for Watershed Protection):

- Obtain a long-term rainfall record from a nearby weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). Long-term rainfall records can be obtained from many sources, including NOAA at http://cdo.ncdc.noaa.gov/pls/plclimprod/poemain.accessrouter?datasetabbv=SOD&countryabbv=&georegionabbv=.
- Remove data for small rainfall events that are 0.1 inch or less and snowfall events that do not immediately melt from the data set. These events should be deleted since they do not typically cause runoff and could potentially cause the analyses of the 95th percentile storm runoff volume to be inaccurate.
- Using a spreadsheet or simple statistical package, sort the rainfall events from highest to lowest. In the next column, calculate the percentage of rainfall events that are less than each ranked event (event number/total number of events). For example, if there were 1,000 rainfall events and the highest rainfall event was a 4" event, then 999 events (or a percentile of 999/1000, or 99.9%) are less than the 4" rainfall event.
- Use the rainfall event at 95% as the 95th percentile storm event.

Option 2: Site-Specific Hydrologic Analysis

Another approach to establishing the performance design objective is to design, construct, and maintain stormwater management practices that preserve the pre-development runoff conditions following construction. Option 2 allows the designer to conduct a site-specific hydrologic analysis to determine the pre-development runoff conditions instead of using the estimated volume approach of Option 1. Under Option 2, the pre-development hydrology would be determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools. If the designer elects to use Option 2, the designer would then identify the pre-development condition of the site and quantify the post-development runoff volume and peak flow discharges that are equivalent to pre-development conditions. The post-construction rate, volume, duration and temperature of runoff should not exceed the pre-development rates and the predevelopment hydrology should be replicated through site design and other appropriate practices to the maximum extent technically feasible. These goals should be accomplished through the use of infiltration, evapotranspiration, and/or rainwater harvesting and use. Defensible and consistent hydrological assessment tools should be used and documented. Additional discussions of appropriate methodologies to use in assessing site hydrology have been included in the technical sections of this document. See, for example, the discussion of spreadsheet versions or curve numbers based on the Natural Resource Conservation Service Technical Release 55 (TR-55) Method in Appendix A of this document.

Development

The pre-development hydrologic condition of the site is the combination of runoff, infiltration and evapotranspiration rates and volumes that typically existed on the facility site before "development" on a greenfields site (meaning any construction of infrastructure on undeveloped land such as meadows or forests). In practice, determining the pre-development hydrology of a given site can be difficult if there is no suitable reference site. As a result, reference conditions for typical land cover types in the locality often are used to approximate what fraction of the precipitation ran off, soaked into the ground or was evaporated from the landscape. The use of reference conditions can be problematic if suitable data are not available or unique site conditions exist that do not fit within a typical land use cover type for the area, e.g., meadow or forest. In cases where suitable data from comparable conditions cannot be found or is otherwise inadequate to be used in conducting an Option 2 analysis for the specific area being considered for development or redevelopment, the project sponsor should use the Option 1 analytical framework.

Re-development

For re-development sites, existing site conditions and uses of the site can influence the amount of runoff that can be managed on site through infiltration, evapotransporation and harvest and use and thus the performance design objective. In these cases the design process in Figure 8 and Scenario 9 illustrate the decision processes that can be used.

In the context of some re-development projects, fully restoring predevelopment hydrology can be difficult to achieve and Congress recognized this potential difficulty by including the METF language in the statute. In these cases, Congressional intent can be best carried out by using a systematic METF analysis to determine what practices can be implemented at the site to maintain or store the hydrologic condition of the site. Scenarios 1-8 provide examples of METF analyses that demonstrate that pre-development hydrology can be achieved. Scenario 9 provides an example of an METF analysis that demonstrates that pre-development hydrology cannot be fully achieved and illustrates the extent to which pre-development hydrology can be restored.

Note: *It should also be emphasized that the performance based approach in Option 1 is intended to be a surrogate for determining the pre-development reference condition and this standard is intended to be used in cases where it is more practical, cost effective, and/or expeditious than Option 1, or where it is difficult or infeasible to identify the relevant reference conditions for the site.*

Determination of Maximum Extent Technically Feasible

Compliance with Section 438 requires that stormwater management measures are implemented to the maximum extent technically feasible (METF) to maintain or restore the pre-development hydrology conditions specifically with respect to temperature, rate, volume, and duration of flow.

Performance or design goals based on the pre-development hydrology can be established by using options such as the following: Retention of the 95th percentile rainfall event (Option 1), or through a site-specific hydrologic analysis that estimates the volume of infiltration, evapotranspiration or onsite stormwater harvesting and use based on site-specific hydrologic conditions (Option 2).

Technical Infeasibility

For projects where technical infeasibility exists, the federal agency or department sponsoring the project should document and quantify that stormwater strategies, such as infiltration, evapotranspiration, and harvesting and use have been used to the METF, and that full employment of these types of controls are infeasible due to site constraints. Some western states place restrictions on harvesting and use due to water rights, however, these requirements do not necessarily preclude the sponsor of the project from implementing strategies such as infiltration and evapotranspiration. Documentation of technical infeasibility should include, but may not be limited to, engineering calculations, geologic reports, hydrologic analyses, and site maps. A determination that the performance design goals cannot be met on site should include analyses that rule out the use of an adequate combination of infiltration, evapotranspiration, and use measures. Examples of where site conditions may prevent the full employment of appropriate management techniques to the METF include a combination of:

- The conditions on the site preclude the use of infiltration practices due to the presence of shallow bedrock, contaminated soils, near surface ground water or other factors such as underground facilities or utilities.
- The design of the site precludes the use of soil amendments, plantings of vegetation or other designs that can be used to infiltrate and evapotranspirate runoff.
- Water harvesting and use are not practical or possible because the volume of water used for irrigation, toilet flushing, industrial make-up water, wash-waters, etc. is not significant enough to warrant the design and use of water harvesting and use systems.
- Modifications to an existing building to manage stormwater are not feasible due to structural or plumbing constraints or other factors as identified by the facility owner/operator.
- Small project sites where the lot is too small to accommodate infiltration practices adequately sized to infiltrate the volume of runoff from impervious surfaces,
- Soils that cannot be sufficiently amended to provide for the requisite infiltration rates,
- Situations where site use is inconsistent with the capture and use of stormwater or other physical conditions on site that preclude the use of plants for evapotranspiration or bioinfiltration.
- Retention and/or use of stormwater onsite or discharge of stormwater onsite via infiltration has a significant adverse effect on the site or the down gradient water balance of surface waters, ground waters or receiving watershed ecological processes.

- State and local requirements or permit requirements that prohibit water collection or make it technically infeasible to use certain GI/LID techniques.
- Compliance with the Section 438 requirements would result in the retention and/or use of stormwater on the site such that an adverse water balance impact may occur to the receiving surface waterbody or ground water.

Please note that a single one of these characteristics is very unlikely to preclude meeting the performance standard, but a combination of factors may.

In cases where the facility has a defensible showing of technical infeasibility and can provide adequate documentation of site conditions or other factors that preclude full implementation of the performance design goal, the facility should still install stormwater practices to infiltrate, evapotranspire and/or harvest and use onsite the maximum amount of stormwater technically feasible. Note: Facilities must still comply with all other applicable federal, state and local requirements.

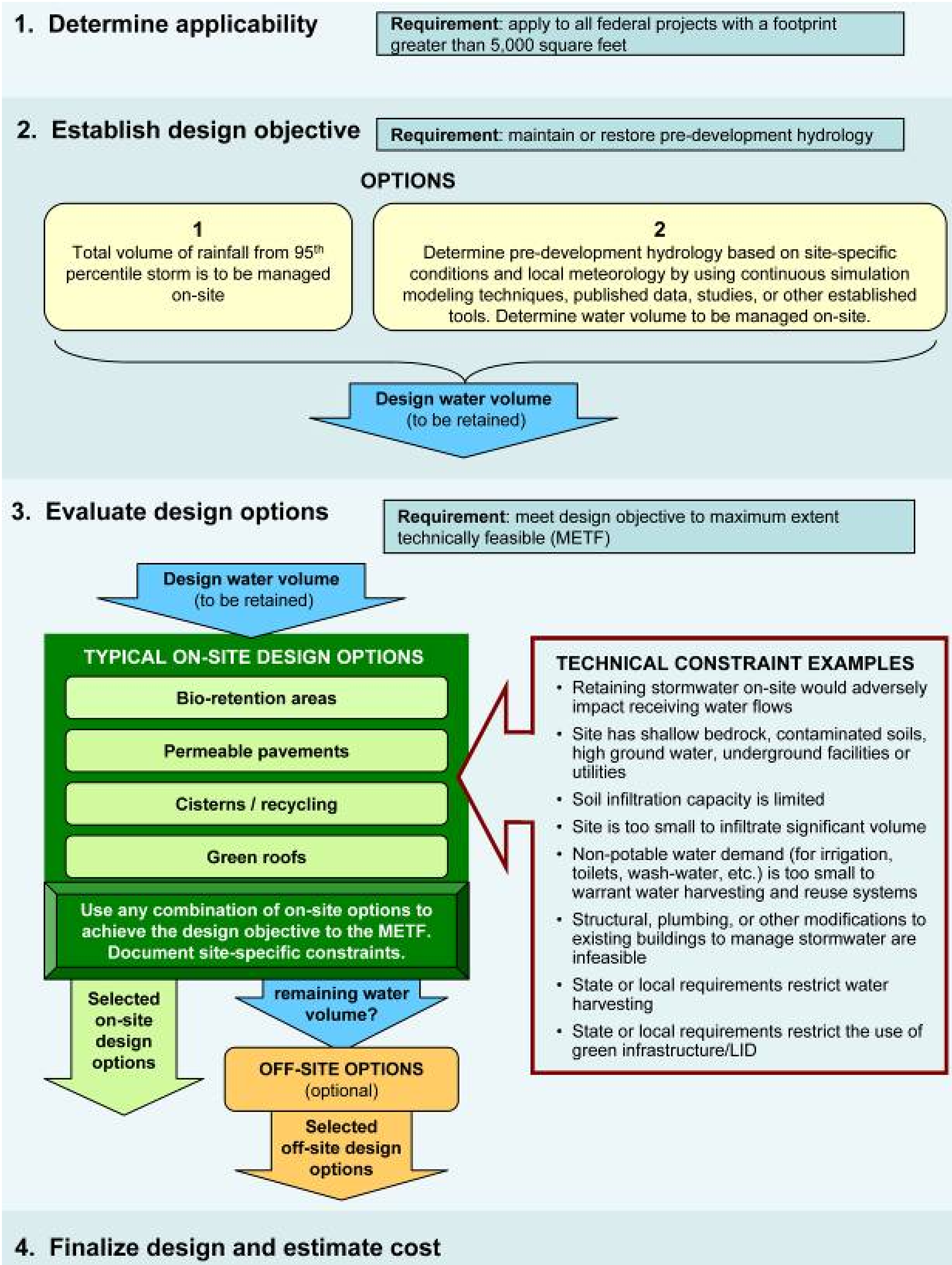


Figure 8. Section 438 Implementation Process

Documenting EISA Section 438 Implementation
Each agency or department is responsible for ensuring compliance with Section 438. It is recommended that: 1) the final design and as-built drawings of each facility shall be reviewed by a registered professional engineer and 2) the agency or department develop and maintain documentation of the following design criteria for each project subject to Section 438:

- Site evaluation and soils analysis
- Calculations for the 95th percentile rainfall event or the pre-development runoff volumes and rates to identify the volume of stormwater requiring management
- Documentation of modifications to the performance design objective based on technical constraints (site-specific METF determination)
- The site design and stormwater management practices employed on the site
- Design calculations for each stormwater management practice employed
- The respective volume of stormwater managed by each practice and the system as a whole
- Operations and maintenance protocols for the stormwater management system

The information should provide the necessary documentation and detail to demonstrate compliance and operation of stormwater management practices for the entire site.

Common Green Infrastructure/Low Impact Development Tools to Implement Section 438
Although Congress did not prescribe specific practices to be used to implement Section 438 it can be inferred that one of the goals of the Act was to promote the use of innovative stormwater management approaches, designs and practices that better protect receiving water quality, flow regimes and provide other important environmental benefits. GI/LID are preferred practices, to be supplemented with or replaced with conventional controls when site specific conditions dictate.

The GI/LID management approaches and technologies that federal agencies would typically use enhance and/or mimic the natural hydrologic cycle processes of infiltration, evapotranspiration, and use. Federal agencies can also use footprint reduction practices (e.g., building up instead of out) to reduce their stormwater impact. GI/LID approaches include biological systems and engineered systems. These include but are not necessarily limited to:

- Rain gardens, bioretention, and infiltration planters
- Porous pavements
- Vegetated swales and bioswales
- Green roofs
- Trees and tree boxes
- Pocket wetlands
- Reforestation/revegetation using native plants
- Protection and enhancement of riparian buffers and floodplains
- Rainwater harvesting for use (e.g., irrigation, HVAC make-up, non-potable indoor uses).

GI/LID practices are recommended to implement EISA Section 438 for the following reasons:

- cost savings in many cases

Figure 9. Disconnected downspout discharging to planter box.

- overall environmental performance
- pollutant loading reduction capability
- pollution prevention focus
- effectiveness in managing runoff volumes and rates
- energy efficient and energy conservative
- appropriate in a wide range of site condition and locations
- appropriate for new development and redevelopment projects
- appropriate at multiple scales of development, e.g., site, neighborhood, region

For more information on specific GI/LID practices and how they function, visit: www.epa.gov/greeninfrastructure and www.epa.gov/nps/lid.

Cost of Compliance

The cost of complying with Section 438 may require the use of approaches and techniques that initially may be more costly to design and implement. It is anticipated that as the expertise of the implementing agency or department increases and the demand for GI/LID materials and equipment increases that the overall costs of the projects will be lower or equivalent to the costs of constructing conventional stormwater practices. Initial studies conducted by EPA and others suggest that the use of GI/LID practices can be cost competitive. Recent evaluations of GI/LID projects have identified opportunities for cost savings because of reduced infrastructure and site preparation demands. In addition, longer term studies have indicated that GI/LID practices are continuing to gain cost efficiency as they are adopted more widely and with greater frequency thus reducing overall implementation costs.

In *Reducing Stormwater Costs through LID Strategies and Practices* (EPA 841-F-07-006, December 2007 - available for download at www.epa.gov/nps/lid), EPA examined 17 case studies in which conventional development costs were compared to GI/LID costs. In the great majority of cases, the GI/LID approach was between 15 and 80 percent less expensive than conventional control measures because implementation of GI/LID practices can offset costs of conventional construction and stormwater management approaches. Significant cost savings that were identified in the report include:

- Elimination or reduction of detention ponds
- Elimination or reductions of stormwater and CSO treatment and conveyance systems such as pipes, storage structures, stormwater treatment devices, and other related stormwater infrastructure
- Narrower streets with reduced material demands

- Fewer square yards of sidewalks
- Reduced land purchases for stormwater control structures

In addition, other benefits were achieved through the use of GI/LID such as more beneficial uses of land previously dedicated to stormwater devices, increased livability and higher property values.

There are many different combinations of practices that can be employed at particular sites to achieve pre-development hydrology. In selecting the appropriate set of practices to be used at the site, project sponsors should consider a broad range of factors, including cost-effectiveness of particular combinations of practices as applied to the site, as well as the potential for ancillary cost savings or community benefits (e.g., elimination or reduction of infrastructure costs, or the creation of attractive green spaces). EPA encourages project sponsors to include these factors in the planning and design phases of their projects so as to maximize triple bottom-line (economic, environmental, and social) results.

E. Calculating the 95th Percentile Rainfall Event

A long period of precipitation records, i.e., a minimum of 10 years of data, is needed to determine the 95th percentile rainfall event for a location. Thirty years or more of monitoring data are desirable to conduct an unbiased statistical analysis. The National Climatic Data Center (NCDC) provides long-term precipitation data for many locations of the United States. You can download climate data from their Web site (www.ncdc.noaa.gov) or by ordering compact discs (NOTE: The NCDC charges a fee for access to their precipitation data). Local airports, universities, water treatment plants, or other facilities might also maintain long-term precipitation records. Data reporting formats can vary based on the data sources. In general, each record should include the following basic information:

- Location (monitoring station)
- Recording time (usually the starting time of a time-step)
- Total precipitation depth during the time-step

In addition to the above information, a status flag is sometimes included to indicate data monitoring errors or anomalies. Typical NCDC flags include A (end accumulation), M (missing data), D (deleted data), or I (incomplete data). If there are no flags, the record has passed the quality control as prescribed by the NCDC and has been determined to be a valid data point.

There are several data processing steps to determine the 95th percentile rainfall event using a spreadsheet. These steps are summarized below:

1. Obtain a long-term 24-hr precipitation data set for a location of interest (i.e., from the NCDC website).

2. Import the data into a spreadsheet. In MS Excel [Data / Import External Data / Import Data]

3. Rearrange all of the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.

	A	B	C	D
1	Date	Prcp		
2	1/2/1921	0.05		
3	1/3/1921	0		
4	1/4/1921	0		
5	1/5/1921	0.33		
6	1/6/1921	0.08		
7	1/7/1921	0.08		
8	1/8/1921	0.19		
9	1/9/1921	0		

4. Review the records to identify if there are early periods with a large number of flagged data points (e.g., erroneous data points). Select a long period of good recording data that represents, ideally, 30 years or more of data. Remove all of the extra data (if not using the entire dataset).

5. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.

6. Remove small rainfall events (typically less than 0.1 inches), which may not contribute to rainfall runoff. These small events are categorized as depressional storage, which, in general, does not produce runoff from most sites.

	A	B	C	D
1	Date	Prcp		
2	1/5/1921	0.33		
3	1/8/1921	0.19		
4	1/14/1921	1.04		
5	2/6/1921	0.12		
6	2/11/1921	0.63		
7	2/20/1921	1.33		
8	2/28/1921	0.43		
9	3/3/1921	0.13		

Note: Steps 4 through 6 can be processed by applying data sort, delete and re-sort spreadsheet functions. In MS Excel [Data / Sort]

7. Calculate the 95th percentile rainfall amount by applying the PERCENTILE spreadsheet function at a cell. In MS Excel [=PERCENTILE(precipitation data range,95%)]

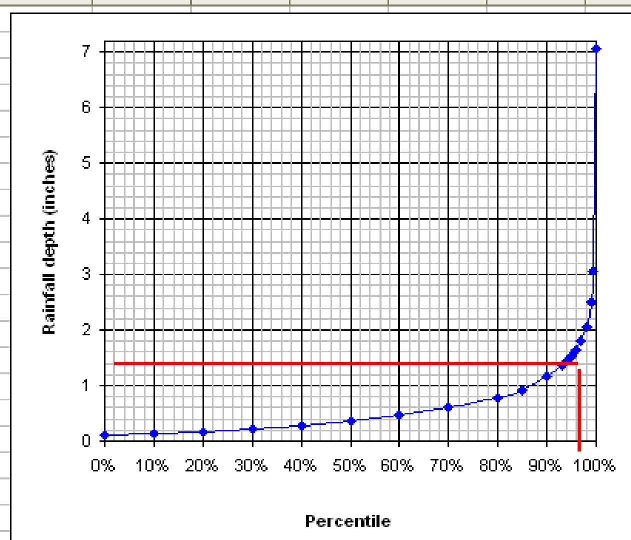
	A	B	C	D	E	F
1	Date	Prcp				
2	1/5/1921	0.33		=PERCENTILE(B:B,95%)		
3	1/8/1921	0.19		1.52		
4	1/14/1921	1.04				
5	2/6/1921	0.12				
6	2/11/1921	0.63				
7	2/20/1921	1.33				
8	2/28/1921	0.43				

Note: The PERCENTILE function returns the nth percentile of value in the entire precipitation data range. This function can be used to determine the 95th percentile storm event that captures all but the largest 5% of storms.

8. The 95th percentile was calculated in the previous step. However, if the user would like to see this information represented graphically and get a relative sense of where individual storm percentiles fall in terms of rainfall depths, the following methodology can be used. Derive a table showing percentile versus rainfall depth to draw a curve as shown below. The PERCENTILE spreadsheet function can be used for each selected percent. It is recommended to include at least 6 points between 0% and 100% (several points should be between 80% and 100% to draw an accurate curve).

	A	B	C	D	E	F	G
1	Date	Prcp		Percentile	Rainfall		
2	1/5/1921	0.33		0%	=PERCENTILE(B:B,D2)		
3	1/8/1921	0.19		10%	=PERCENTILE(B:B,D3)		
4	1/14/1921	1.04		20%	=PERCENTILE(B:B,D4)		
5	2/6/1921	0.12		30%	=PERCENTILE(B:B,D5)		
6	2/11/1921	0.63		40%	=PERCENTILE(B:B,D6)		

	A	B	C	D	E
1	Date	Prcp		Percentile	Rainfall
2	1/5/1921	0.33		0%	0.1
3	1/8/1921	0.19		10%	0.13
4	1/14/1921	1.04		20%	0.17
5	2/6/1921	0.12		30%	0.22
6	2/11/1921	0.63		40%	0.28
7	2/20/1921	1.33		50%	0.36
8	2/28/1921	0.43		60%	0.46
9	3/3/1921	0.13		70%	0.6
10	3/9/1921	0.31		80%	0.79
11	3/13/1921	0.46		85%	0.93
12	3/25/1921	0.47		90%	1.16
13	3/28/1921	0.12		93%	1.35
14	4/1/1921	0.36		94%	1.44
15	4/9/1921	0.69		95%	1.52
16	4/15/1921	0.24		96%	1.65
17	4/17/1921	0.32		97%	1.82
18	4/18/1921	0.55		98%	2.068
19	4/23/1921	0.69		99%	2.508
20	4/24/1921	0.19		99.5%	3.049
21	4/30/1921	1.44		100%	7.06



Use the spreadsheet software to create of plot of rainfall depth versus percentile, as shown above. The 95th percentile storm event should correlate to the rainfall depth calculated in step 7, however the graph can be used to calculate rainfall depths at other percentiles (e.g., 50%, 90%).

Part II: Case Studies on Capturing the 95th Percentile Storm Using Onsite Management Practices

INTRODUCTION

This section contains nine case studies that are intended to be representative of the range of projects that are subject to the requirements legislated in Section 438 of the Energy Independence and Security Act. The facility examples in the case studies were selected to illustrate project scenarios for differing geographic locations, site conditions, and project sizes and types. As noted in Part I, all projects with a footprint greater than 5,000 square feet must comply with the provisions of Section 438. What this means is that both new development and redevelopment projects should be designed to infiltrate, evapotranspirate, and/or harvest and use runoff to the maximum extent technically feasible (METF) to maintain or restore the pre-development hydrology of the site. Scenarios 1-8 are examples of sites where it was technically feasible to design the stormwater management system to retain the 95th percentile storm onsite. Scenario 9, however, was provided as an example of an METF analysis where site constraints allowed the designers to retain only 75% of the 95th percentile storm.

Given the site-specific nature of individual projects, the case study scenarios described herein do not include site specific design features such as runoff routing, specific site infiltration rates, the structural loading capacity of buildings, etc. in terms of stormwater practice selection.

It should be noted that an example of Option 2, which requires a site-specific hydrologic analysis, has not been provided in this document because of the complexity of factors and the lack of general applicability such an analysis would have.

Background

Numerous approaches exist for determining the volume of runoff to be treated through stormwater management. Retaining stormwater runoff from all events up to and including the 95th percentile rainfall event was identified as Option 1 because small, frequently-occurring storms account for a large proportion of the annual precipitation volume. Using GI/LID practices to retain both the runoff produced by small storms and the first part of larger storms can reduce the cumulative impacts of altered flow regimes on receiving water hydrology, e.g., channel degradation and diminished baseflow. For the purposes of this guidance, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites.

Determination of the 95th Percentile Rainfall Event

The 95th percentile rainfall rainfall event was determined using the long-term daily precipitation records from the National Climate Data Center (NCDC, 2007). By analyzing the frequency and rainfall depths from daily rainfall records over 24-hour periods, the 95th percentile storm event can be determined. From a frequency analysis viewpoint, the 95th percentile event is the storm event that is greater than or equal to 95% of all storms that occur within a given period of time. Regional climate conditions and precipitation vary across the U.S. Because of local values, it is essential that the implementing agency or department establish the 95th percentile storm event for the project site since the control volume may vary depending on local weather patterns and conditions.

Onsite Stormwater Management Practice Determinations

For the purposes of the case study scenarios, the following four categories of practices were selected as the most appropriate practices for implementing Section 438 requirements: bioretention, permeable pavements and pavers, cisterns, and green roofs. These practices were selected based on known performance data and cost. For each case study, the same hierarchy of selection criteria was used, i.e., the most cost effective practices were considered before other practices were considered. Bioretention practices were considered first because these systems generally have the lowest cost per unit of stormwater treated (Hathaway and Hunt, 2007). Thus, if the bioretention system could not be designed to adequately capture the desired runoff volume, permeable pavement and pavers, cisterns, and green roofs were considered in that order based on relative cost. In most cases a combination of practices was selected as part of an integrated treatment system. It should be noted that all treatment systems were designed to accomplish the goal of capturing the 95th percentile rainfall event onsite. Examples of onsite stormwater management practices selected for each site are presented in the results section. For the Boston, MA site, it was assumed that bioretention was not feasible in order to simulate a situation where space was severely limited; as a result, interlocking modular pavers were selected as the most cost-effective stormwater management to capture the requisite design volume. To further illustrate the range of site conditions designers may encounter, and how site conditions impact the selection of appropriate control options, Scenario #3 (Cincinnati, OH) was re-analyzed as Scenario #8. In Scenario #8, it was assumed that the site had clay soils and low infiltrative capacity. Given these site conditions, the range of potential control options was more limited and a combination of modular paving blocks, a green roof, and cisterns was ultimately selected based on cost and site suitability factors.

For purposes of these modeling exercises, a number of assumptions were associated with each category of practice. These assumptions are not necessarily an endorsement of a particular design paradigm, but rather were used to keep a somewhat conservative cap on the scenarios in order to demonstrate the feasibility of the approach. For example, bioretention retrofits can and should often be located in prior impervious locations; however, in all modeled scenarios bioretention was restricted to currently landscaped areas. The assumptions were:

- **Bioretention areas**: On-lot retention of stormwater through the use of vegetation, soils, and microbes to capture, treat and infiltrate runoff.

  It is assumed bioretention practices would be installed within currently landscaped pervious areas or that pervious areas would be created for bioretention cells. While termed bioretention, these systems are designed to provide infiltration as well as temporary storage. Bioretention areas would be designed to accept up to a depth of 10 inches of water across the surface of the bioretention cell (see Appendix A). The conceptual design of this storage depth would occur within the media and/or could be included as ponded storage. Further design storage beyond the 10 inches would be acceptable (and encouraged) above the media on a site-by-site basis with ponded depth generally not to exceed 12 inches.

Uniform infiltration was assumed across the entire base of the bioretention cell. No additional media underneath the amended soils were included in the designs with infiltration rates in this layer governed by the *in situ* soils. Underdrains were not modeled directly but could be applied at the point of storage overflow such that no overflow occurs until the design depth of 10 inches is saturated. This approach was selected to maximize the storage and infiltration benefits of these systems. Designs utilizing underdrains at the base of the bioretention cell do not store the requisite volumes because the media is permeable and the underdrain conveys the runoff offsite through the underdrain before it can be infiltrated. Because standard underdrains typically discharge from smaller storms as well, underdrain designs, if employed, should ensure adequate retention capacity for the 95th percentile event volume.

The bioretention footprint for modeling purposes was calculated as one uniform area that did not include side slopes. There is an expectation that actual bioretention cell construction would be distributed throughout the site with targeted locations based on hydrology (natural flow paths) and soils with greater infiltrative capacity. Side slopes may increase the surface excavation area required to accommodate the footprint and freeboard of these systems depending on the design or the bioretention system.

- **Porous/permeable pavement**: Transportation surfaces constructed of asphalt, concrete or permeable pavers that are designed to infiltrate runoff.

  Infiltration was modeled for the entire porous pavement area with drainage pipes used only as overflow outlets. This design was chosen to maximize infiltration capabilities of the system. While many types of porous pavement systems can be used, modular block type pavers were generally applied in this design category under the assumption that they typically include sufficient volumetric storage in the media layer. [Note: Other types of porous pavement applications are available that support heavy loads and can be designed to temporarily store and infiltrate runoff beneath the surface of the pavement.]

  For these systems, an equivalent of 2 inches of design storage depth was assumed. This design depth could be achieved by specifying 10 inches of media depth that had 20% void space. Similarly, this could be achieved by designing six inches of media depth above the bottom surface, with specified media containing 33% void space. This alternative would have the overflow outlet at the 6 inch depth providing an equivalent water storage depth of 2 inches.

  The soils under the paver blocks may require or be subjected to some compaction for engineering stability. As a result, infiltration into underlying soils was modeled conservatively by applying the minimum infiltration rate for each soil type (see Appendix A).

  Generally, porous pavement is not recommended for high traffic areas or loading bays Because of this the scenarios assumed that only a percentage of total parking and road areas on a site can be converted to porous pavement. The assumed maximum percentage applied in the scenarios was set at 60% of the total paved area. Guidance on porous pavements is available at: http://cfpub.epa.gov/npdes/greeninfrastructure/technology.cfm#permpavements

- **Cistern**: Containers or vessels that are used to store runoff for future use.

  Cisterns were modeled in cases where green roofs were not feasible or where it was necessary to include additional storage volume to meet the goal of onsite rainfall runoff capture. The sizes of cisterns would be calculated based on site-specific rainfall, site-specific spatial and structural conditions, use opportunities and rates, and consideration of cost per volume of storage. For simplicity, cistern volume was reported as a total volume. This total volume could be subdivided into any number of cisterns to provide the total necessary storage but should be based on the impervious area and runoff quantities which will flow to the cistern. The most efficient cost per volume storage would need to be considered on a site-by-site basis (see Appendix A).

- **Green roof**: Roof designed with light weight soil media and planted with vegetation.

  Frequently, green rooftop area is limited by structural capacity. In addition, other rooftop equipment may need to be accommodated in this space including HVAC systems and air handlers. For this reason, and to provide a somewhat conservative rate of application, it was assumed for these modeling analyses that up to 30% of a roof's impervious area could be converted into a green roof. Green roof area was assumed to have 1 inch of total effective stormwater storage, i.e., a 2.5 inch media depth with 40% void space (see Appendix A).

General Approach

Using site aerial photos, spatial analysis should be conducted to estimate the land cover types and areas for each site. The surface conditions of each site can be digitized using geographic information systems (GIS) techniques. Alternatively, computer-aided design (CAD) drawings can be used to estimate the surface area of each land cover type. The schematic in Figure 10 illustrates the processes used for selecting and determining the overall size of stormwater management practices for each site.

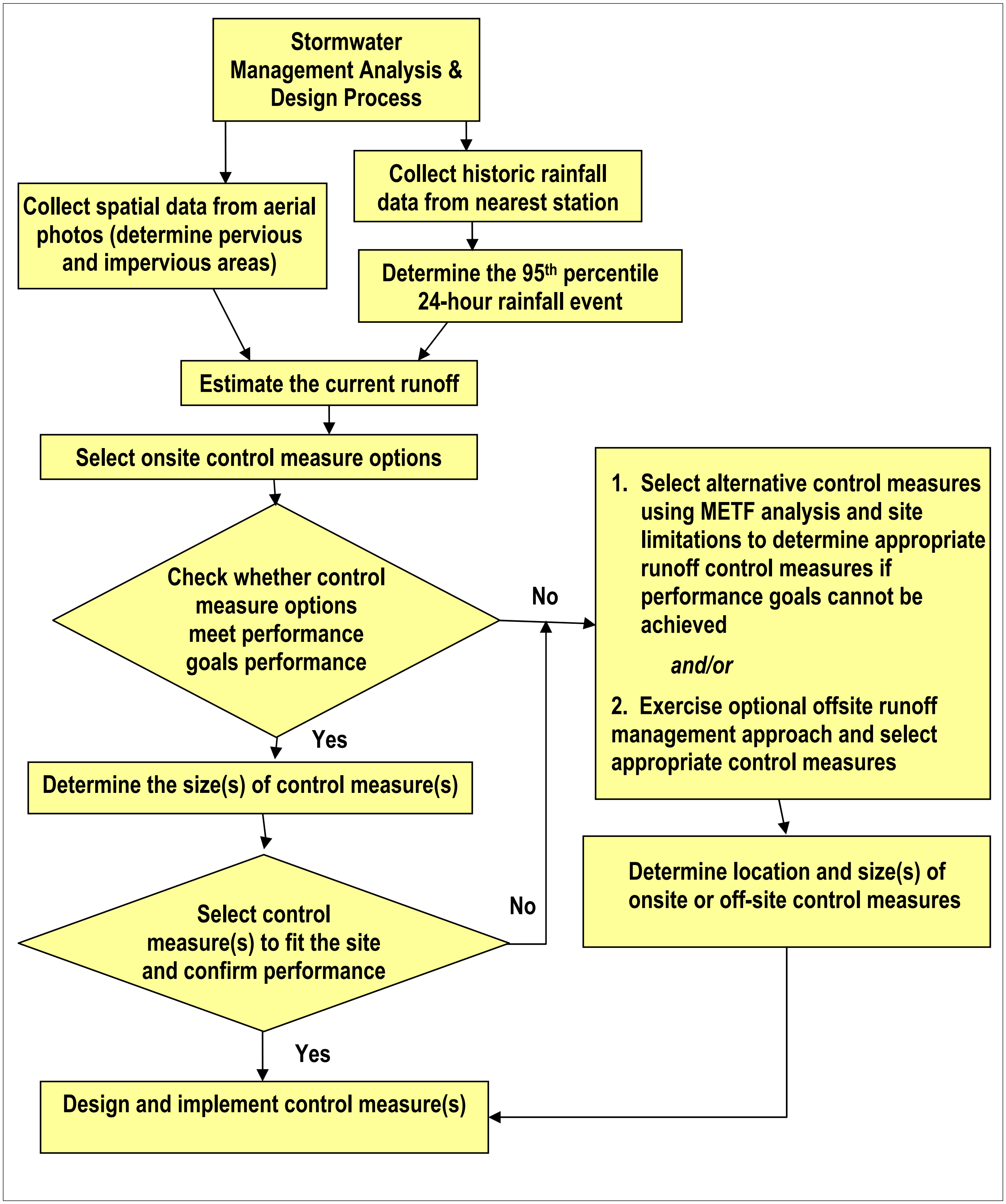


Figure 10. Flow chart depicting the process for determining control measures using the 95th percentile, 24-hour, annual rainfall event.

The following steps provide more detailed information on acquiring and calculating the necessary data to complete the processes indicated in Figure 10. This methodology was used in the scenario analyses that follow.

Collecting spatial data for a site

1. Collect an aerial orthophotograph for the desired site.
2. Digitize land use/land cover conditions using GIS techniques. If CAD drawings of the site exist, they can be used to estimate land cover area (pervious, impervious).
3. Categorize the digitized or planned land use/land cover based on surface hydrologic conditions, e.g., rooftop, pavement, and pervious/landscaped area.
4. Estimate the size of each land use/land cover category (by polygon).

Determining the 95th percentile, 24-hr rainfall event

1. Obtain a long-term 24-hr precipitation data set for the location of interest (i.e., from the NCDC Web site or other source).
2. Import the data into a spreadsheet. *In MS Excel* [Data / Import External Data / Import Data]
3. Rearrange all of the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.
4. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.
5. Remove small rainfall events (typically less than 0.1 inches) that may not contribute to rainfall runoff. These small storms often produce little if any appreciable runoff from most sites and for modeling purposes are typically considered as volume captured in surface depression storage.
6. Calculate the 95th percentile rainfall volume by applying the PERCENTILE spreadsheet function to a range of data cells. The PERCENTILE function returns the nth percentile value in the specified precipitation data range. This function can be used to determine the 95th percentile storm event that captures all but the largest 5% of storms. *In MS Excel* [PERCENTILE(precipitation data range,95%)]

Estimating Current Runoff and Placing onsite control measures to capture the 95th percentile rainfall event

1. Collect spatial data for a site, e.g., rooftop, pavement, and pervious areas as above.
2. Check soil type (USDA mapping, borings, or onsite testing) for the site to determine infiltration parameters. For this modeling, many of the assumptions that pertain to generalized soils groups and their infiltration properties come from the EPA Stormwater Management Model (SWMM 4.x) manual (see Appendix A).
3. Determine the current runoff volume that would occur during a 24 hour period by applying the 95th percentile rainfall to the existing site conditions (land use and soil properties) as above using a hydrologic model (such as TR-55 or SWMM). For this analysis, it is assumed that the rainfall amount is distributed over a 24 hour period. Actual rainfall event duration (and intensity) was not considered for determining rainfall runoff (however, timing was considered when modeling infiltration).
4. Determine flow paths so that management practice placements are in locations where flows can be intercepted and routed to practices. Because this is a site specific effort and may require detailed topographic information or further surveys this would be a task to be

completed onsite and therefore is not included as a part of the modeling scenario exercise.

5. Select onsite control practices to capture the current 95th percentile runoff event; base the selection of appropriate options on site conditions, areas available for treatment options, and other factors such as site use and other constraints.

Note: The steps above have been generalized for the purposes of this guidance. It is recommended that a qualified professional engineer determine or verify that stormwater management practices are sized, placed, and designed correctly. It should also be noted that the methodology to determine rainfall amount used a 24 hour time period based on daily records. Actual rainfall events may have occurred over shorter or longer time periods. Similarly, for modeling purposes, the 24 hour rainfall amount was distributed to pervious and impervious areas (and management practices) as a uniform event occurring during a 24-hour period. A large dataset (greater than 50 years) was used to reasonably represent rainfall depth on a daily bases. It stands to reason that more frequent, shorter duration precipitation events are better represented than less frequent, longer duration precipitation events.

Scenarios

Eight locations were selected for the 9 case studies as shown in Figure 11 and Table 2. Case study numbers 3 and 8 were both developed based on the Cincinnati, Ohio facility, although the site parameters were altered to represent differing site conditions and design constraints. Annual average rainfall depths for these locations range from 7.5 inches to 48.9 inches. Analyses of the 95th percentile rainfall events for these locations produced rainfall depths that range from 1.00 inch to 1.77 inches (Table 2).

Figure 11. Locations for Analyzing Onsite Control Measures.

The government facilities in the 8 case study locations were selected because they represent generic sites from the major climatic regions of the U.S. These facilities also were selected because the sites have a range of site characteristics that can be used to illustrate different site designs and stormwater management options, e.g., pervious, roof, and pavement areas (Table 3). Site sizes ranged from 0.7 to 27 acres with percent site imperviousness area ranging from 47% to 95% of the site. Aerial photos of the sites are included along with site specific rainfall runoff and soil results.

Table 2. Summary of Rainfall Data for the Seven Locations.

No	Location	NCDC Daily Precipitation Data		Rainfall Depth (inches)	
		Period of record	Coverage	Annual average	95th percentile rainfall event
1	Charleston, WV	1/1/1948 - 12/31/2006 (59 yrs)	99%	43.0	1.23
2	Denver, CO	1/1/1948 - 12/31/2006 (59 yrs)	96%	15.2	1.07
3	Cincinnati, OH	1/1/1948 - 12/31/2006 (59 yrs)	96%	36.5	1.45
4	Portland, OR	1/1/1941 - 12/31/2006 (66 yrs)	98%	35.8	1.00
5	Phoenix, AZ	1/1/1948 - 12/31/2006 (59 yrs)	99%	7.5	1.00
6	Boston, MA	1/1/1920 - 12/31/2006 (87 yrs)	99%	41.9	1.52
7	Atlanta, GA	1/1/1930 - 12/31/2006 (77 yrs)	100%	48.9	1.77
8	Norfolk, VA	1/1/1957 - 12/31/2006 (50 yrs)	99%	45.4	1.68

The results of the spatial analyses were summarized and divided into three land cover categories; rooftop, pavement, and pervious area, as shown in Table 3.

Table 3. Summary of Land-use Determinations of the Study Sites.

No	Location	Facility Spatial Info (acres)				Site Imperviousness
		Rooftop	Pavement	Pervious	Total	
1	Charleston, WV	0.1	0.4	0.2	0.7	73%
2	Denver, CO	0.5	1.9	2.0	4.5	55%
3	Cincinnati, OH	1.6	8.0	9.4	19	51%
4	Portland, OR	8.8	16.9	1.3	27	95%
5	Phoenix, AZ	0.2	0.7	1.1	2	47%
6	Boston, MA	0.9	1.5	1.1	3.5	69%
7	Atlanta, GA	3.9	10.8	6.2	21	70%
8	Norfolk, VA	0.9	0.55	0.15	1.6	91%

Methods for Determining Runoff Volume

Direct Determination of Runoff Volume

Runoff from each land cover was estimated using a simplified volumetric approach based on the following equation:

$$Runoff = Rainfall - Depression\ Storage - Infiltration\ Loss$$

Again, this methodology does not consider routing of runoff; therefore slope is not considered when calculating on a volumetric basis.

Infiltration loss is calculated only in pervious areas (e.g., there is no infiltration in impervious areas). In this analysis, infiltration was estimated using Horton's equation:

$$F_t = f_{\min} + (f_{\max} - f_{\min})\, e^{-kt}$$

where, F_t= infiltration rate at time t (in/hr)
$f_{\min}$ = minimum or saturated infiltration rate (in/hr)
$f_{\max}$ = maximum or initial infiltration rate (in/hr)
k = infiltration rate decay factor (/hr) and
t = time (hr) measured from time runoff first discharged into infiltration area

Infiltration loss for the 24-hr rainfall duration was estimated by the following equation with assumptions of a half hour Δt and uniform rainfall distribution in time:

$$\textit{Infiltration Loss} = \sum (f \cdot \Delta t)$$

To more accurately describe the dynamic process of infiltration associated with Horton's equation, infiltration loss was integrated over a 24-hour period using a half hour time step while applying the maximum and minimum infiltration rates (in/hr) with time using the appropriate soil decay factor. The results of this process are further illustrated in Appendix A.

Once runoff from each land cover was estimated, the total runoff from a site can be obtained using an area-weighted calculation as shown below:

$$\textit{Runoff}_{\text{site}} = \{(\textit{Runoff}_{\text{roof}} \times A_{\text{roof}}) + (\textit{Runoff}_{\text{pavement}} \times A_{\text{pavement}}) + (\textit{Runoff}_{\text{pervious}} \times A_{\text{pervious}})\} / A_{\text{site}}$$

Where $\textit{Runoff}_{\text{site}}$ = total runoff from the site (inches); A_{site} = site area (acres); $\textit{Runoff}_{\text{roof}}$ = runoff from rooftop (inches); A_{roof} = rooftop area (acres); $\textit{Runoff}_{\text{pavement}}$ = runoff from pavement area (inches); A_{pavement} = pavement area (acres); $\textit{Runoff}_{\text{pervious}}$ = runoff from pervious area (inches); and A_{pervious} = pervious area (acres).

An example demonstrating how to calculate runoff by applying the Direct Determination method is presented below using the Charleston, WV (Scenario #1) site condition presented in Tables 2 and 3.

$$\textit{Runoff}_{\text{roof}} = 95^{th}\ \textit{Rainfall} - \textit{Depression Storage}$$
$$= 1.23 - 0.1 = 1.13 \text{ inches}$$

$$\textit{Runoff}_{\text{pavement}} = 95^{th}\ \textit{Rainfall} - \textit{Depression Storage}$$
$$= 1.23 - 0.1 = 1.13 \text{ inches}$$

$$\textit{Runoff}_{\text{pervious}} = 95^{th}\ \textit{Rainfall} - \textit{Depression Storage} - \textit{Infiltration Loss}$$
$= 1.23 - 0.1 - 9.73 = 0$ inches (i.e., no runoff because the result is a negative number)

$$Runoff_{site} = \{(Runoff_{roof} \times A_{roof})+(Runoff_{pavement} \times A_{pavement})+(Runoff_{pervious} \times A_{pervious})\}/A_{site}$$
$$= \{(1.13 \times 0.10)+(1.13\times 0.41)+(0 \times 0.19)\}/0.7 = 0.82 \text{ inches}$$

Infiltration loss was estimated based on soil type B by applying the Horton equation as described above. Because the volume removed from surface runoff through infiltration was substantial, no runoff occurred from the pervious area.

In cases where sites had limited physical space available for stormwater management, a series of practices was used (e.g., treatment train) to simulate the runoff and infiltrative behavior of the system. For example, if there was inadequate area and infiltrative capacity to infiltrate 100 percent of the 95th percentile storm event within a bioretention system another onsite management practice was selected to manage the runoff that could provide the necessary capacity. In this manner, excess runoff was routed to another management practice in the series of treatment cells where possible.

Two types of soils were considered for every site: hydrologic soil group B and C (except for scenario 8 in which hydrologic soil group D was used). Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and either loamy sand or sandy loam textures with some loam, silt loam, silt, or sandy clay loam soil textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam soil textures with some clay, silty clay, or sandy clay textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments (USDA-NRCS, 2007). The application of these hydrologic soil groups was intended to give reasonable and somewhat conservative estimates of infiltration capacity.

General hydrologic parameters in this analysis were assumed as follows (see Appendix A for citations of assumptions):

- Depression storage (or initial abstraction)
    - Rooftop: 0.1 inches
    - Pavement: 0.1 inches
    - Pervious area: 0.2 inches

- Horton Infiltration parameters
    - Hydrologic Soil Group B
        - Maximum infiltration rate: 5 in/hr
        - Minimum infiltration rate: 0.3 in/hr
        - Decay factor: 2 /hr

    - Hydrologic Soil Group C
        - Maximum infiltration rate: 3 in/hr
        - Minimum infiltration rate: 0.1 in/hr
        - Decay factor: 3.5 /hr

- Design storage assumptions of control measures
  - Bioretention: up to 10 inches (but variable based on balancing necessary storage volume, media depth for plant survivorship, and surface area limitations)
  - Green roof: 1 inch (2.5 inches deep media with 40% void space)
  - Porous pavement: 4 inches (10 inches deep media with 40% void space)

Other Methods for Estimating Runoff Volume

Runoff from a site after applying the 95th percentile storm can be estimated by using a number of empirical, statistical, or mathematical methods. Several methods were considered in this analysis. The Rational Method can be used to estimate peak discharge rates and the Modified Rational Method can be used to develop a runoff hydrograph. The NRCS TR-55 model can be used to predict runoff volume and peak discharge. TR-55 can also be used to develop a runoff hydrograph. The EPA Stormwater Management Model (SWMM) can be used to simulate rainfall-runoff, pollutant build-up and wash-off, transport-storage-treatment of stormwater flow and pollutants, backwater effects, etc. for a wide range of temporal and spatial scales. The SWMM model can be fit to model a small site with a distributed system. Hydrologic Simulation Program – Fortran (HSPF, USDA) is a watershed and land use based lumped model that can be used to compute the movement of water and pollutants when evaluating the effects of land use change, reservoir operations, water quality control options, flow diversions, etc. In general, regionally calibrated modeling parameters are incorporated into HSPF. QUALHYMO is a complete hydrologic and water quality model, which can be used to factor in snowmelt or soil moisture conditions or to simulate system behavior based on infiltration and ET, ground water storage tracking, baseflow and deep volumetric losses, and other variables.

Many of the existing tools for analyzing distributed systems use some part or all of the principles or formulae of the modeling approaches highlighted above. For example, the Emoryville spreadsheet control measure model (Emoryville, CA) uses a runoff coefficient (i.e., Rational Method) for analyzing lot-level to neighborhood-scale control measure sizing. The Green Calculator (Center for Neighborhood Technologies) estimates the benefit of onsite GI/LID options on a neighborhood-scale by applying the curve numbers (i.e., TR-55) and the Modified Rational Method. The Northern Kentucky Spreadsheet Tool uses a TR-55 based approach for control measure sizing on neighborhood or site level spatial scales. The WWHM (Western Washington Hydrology Model) is a regionally calibrated HSPF model intended for use in sizing stormwater detention and water quality facilities to meet the Washington State Department of Ecology standards. WBM-QUALHYMO is a Canadian model used in conjunction with the Water Balance Model (WBM). This model can be used to continuously simulate stormwater storage routing, stream erosion, drainage area flow routing, and snowmelt runoff (and ultimately freeze-thaw). Table 4 contains a summary of these different methods based on generic modeling features.

Table 4. Potential Methods for Analyzing Control Measures.

Model Considerations		Rational Method	TR-55	SWMM	Direct Determination	HSPF	QUALHYMO
Temporal scale	Single Event	Yes	Yes	Yes	Yes	Yes	Yes
	Continuous Simulation	No	No	Yes	Possible	Yes	Yes
Spatial scale	Lot-level	Yes	Yes[b]	Yes	Yes	No	No
	Neighborhood	Yes	Yes	Yes	Yes	Possible	Possible
	Regional	Yes	Yes[c]	Yes	No	Yes	Yes
Outputs	Peak Discharge	Yes	Yes	Yes	No	Yes	Yes
	Runoff Volume	Yes	Yes	Yes	Yes	Yes	Yes
	Hydrograph	Yes[a]	Yes	Yes	No	Yes	Yes
	Water Quality	No	No	Yes	Possible	Yes	Yes

[a] Modified Rational Method

[b] No less than 1 acre.

[c] No more than 25 square miles (up to 10 subareas).

From the viewpoint of modeling both lot-level and neighborhood scale projects, the Rational Method, NRCS TR-55, SWMM, and Direct Determination approaches were selected for use in scenario analyses. Strength and weakness of these methods are presented below:

Table 5. Comparison of approaches for determining runoff volume.

Method	Strengths	Weaknesses
Direct Determination	• Methodology for runoff determination is same as SWMM • Models basic hydrologic processes directly (explicit) • Simple spreadsheet can be used	• Direct application of Horton's method may estimate higher infiltration loss, especially at the beginning of a storm • Does not consider flow routing
Rational Method	• Method is widely used • Simple to use and understand	• Cannot directly model storage-oriented onsite control measures
TR-55	• Method is widely used • Simple to use and understand	• May not be appropriate for estimating runoff from small storm events because depression storage is not well accounted for
SWMM	• Method is widely used • Can provide complete hydrologic and water quality process dynamics in stormwater analysis	• Needs a number of site-specific modeling parameters • Generally requires more extensive experience and modeling skills

Each method requires specific parameters for estimating runoff from a site. Runoff coefficients for the Rational Method are assumed to be 0.9 for rooftop and pavement areas, and 0.1 and 0.135 for Group B and C soil pervious areas, respectively (Caltrans, 2003). The slope of the pervious area was assumed to be an average of 2%. Applying these runoff coefficients for each surface, the overall area-weighted runoff coefficient can be determined.

When applying the NRCS TR-55 method, Curve Numbers (CNs) should be determined for each drainage area. For rooftop and pavement areas the CN was assumed to be 98, and pervious area CN was determined on the basis of the hydrologic soil group and the status of grass cover condition. Curve numbers for pervious areas were assumed to be 61 and 74 for Group B and C soils, respectively, with an assumption of over 75% grass cover. The overall CN can be estimated by using an area-weighted calculation (USDA-SCS, 1986).

In SWMM modeling, infiltration was modeled using Horton's equation. The same infiltration parameters and depression storage values used in the direct determination method of runoff treatment volume described earlier were applied to the SWMM analyses. The average slope of the pervious area was again assumed to be 2%. The same uniform rainfall distribution and time step was applied for the SWMM model runs.

Runoff Methodology Results

Stormwater management practice sizes (and depth) were determined using the Direct Determination approach to capture the volume of runoff generated in a 95^{th} percentile rainfall event at each location. Total acreage, impervious area, the 95^{th} percentile rainfall event, the current expected runoff for the 95^{th} percentile rainfall event, and the future runoff with stormwater management controls were reported for each site. Results were summarized for the two soil types (three soil types for scenarios #3 and #8 in Cincinnati). The spatial location of onsite control measures was also illustrated in the site aerial photo figures. Note that site practices were placed only on undeveloped or landscaped areas without regard for true flow paths or technical feasibility. It may be preferred to place practices in existing impervious areas, if possible. For the purposes of this modeling exercise, the least cost and most practical solutions were used, i.e., locating bioretention systems on undeveloped or landscaped areas. On an actual site, flow paths would be determined and berms and swales might be used to route runoff to areas that are most suitable for infiltration. In other cases, areas that are currently impervious could be modified to accept runoff, e.g., impermeable pavements removed and replaced by permeable, sidewalks could be redesigned to include sidewalk bioretention cells and streets could be designed with flow through or infiltration curb bumpouts/raingardens.

To compare other approaches of runoff estimation, alternate methodologies were also employed for three scenarios. TR-55 was used for Scenario #1 (Atlanta), the Rational Method was applied to Scenario #2 (Denver), and the SWMM was run for Scenario #7 (Charleston).

Although flood control is not the focus of this guidance, most localities have flood control requirements that will need to be considered in designing control measures to comply with Section 438. For flood control purposes, TR-55 was used to model the 10 year frequency design storm for each site under the assumption that all stormwater management practices were in place. The 10-year design storms were selected from the NRCS TR-55 Manual (USDA, 1986) for both the Eastern U.S. and the Western U.S. Precipitation Frequency Maps (www.wrcc.dri.edu/pcpnfreq.html). The 10-year frequency design storm was selected because it represents a common design standard used by state and local governments in order to manage peak rates of runoff and prevent flooding.

<u>COST ESTIMATES FOR SELECTED SCENARIOS</u>

Scenarios #2 and 7 include cost estimates comparing the capital costs for a design to comply with Section 438 (retention of the 95th percentile rainfall event) and capital costs for a traditional stormwater management design (e.g., typical curb and gutter, off-site pond for stormwater management). These costs are based on average unit costs to construct both traditional and GI/LID controls.

Scenario #1 - Charleston, WV

A 0.7-acre site with 73% impervious area was selected from Charleston, West Virginia (Figure 12). If the 95th percentile rainfall event (1.23 inches) occurred on the existing site (i.e., with no control measures), 0.82 inches of runoff using the Direct Determination method would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.03 acres if hydrologic soil group B is present, or 0.06 acres if hydrologic soil group C (Table 6) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 0.2 acres of pervious area would be available for the placement of bioretention systems. The effective design storage depth within the designated bioretention area was 8 inches.

Figure 12. Actual Site and Onsite Control Measures (Charleston, WV)

Table 6. Estimated Sizes of Onsite Control Measures for Scenario #1 (Charleston, WV)

Total Area (acres)		0.7	
Estimated Imperviousness (%)		73%	
95th Percentile Rainfall Event (inches)		1.23	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.82	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by Direct Determination method (acres)		0.03	0.06
Bioretention estimated by SWMM (acres)		0.03	0.05
Off-site storage necessary to control the 10-yr event of 3.9 inches (acre-ft)	With onsite controls	0.10	0.12
	Without onsite controls	0.16	0.17

Note: The two hydrologic methods used (direct determination and SWMM) estimated similar bioretention sizes.

Scenario #2 - Denver, CO

A 4.5-acre site with 55% impervious area was selected from Denver, Colorado (Figure 13). If the 95th percentile rainfall event (1.07 inches) occurred on the existing site (i.e., with no control measures), 0.53 inches of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.16 acres if the hydrologic soil group B is present or 0.3 acres if hydrologic soil group C (Table 7) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 2 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 6 inches.

Figure 13. Actual Site and Onsite Control Measures (Denver, CO)

Table 7. Estimated Sizes of Onsite Control Measures for Scenario #2 (Denver, CO)

Total Area (acres)		4.5	
Estimated Imperviousness (%)		55%	
95th Percentile Rainfall Event (inches)		1.07	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.53	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination method (acres)		0.16	0.3
Bioretention estimated by Rational Method (acres)		0.16	0.28
Off-site storage necessary to control the 10-yr event of 3.2 inches (acre-ft)	With onsite controls	0.35	0.52
	Without onsite controls	0.64	0.64

Cost estimates were also developed for this scenario (Table 8) to compare the costs of installing onsite control measures to retain the 95th percentile rainfall event versus the costs to install traditional stormwater management controls (e.g., curbs and gutters combined with off-site retention such as extended detention wet ponds). In a GI/LID scenario, the bioretention cell would occupy a specified area. This same area in a traditional design would be covered in turf since the pond would typically be offsite and not occupy the area planted in turf. Table 8 includes this cost under the traditional column. Note: typical land development practices involve mass clearing and grading so little or no pre-existing vegetation is typically retained. It is also assumed that the use of GI/LID practices would require less underground infrastructure because the traditional design typically routes stormwater underground to an off-site pond via pipes or culverts while GI/LID practices are designed to manage runoff onsite and as close to its source as possible. They are also dispersed across the site and routing occurs through surface drainage via bioswales and overland flow. As a result GI/LID practices do not require as much or any hard or grey infrastructure. The cost estimates were developed for Hydrologic Soil Group B.

Table 8. Estimated Costs for Scenario #2 (Denver, CO)

Sizes of Onsite Control Practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.07	
Bioretention (acres)		0.1	
Paver blocks (acres)		0	
Green roof (acres)		0	
Off-site Pond	WQV (ac-ft)	-	0.18
	10-Yr Fld Cntr (ac-ft)	0.15	0.14
Total Off-Site Requirement (ac-ft)		0.15	0.32
Land Area (assumes avg 3 ft depth)		0.05	0.11
% of the site		2.8%	
Costs of Onsite Control Practices			
Biorention/alternative		$32,495	$4,187
Off-site Pond	WQV (ac-ft)		$14,833
	10-Yr Fld Cntr (ac-ft)	$10,073	$9,527
Infrastructure	Pipe	$8.990	$16,982
	Inlet	$9.920	$14,880
Land Area (assumes $300K/acre)		$14,500	$31,500
Sum		**$75,978**	**$91,909**
% difference from Traditional		**-17.3%**	

<u>Scenario #3 - Cincinnati, OH</u>

A 19-acre site with 51% impervious area was selected in Cincinnati, Ohio (Figure 14). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., no control measures were in place), 0.68 inches of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.8 acres if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 9) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Figure 14. Actual Site and Onsite Control Measures (Cincinnati, OH)

Table 9. Estimated Sizes of Onsite Control Measures for Scenario #3 (Cincinnati, OH)

Total Area (acres)		19	
Estimated Imperviousness (%)		51%	
95th Percentile Rainfall Event (inches)		1.45	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.68	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.8	1.3
Off-site storage necessary to control the 10-yr event of 4.2 inches (acre-ft)	With onsite controls	2.42	3.24
	Without onsite controls	3.29	3.73

Scenario #4 - Portland, OR

A 27-acre site with 95% impervious area was selected in Portland, Oregon (Figure 15). If the 95th percentile rainfall event (1.0 inches) occurred on the existing site (i.e., no control measures), 0.86 inches of runoff would be generated and require management. This site has the greatest imperviousness among the 7 sites.

Given these site conditions, there is not enough pervious area to manage the entire runoff volume discharged by the 95th percentile rainfall event with bioretention. As a result, other practices were evaluated and selected. The practices integrated into the design included a green roof, cisterns, and porous pavement. Based on the technical considerations of constructing and maintaining control measures at the site, it was assumed that approximately 30% of the available pervious area could be converted into bioretention cells; 20% of total rooftop area could be converted into green roofs; 40% of paved area could be converted into paver blocks; and 50,000 gallons of total volume could be captured in cisterns for use on this urbanized site. Using this system of four different practices, all runoff for the 95th percentile rainfall event would be retained (Table 10).

Figure 15. Actual Site and Onsite Control Measures (Portland, OR)

Table 10. Estimated Sizes of Onsite Control Measures for Scenario #4 (Portland, OR)

Total Area (acres)		27	
Estimated Imperviousness (%)		95%	
95th percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.86	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Paver block area estimated by Direct Determination (acres)		1.4	3.5*
Bioretention estimated by Direct Determination (acres)		0.4	
Green Roof estimated by Direct Determination (acres)		1.7	
Cistern volume estimated by Direct Determination (gallons)		50,000	
Off-site storage necessary to control the 10-yr event of 3.7 inches (acre-ft)	With onsite controls	5.37	5.62
	Without onsite controls	7.70	7.71

*The size of porous pavement area was increased because the other control options were maximized based on

A total of 1.3 acres of the site is pervious area or landscaped of which, 0.4 acres (30% of the pervious area) could be converted to bioretention cells that have a storage depth of 10 inches. Of the 8.8 acres of current rooftop area, 1.7 acres (20% of the rooftop area) could be retrofitted into green roof areas. Of the 16.9 acres of paved area, 1.4 acres (8% of the paved area) for hydrologic soil group B, or 3.5 acres (20% of the paved area) for hydrologic soil group C, of paver block systems could be implemented. One or more cisterns (as indicated in Figure 15) could be used to capture up to 50,000 gallons of runoff from rooftop areas. Note: The high percentage of imperviousness of the site (95%) requires that all infiltration designs be based on resident soil type and design volumes, or with adequate sub-bases or amended soils.

Scenario #5 – Near Phoenix, AZ

A 2-acre site with 47% impervious area was selected near Phoenix, Arizona (Figure 16). If the 95th percentile rainfall event (1.0 inches) occurred on the existing site (i.e., with no control measures), 0.42 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.06 acres if the hydrologic soil group B is present or 0.1 acres if hydrologic soil group C (Table 11) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 1.1 acres of pervious area is available for the placement of these practices. The design storage depth of media within the designated bioretention area was 6 inches. Note: If the design storage depth were increased to 10 inches, the off-site storage necessary for the 10-year event could be reduced to 0.03 acre-ft for type B soils and 0.08 acre-ft for type C soils.

Figure 16. Actual Site and Onsite Control Measures (Phoenix, AZ)

Table 11. Estimated Sizes of Onsite Control Measures for Scenario #5 (Phoenix, AZ)

Total Area (acres)		2	
Estimated Imperviousness (%)		47%	
95th Percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.42	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.06	0.1
Off-site storage necessary to control the 10-yr event of 2.4 inches (acre-ft)	With onsite controls	0.05	0.12
	Without onsite controls	0.18	0.18

Scenario #6 - Boston, MA

A 3.5-acre site with 69% impervious area was selected in Boston, Massachusetts (Figure 17). If the 95th percentile rainfall event (1.52 inches) occurred on the existing site (i.e., with no control measures), 0.98 inches of runoff would be generated and require management. Given these site characteristics, there is adequate area to place appropriately sized bioretention cells to capture the 95th percentile storm event. However, for the purposes of this analysis, unspecified conditions preclude the use of bioretention. As a result, a paver block system was selected as the best onsite control measure and the system was designed such that the necessary design parameters could be achieved by storing some of the volume in the paver media and by infiltrating the remainder of the volume. The runoff from the 95th percentile rainfall event could be retained by installing a paver block area totaling 0.4 and 0.8 acres assuming soil types B and C, respectively (Table 12). For the purposes of this case study, a total of 1.5 acres of parking lot was made available to accommodate the paver block system. The area retrofitted with paver blocks would primarily be dedicated for use as parking stalls.

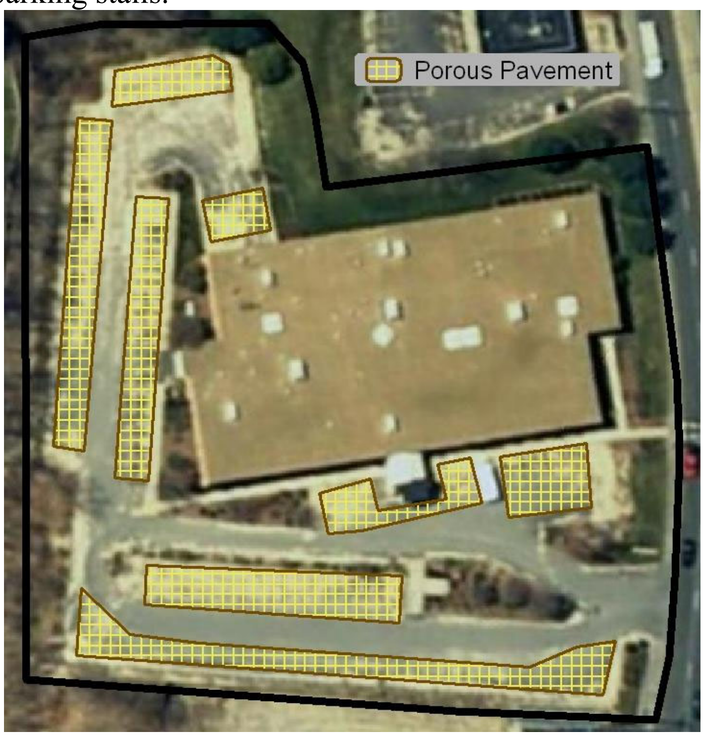


Figure 17. Actual Site and Onsite Control Measures (Boston, MA)

Table 12. Estimated Sizes of Onsite Control Measures for Scenario #6 (Boston, MA)

Total Area (acres)		3.5	
Estimated Imperviousness (%)		69%	
95th Percentile Rainfall Event (inches)		1.52	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.98	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Paver block area estimated by Direct Determination (acres)		0.4	0.8
Off-site storage necessary to control 10-yr event of 4.5 inches (acre-ft)	With onsite controls	0.59	0.71
	Without onsite controls	0.89	0.96

Scenario #7 - Atlanta, GA

A 21-acre site with 70% impervious area was selected in Atlanta, Georgia (Figure 18). If the 95th percentile rainfall event (1.77 inches) occurred on the existing site (i.e., with no control measures), 1.17 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could not be adequately retained solely with bioretention systems. Based on the technical considerations of constructing and maintaining control measures at the site, it was assumed that up to 15% of the pervious area could be converted into bioretention cells and up to 40% of paved area could be converted into a paver block system. If the stormwater management techniques used on the site includes both bioretention and paver blocks as presented in Table 13, then all runoff for the 95th percentile rainfall event would be controlled.

Figure 18. Actual Site and Onsite Control Measures (Atlanta, GA)

Table 13. Estimated Sizes of Onsite Control Measures for Scenario #7 (Atlanta, GA)

Total Area (acres)		21	
Estimated Imperviousness (%)		70%	
95th Percentile Rainfall Event (inches)		1.77	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		1.17	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.9	
Paver block area estimated by the Direct Determination (acres)		0.9	3.2*
Bioretention estimated by TR-55		0.8**	0.9
Paver block area estimated by TR-55		0**	1.84
Off-site storage necessary to control 10-yr event of 6.0 inches (acre-ft)	With onsite controls	5.85	6.62
	Without onsite controls	7.25	8.49

*The size of porous pavement was increased because the bioretention already reached its maximum size based on the site-specific design assumptions.

**Because TR-55 estimated smaller runoff in this scenario, bioretention can retain all of the 95th percentile runoff if the site has soil group B.

For the example site in Atlanta, GA, areas of 1.8 acres for hydrologic soil group B, and 4.1 acres for hydrologic soil group C, would be required to manage the runoff discharged from a 95th percentile rainfall event. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 6.2 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 10 inches. Permeable pavement systems could be used to treat the remaining volume on the 10.8 acres of existing paved area.

In applying the TR-55 model, the overall curve numbers for the site were 87 and 91 for Group B and C soils, respectively. TR-55 was used to estimate 0.73 inches of runoff for soil group B and 0.97 inches for soil group C, which are smaller numbers than the 1.17 inches of runoff estimated by the Direct Determination method. As a result, the sizes of the onsite control measures designed using the TR-55 model were smaller than those designed using the Direct Determination method. Note: It is recommended that caution be exercised when using TR-55 to model storms less than 0.5 inches per event. See application of TR-55 in Table 5.

Cost estimates were also developed for this scenario (Table 14) to compare the costs to install onsite control measures to retain the 95th percentile rainfall event, and costs to install traditional stormwater management controls (e.g., primarily curb and gutter with off-site retention). The cost estimates were developed for Hydrologic Soil Group B.

Table 14. Estimated Costs for Scenario #7 (Atlanta, GA)

Sizes of Onsite Control Practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.77	
Bioretention (acres)		0.94	
Paver blocks (acres)		0.86	
Off-site Pond	WQV (ac-ft)	-	1.75
	10-Yr Fld Cntr (ac-ft)	0.84	0.0
Total Off-Site Requirement (ac-ft)		0.84	1.75
Land Area (assumes avg 3 ft depth)		0.28	0.58
% of the site		8.5%	
Costs of Onsite Control Practices			
Biorention/alternative		$232,923	$30,617
Paver block/alternative		$236,878	$88,409
Off-site Pond	WQV (ac-ft)	$0	$72,888
	10-Yr Fld Cntr (ac-ft)	$39,648	$0
Infrastructure	Pipe	$54,827	$191,095
	Inlet	$52,080	$79,360
Land Area (assumes $300K/acre)		$84,000	$175,000
Sum		**$700,356**	**$637,368**
% difference from Traditional		**9.9%**	

Scenario #8 - Cincinnati, OH

A 19-acre site with 51% impervious area was selected in Cincinnati, Ohio (Figure 19). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., with no control measures), 0.68 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.8 acres if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 9) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Scenario #8 represents an alternative to the Cincinnati, scenario in #3 (Figure 14). In this case, hydrologic soil group D was selected to represent the soil characteristics present for the entire site. Alternatively, simulations could have been run under the assumption that the use of infiltration practices were precluded by contaminated soils or high ground water tables. Under these site conditions, bioretention options are severely limited and cannot be used to adequately capture the entire 95th percentile storm event. As a result, options such as cisterns and green roofs were considered. In the absence of management practices, the 95th percentile rainfall event discharges 1.45 inches of stormwater and 0.53 inches of this runoff is captured by onsite depression storage. The difference, 0.92 inches of runoff, would then require capture and management. Based on the technical considerations of constructing and maintaining controls at the site, it was assumed that up to 20% of pervious area can be converted into bioretention areas; up to 30% of paved area can be converted into porous pavement; and up to 30% of the rooftop area can be converted into green roofs. Cisterns can be added to the system if additional storage volume is required. It should be noted that green roofs were selected lowest in the hierarchy of practices evaluated because of cost and potential structural issues associated with design and placement on existing buildings. By using the four onsite control options as presented in Table 15, all runoff for the 95th percentile rainfall event would be retained. From a management perspective, it was assumed that the design storage depth within the designated bioretention area was 6 inches because of the low infiltration rates adopted for this scenario.

Figure 19. Actual Site and Onsite Control Measures (Cincinnati, OH)

Table 15. Estimated Sizes of Onsite Control Measures for Scenario #8 (Cincinnati, OH)

Total Area (acres)	19
Estimated Imperviousness (%)	51%
95th Percentile Rainfall Event (inches)	1.45
Expected Runoff for the 95th Percentile Rainfall Event (inches)	0.92
Stormwater Management Applied	Hydrologic Soil Group D
Bioretention estimated by Direct Determination (acres)	1.9
Paver block area estimated by Direct Determination (acres)	2.4
Green Roof estimated by Direct Determination (acres)	0.5
Cisterns estimated by Direct Determination (gallons)	13,000

This site contains a total of 9.4 acres of pervious area, 8.0 acres of paved area, and 1.6 acres of rooftop area. If 1.9 acres (20%) of the pervious area were converted to bioretention cells; 2.4 acres (30%) of parking lot converted to paver blocks; and 0.5 acres (30%) of rooftop area were retrofitted to green roof areas for this site, then 97% of stormwater runoff from the 95th percentile storm would be captured on site. By also adding one or more cisterns (as indicated in Figure 19), an additional 13,000 gallons could be captured, thus illustrating that 100% of the rainfall from the 95th percentile event can be managed onsite with GI/LID practices.

Scenario #9 – Norfolk, VA

A 1.6 acre site with 91% impervious area was selected from Norfolk, Virginia. Table 16 contains the land use categories for the site. Figure 20 depicts the site and associated facilities. Site specific factors based on an METF analysis allow management of 75 % of the 95th percentile storm onsite (1.27 inches). The remaining portion of the 95th percentile rainfall event (0.41 inches would be discharged off of the site.

Table 16. Land Use Determination After Redevelopment

Land Use	Acres	Site Coverage Percent
Building	0.90	56.3
Parking	0.35	21.9
Streets/Sidewalks	0.20	12.5
Undeveloped	0.15	9.3
Total	**1.60**	**100%**

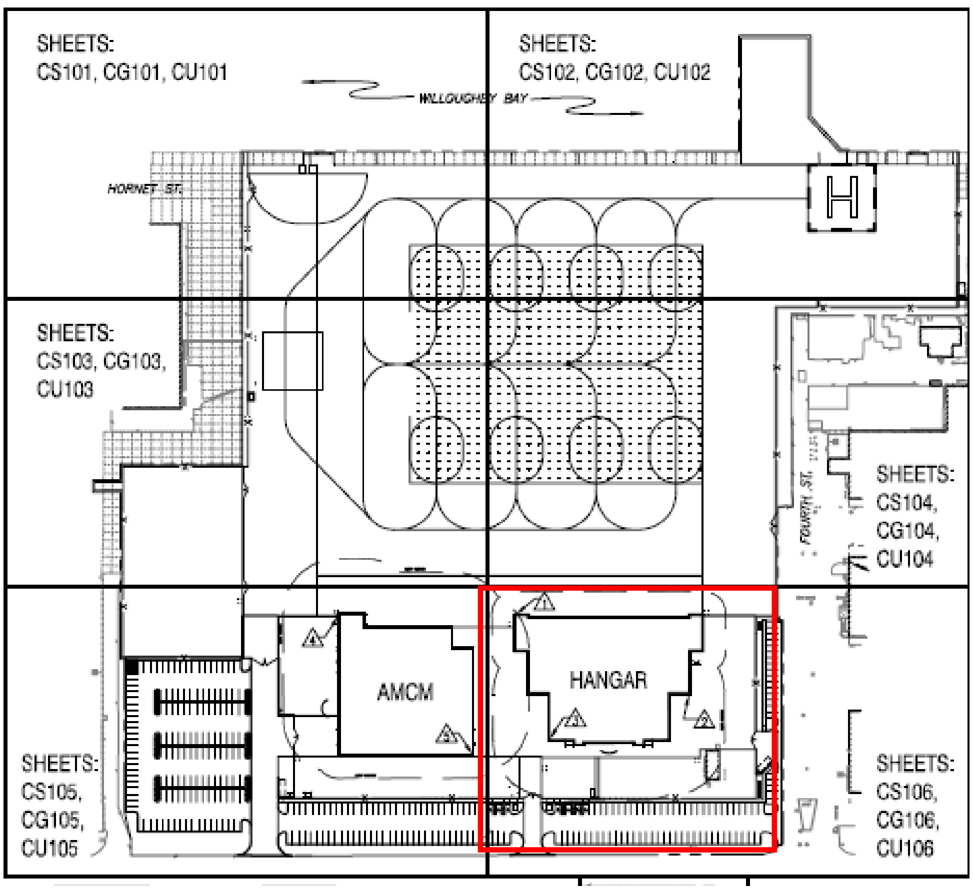


Figure 20. Proposed Redevelopment Scenario

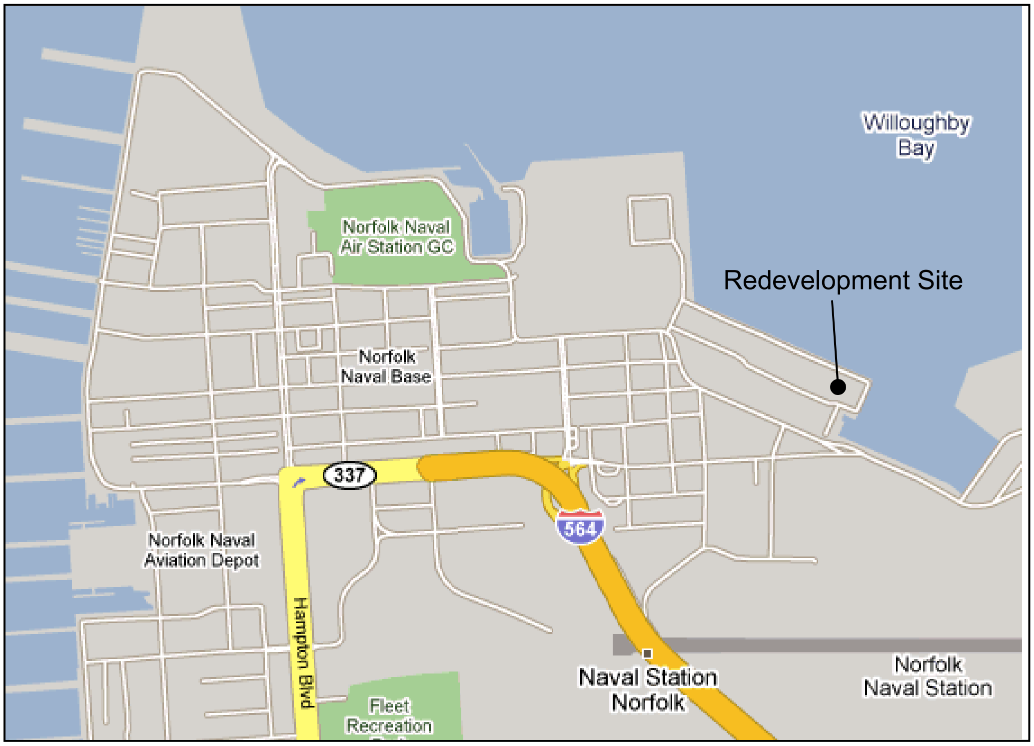


Figure 21. Location of Facility (Norfolk, VA)

Site conditions and intended uses limited the number of practices that were technically feasible to use onsite to manage runoff. For example, the use of a green roof was not feasible because the project includes the construction of an airplane hanger which lacks the structural strength to support a green roof. Cisterns were also not included in the set of suitable practices based on the analysis, which considered the number of people and amount of daily water use at the site, i.e., 40 people x 3.5 toilet flushes per day would use only 280 gallons of runoff per day or 2,000 gallons per week. Stormwater use for HVAC make-up would also be negligible based on the typical cooling system design. To put things in perspective, if the hanger rooftop covers the entire building footprint, 41,000 gallons of runoff would be generated from a 1.68 inch rainfall. Assuming a drawdown of 2,000 gallons per week based on toilet flushing, the users would only use 5% of the 95th percentile event. Because of the relatively large volume of water that would need to be collected and used, cisterns were not considered a feasible option to manage a significant volume of runoff at the site.

However, site conditions did allow for the use of both permeable pavement and bioretention practices. Approximately 0.15 acres (6,500 sf) of the proposed site is undeveloped and available for bioretention. Based on Department of Defense facility requirements, ten percent of the parking area is designed with landscaping, usually around the perimeter and in landscaped islands. If this ten percent were designed as bioretention cells, then 0.035 acres of bioretention would be achieved. If bioretention cells were also placed in about 30% of the undeveloped area of the project, then an additional 0.045 acres of bioretention could be implemented. Note: not all undeveloped land was assumed to be available for bioretention because of conflicts with site utilities, security and anti-terrorism requirements and slopes that limited the use of infiltration practices directly adjacent to the hanger.

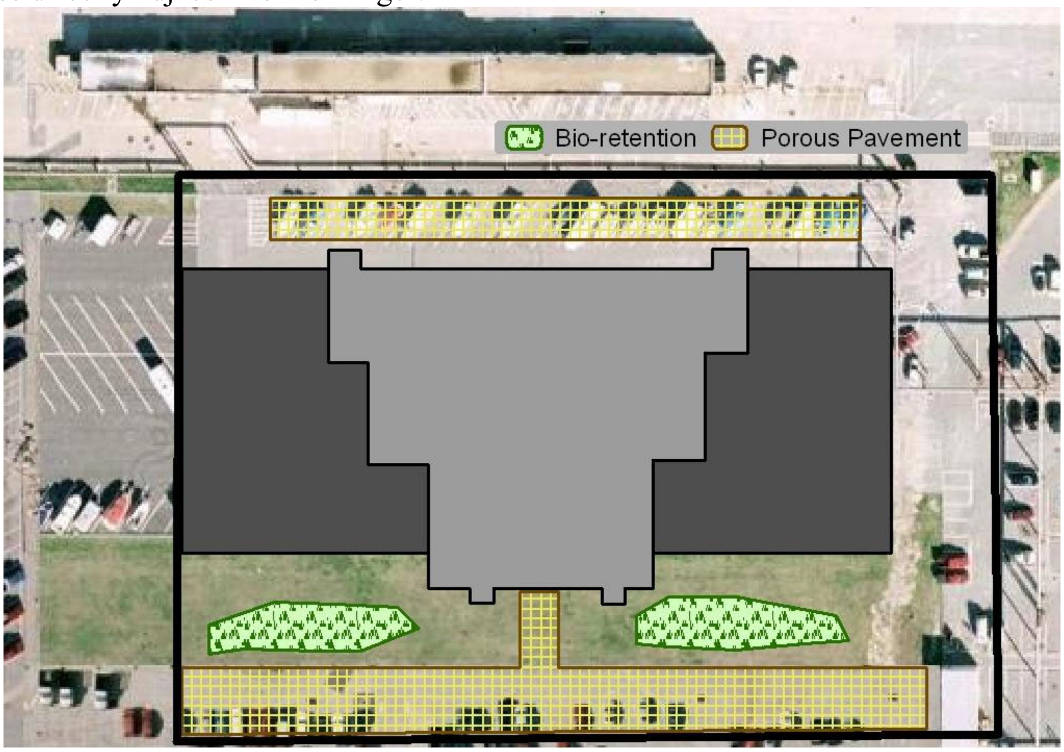


Figure 22. Actual Site and Onsite Control Measures (Norfolk, VA)

Table 17. Estimated Sizes of Onsite Control Measures for Scenario #9 (Norfolk, VA)

Total Area (acres)	1.6
Estimated Imperviousness (%)	91%
95th Percentile Rainfall Event (inches)	1.68
Expected Runoff for the 95th Percentile Rainfall Event (inches)	1.50
Stormwater Management Area Required	Hydrologic Soil Group D
Porous Pavement estimated by Direct Determination method (acres)	0.21
Bioretention estimated by Direct Determination method (acres)	0.08

The bioretention cells were designed with an effective storage depth of 10 inches, which included a depth from media surface to outlet of 10 inches. In this case study, state regulations precluded the project from taking credit for the storage potential provided by the void space within the bioretention cell media. Similarly, approximately 0.55 acres of the proposed site is impervious due to parking lots, streets, and sidewalks. Due to manufacturer's recommendations that permeable pavement materials not be used in applications subject to heavy loads and potential pollutant exposure the access roads and parking lot access isles were assumed to be constructed from conventional impervious concrete or asphalt. Thus 60% of the parking area (primarily parking stalls and sidewalks), which is about 38% of the entire paved area, is assumed to be suitable for paver blocks. A high water table at the site limited the modeled net storage depth under paver blocks placed in the parking areas and sidewalks to four inches. This storage was calculated using the assumption that the pavement sub-base of 12 inches would have a minimum void space of approximately 30%.

COMPARISON OF THE RUNOFF ESTIMATION METHODS

As illustrated in each of the case studies above, runoff of the 95th percentile storm was estimated in order to size onsite control measures. These estimates were produced by applying four different methods: the Direct Determination method, the Rational Method, the NRCS TR-55, and the EPA SWMM. The results comparing each of these methods for scenarios 1-7 are presented in Table 18.

Table 18. Comparison of the estimated runoff (unit: inches)

	Method	Direct Determination		Rational Method		TR-55		SWMM	
	Soil Groups	B	C	B	C	B	C	B	C
1	Charleston, WV	0.82	0.82	0.83	0.84	0.36	0.53	0.82	0.83
2	Denver, CO	0.53	0.53	0.57	0.59	0.12	0.26	0.53	0.53
3	Cincinnati, OH	0.68	0.68	0.73	0.76	0.26	0.46		
4	Portland, OR	0.86	0.86	0.86	0.86	0.63	0.71		
5	Phoenix, AZ	0.42	0.42	0.46	0.48	0.06	0.17		
6	Boston, MA	0.98	0.98	0.99	1.00	0.51	0.70		
7	Atlanta, GA	1.17	1.17	1.17	1.19	0.73	0.97	1.19	1.23

As shown in the above table, the estimated runoff results from direct determination, the Rational Method, and SWMM are relatively similar. Runoff volumes using TR-55 are lower than the other estimates. SWMM modeling results using NRCS 24-hour rainfall distributions were nearly identical to the results based on uniform distribution.

Table 19. Applicability of the methods for analyzing onsite control measures

Purpose	Direct Determination	Rational Method	TR-55*	SWMM
Planning Tool	Applicable	Applicable	Applicable	Applicable
Preliminary Design	Applicable	Applicable	Applicable	Applicable
Detailed Design	Not applicable	Not applicable	Not applicable	Applicable
Actual Assessment (Long-term)	Not applicable	Not applicable	Not applicable	Applicable
Water Quality	Not applicable	Not applicable	Not applicable	Applicable

*Use with caution when applying this method for small storms

CONCLUSIONS

Although sites varied in terms of climate and soil conditions, in most of the scenarios selected, the 95th percentile storm event could be managed onsite with GI/LID systems. There are other infiltration, evapotranspiration and capture and use stormwater management options available than those used in these analyses. These options provide site managers additional flexibility to choose appropriate systems and practices to manage site runoff.

REFERENCES

Booth, Derek Direct Testimony. 2008. *Pollution Control Hearings Board for the State of Washington*, Puget Soundkeeper Alliance and People for Puget Sound; Pierce County Public Works and Utilities Department; City of Tacoma; The Port of Seattle; Snohomish County; Clark County; and Pacificorp and Puget Sound Energy, Appellants, vs. Department of Ecology, Respondent, and King County; City of Seattle; Port of Tacoma, and Washington State Department of Transportation, Intervenors, August 2008.

California Department of Transportation (Caltrans). 2003. *Caltrans Storm Water Quality Handbooks*. California Department of Transportation.

Casey Trees. 2007. *The Case for Trees – Relief from Summer Heat*, www.caseytrees.org/resources/casefortrees.html.

Galli, John. 1991. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices in Maryland*, Anacostia Restoration Team for the Maryland Department of the Environment, Washington, DC.

Grant, Gary, Luke Engleback and Barry Nicholson. 2003. *Green Roofs: Their Existing Status and Potential for Conserving Biodiversity in Urban Areas, Report Number 498*, English Nature Research Reports.

Hathaway, J., and W.F. Hunt. 2007. *Stormwater BMP Costs*. North Carolina Department of Environment and Natural Resources. www.bae.ncsu.edu/stormwater/PublicationFiles/DSWC.BMPcosts.2007.pdf.

Hirschman, David and John Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*, Center for Watershed Protection, www.cwp.org/postconstruction.

Holz, Thomas Written Direct Testimony. 2008. *Pollution Control Hearings Board for the State of Washington*, Puget Soundkeeper Alliance and People for Puget Sound; Pierce County Public Works and Utilities Department; City of Tacoma; The Port of Seattle; Snohomish County; Clark County; and Pacificorp and Puget Sound Energy, Appellants, vs. Department of Ecology, Respondent, and King County; City of Seattle; Port of Tacoma, and Washington State Department of Transportation, Intervenors, August 2008.

Horner, Richard Direct Testimony. 2008. *Pollution Control Hearings Board for the State of Washington*, Puget Soundkeeper Alliance and People for Puget Sound; Pierce County Public Works and Utilities Department; City of Tacoma; The Port of Seattle; Snohomish County; Clark County; and Pacificorp and Puget Sound Energy, Appellants, vs. Department of Ecology, Respondent, and King County; City of Seattle; Port of Tacoma, and Washington State Department of Transportation, Intervenors, August 2008.

National Climatic Data Center (NCDC). 2007. NCDC precipitation data, CD-ROM, National Climatic Data Center.

National Research Council. 2008. *Urban Stormwater Management in the United States*, The National Academies Press, Washington, DC.

Shaver, E., R. Horner, J. Skupien, C. May, and G. Ridley. 2007. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues – 2nd Edition*, North American Lake Management Society, Madison, WI.

Schueler, T. and M. Helfrich. 1988. "Design of Wet Extended Detention Pond Systems," *Design of Urban Runoff Controls*, L. Roesner and B. Urbonas eds., American Society of Civil Engineers, New York, NY.

Schueler, T and H. Holland. 2000. *The Practice of Watershed Protection: Techniques for Protecting our Nation's Streams, Lakes, Rivers, and Estuaries*. Center for Watershed Protection, Ellicott City, MD.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2007. *National Engineering Handbook*, title 210–VI. Part 630, chapter 7. Washington, DC. http://directives.sc.egov.usda.gov/.

U.S. Department of Agriculture, Soil Conservation Service. 1986. *Urban Hydrology for Small Watersheds*. Technical Release No. 55. Second Edition. Washington, D.C.

U.S. Environmental Protection Agency, *Managing Wet Weather with Green Infrastructure*, www.epa.gov/greeninfrastructure.

Vingarzan and Taylor. 2003. *Trend Analysis of Ground Level Ozone in the Greater Vancouver/ Fraser Valley Area of British Columbia*, Environment Canada – Aquatic and Atmospheric Sciences Division.

Wisconsin DNR. 2008. *Impact of Redevelopment on TSS Loads, Runoff Management*, available at http://www.dnr.state.wi.us/runoff/pdf/rules/nr151/Impact_of_RedevTSSLoads_021308.pdf.

APPENDIX A: Runoff Methodology Parameter Assumptions

Runoff from each land cover was estimated by the following equation:

$$Runoff = Rainfall - Depression\ Storage - Infiltration\ Loss \quad (1)$$

Depression Storage

Reference depression storage (inches)

Reference	Impervious	Pervious
1	0.05 - 0.1	0.1 - 0.3
2	0.01 - 0.11	0.02 - 0.6
3	0.1	0.2

1. ASCE, (1992). *Design & Construction of Urban Stormwater Management Systems*. New York, NY.
2. Marsaleck, J., Jimenez-Cisreros, B., Karamouz, M., Malmquist, P-R., Goldenfum, J., and Chocat, B. (2007). *Urban Water Cycle Processes and Interactions. Urban Water Series*, UNESCO-IHP, Tyler & Francis.
3. Walesh, S. G. (1989).*Urban Surface Water Management*. John Wiley & Sons, Inc.

Based on the above reference data, depression storage (or initial abstraction, the rainfall required for the initiation of runoff) to the direct determination method was assumed as follows:

- Rooftop: 0.1 inches
- Pavement: 0.1 inches
- Pervious area: 0.2 inches

Infiltration

Infiltration loss occurs only in pervious areas. In this analysis, infiltration was estimated by Horton's equation:

$$F_t = f_{\min} + (f_{\max} - f_{\min})\, e^{-k\,t} \quad (2)$$

where, F_t = infiltration rate at time t (in/hr),
$f_{\min}$ = minimum or saturated infiltration rate (in/hr),
$f_{\max}$ = maximum or initial infiltration rate (in/hr),
k = infiltration rate decay factor (/hr), and
t = time (hr) measured from time runoff first discharged into infiltration area

Reference infiltration parameters

Maximum infiltration rate (in.hr), f_{max}

Infiltration (in/hr)	Partially dried out with		Dry soils with	
	No vegetation	Dense vegetation	No vegetation	Dense vegetation
Sandy	2.5	5	5	10
Loam	1.5	3	3	6
Clay	0.5	1	1	2

Reference: Huber, W. C. and Dickinson, R. (1988). *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Minimum infiltration rate (in/hr), f_{min}

Hydrologic Soil Group	Infiltration (in/hr)
A	0.45 - 0.30
B	0.30 - 0.15
C	0.15 - 0.05
D	0.05 - 0

A: well drained sandy; D: poorly drained clay
Reference: Huber, W. C. and Dickinson, R. (1988). *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Decay coefficient, k

Soils	k (sec^{-1})	k (hr^{-1})
Sandy	0.00056	2
⇕	0.00083	3
	0.00115	4
Clay	0.00139	5

Reference: Huber, W. C. and Dickinson, R. (1988). *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Based on the above reference data, infiltration parameters to the direct determination method were assumed as follows:

- Hydrologic Soil Group B
  - Maximum infiltration rate: 5 in/hr
  - Minimum infiltration rate: 0.3 in/hr
  - Decay factor: 2 /hr
- Hydrologic Soil Group C
  - Maximum infiltration rate: 3 in/hr
  - Minimum infiltration rate: 0.1 in/hr
  - Decay factor: 3.5 /hr
- Hydrologic Soil Group D
  - Maximum infiltration rate: 1 in/hr
  - Minimum infiltration rate: 0.02 in/hr
  - Decay factor: 5 /hr

Infiltration loss for the 24-hr rainfall duration was estimated by the following equations with assumptions of a half hour Δt:

$$\textit{Infiltration Loss at the } n^{th} \textit{ time-step} = (f \cdot \Delta t) = \{(f_{n-1} + f_n)/2) \cdot \Delta t\} \quad (3)$$

$$\textit{Integrated Infiltration Loss for 24 hours} = \sum (f \cdot \Delta t) \quad (4)$$

Integrating infiltration loss during 24 hours with a half hour Δt

time-step	t (hr)	Infiltration rate (in/hr) [a]			Infiltration volume (inches) [b]		
		Soil B	Soil C	Soil D	Soil B	Soil C	Soil D
0	0	5	3	1	0	0	0
1	0.5	2.03	0.60	0.100	1.757	0.901	0.275
2	1	0.94	0.19	0.027	0.741	0.198	0.032
3	1.5	0.53	0.12	0.021	0.368	0.076	0.012
4	2	0.39	0.10	0.02	0.230	0.054	0.01
5	2.5	0.33	0.1	0.02	0.179	0.05	0.01
6	3	0.31	0.1	0.02	0.161	0.05	0.01
7	3.5	0.30	0.1	0.02	0.154	0.05	0.01
8	4	0.3	0.1	0.02	0.15	0.05	0.01
9	4.5	0.3	0.1	0.02	0.15	0.05	0.01
10	5	0.3	0.1	0.02	0.15	0.05	0.01
11	5.5	0.3	0.1	0.02	0.15	0.05	0.01
12	6	0.3	0.1	0.02	0.15	0.05	0.01
13	6.5	0.3	0.1	0.02	0.15	0.05	0.01
14	7	0.3	0.1	0.02	0.15	0.05	0.01
15	7.5	0.3	0.1	0.02	0.15	0.05	0.01
16	8	0.3	0.1	0.02	0.15	0.05	0.01
17	8.5	0.3	0.1	0.02	0.15	0.05	0.01
18	9	0.3	0.1	0.02	0.15	0.05	0.01
19	9.5	0.3	0.1	0.02	0.15	0.05	0.01
20	10	0.3	0.1	0.02	0.15	0.05	0.01
21	10.5	0.3	0.1	0.02	0.15	0.05	0.01
22	11	0.3	0.1	0.02	0.15	0.05	0.01
23	11.5	0.3	0.1	0.02	0.15	0.05	0.01
24	12	0.3	0.1	0.02	0.15	0.05	0.01
25	12.5	0.3	0.1	0.02	0.15	0.05	0.01
26	13	0.3	0.1	0.02	0.15	0.05	0.01
27	13.5	0.3	0.1	0.02	0.15	0.05	0.01
28	14	0.3	0.1	0.02	0.15	0.05	0.01
29	14.5	0.3	0.1	0.02	0.15	0.05	0.01
30	15	0.3	0.1	0.02	0.15	0.05	0.01
31	15.5	0.3	0.1	0.02	0.15	0.05	0.01
32	16	0.3	0.1	0.02	0.15	0.05	0.01
33	16.5	0.3	0.1	0.02	0.15	0.05	0.01
34	17	0.3	0.1	0.02	0.15	0.05	0.01
35	17.5	0.3	0.1	0.02	0.15	0.05	0.01
36	18	0.3	0.1	0.02	0.15	0.05	0.01
37	18.5	0.3	0.1	0.02	0.15	0.05	0.01
38	19	0.3	0.1	0.02	0.15	0.05	0.01
39	19.5	0.3	0.1	0.02	0.15	0.05	0.01
40	20	0.3	0.1	0.02	0.15	0.05	0.01
41	20.5	0.3	0.1	0.02	0.15	0.05	0.01
42	21	0.3	0.1	0.02	0.15	0.05	0.01
43	21.5	0.3	0.1	0.02	0.15	0.05	0.01
44	22	0.3	0.1	0.02	0.15	0.05	0.01

45	22.5	0.3	0.1	0.02	0.15	0.05	0.01
46	23	0.3	0.1	0.02	0.15	0.05	0.01
47	23.5	0.3	0.1	0.02	0.15	0.05	0.01
48	24	0.3	0.1	0.02	0.15	0.05	0.01
Sum: Infiltration loss during 24 hours [c]					9.743	3.430	0.769

[a] Calculated infiltration rate at each time by Equation (2)
[b] Calculated infiltration volume from the previous time to the current time by Equation (3)
[c] Integrated infiltration volume for 24 hours with a half hour Δt by Equation (4)

Based on the above calculation, 24-hr infiltration losses for pervious areas and bioretention areas were modeled as follows:

- Soil Group B: 9.743 inches
- Soil Group C: 4.430 inches
- Soil Group D: 0.769 inches

Infiltrations of underlying soils at paver blocks were modeled conservatively by applying the minimum infiltration rate for each soil type (Infiltration loss = $f_{min} \cdot 24$) because the soils under the paver blocks may require or be subjected to some compaction for engineering stability. The estimated infiltration losses for each soil are presented below:

- Soil Group B: (0.3 in/hr) · (24 hrs) = 7.2 inches
- Soil Group C: (0.1 in/hr) · (24 hrs) = 2.4 inches
- Soil Group D: (0.02 in/hr) · (24 hrs) = 0.48 inches

Design Storage of Management Practices

Bioretention

Reference	Ponding (inches)[1]	Mulch (inches)	Soil media (ft)	Soil Media Porosity	Underdrain
1	up to 12	2 - 4 (optional)	1 - 1.5	about 40%	bioretention systems utilize infiltration rather than an underdrain
2	6 - 12	2 - 3	2.5 - 4	about 40%	recommended, especially if initial testing infiltration rate < 0.52 in/hr
3	6 - 12		2 - 4		
4		2 - 3	1.5 - 4		if necessary
5	up to 6		1.5 - 2	30 - 40%	Optional
6	6 - 18	as needed	2 - 4		if necessary

1. State of New Jersey. (2004). *New Jersey Stormwater Best Management Practices Manual* www.nj.gov/dep/stormwater/tier_A/pdf/NJ_SWBMP_9.1 print.pdf.
2. Maryland Department of the Environment (MDE), (2000). *2000 Maryland Stormwater Design Manual, Volumes I & II*, prepared by the Center for Watershed Protection and the Maryland Department of the Environment, Water Management Administration, Baltimore, MD. www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp.

[1] Ponding is a measure of retention capacity

3. Clar, M. L. and R. Green, (1993). *Design Manual for Use of Bioretention in Storm Water Management*, prepared for the Department of Environmental Resources, Watershed Protection Branch, Prince George's County, MD, prepared by Engineering Technologies Associates, Inc. Ellicott City, MD, and Biohabitats, Inc., Towson, MD.
4. U.S. Environmental Protection Agency. (1999). *Storm Water Technology Fact Sheet: Bioretention*. EPA 832-F-99-012. Office of Water. US Environmental Protection Agency. Washington, D.C. www.epa.gov/owm/mtb/biortn.pdf.
5. Prince George's County. *Bioretention Design Specifications and Criteria*. Prince George's County, Maryland. www.co.pg.md.us/Government/AgencyIndex/DER/ESG/Bioretention/pdf/bioretention_design_manual.pdf.
6. City of Indianapolis. (2008). *Indianapolis Stormwater Design Manual*. www.sustainindy.org/assets/uploads/4_05_Bioretention.pdf.

Paver Blocks

Reference	Media (inches)	Void Space
1	12 or more	40%
2	9 or more	40%
3	12 - 36	40%

1. Univ. of California at Davis. (2008). Low Impact Development Techniques: Pervious Pavement. http://extension.ucdavis.edu/unit/center_for_water_and_land_use/pervious_pavement.asp.
2. AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and Atlanta Regional Commission. (2001). Georgia Stormwater Management Manual Volume 2: Technical Handbook www.georgiastormwater.com/.
3. Subsurface Infiltration Bed. www.tredyffrin.org/pdf/publicworks/CH2 - BMP4 Infiltration Bed.pdf.

Green Roofs

Reference	Media (inches)
1	3 - 4
2	1 - 6
3	2 - 6

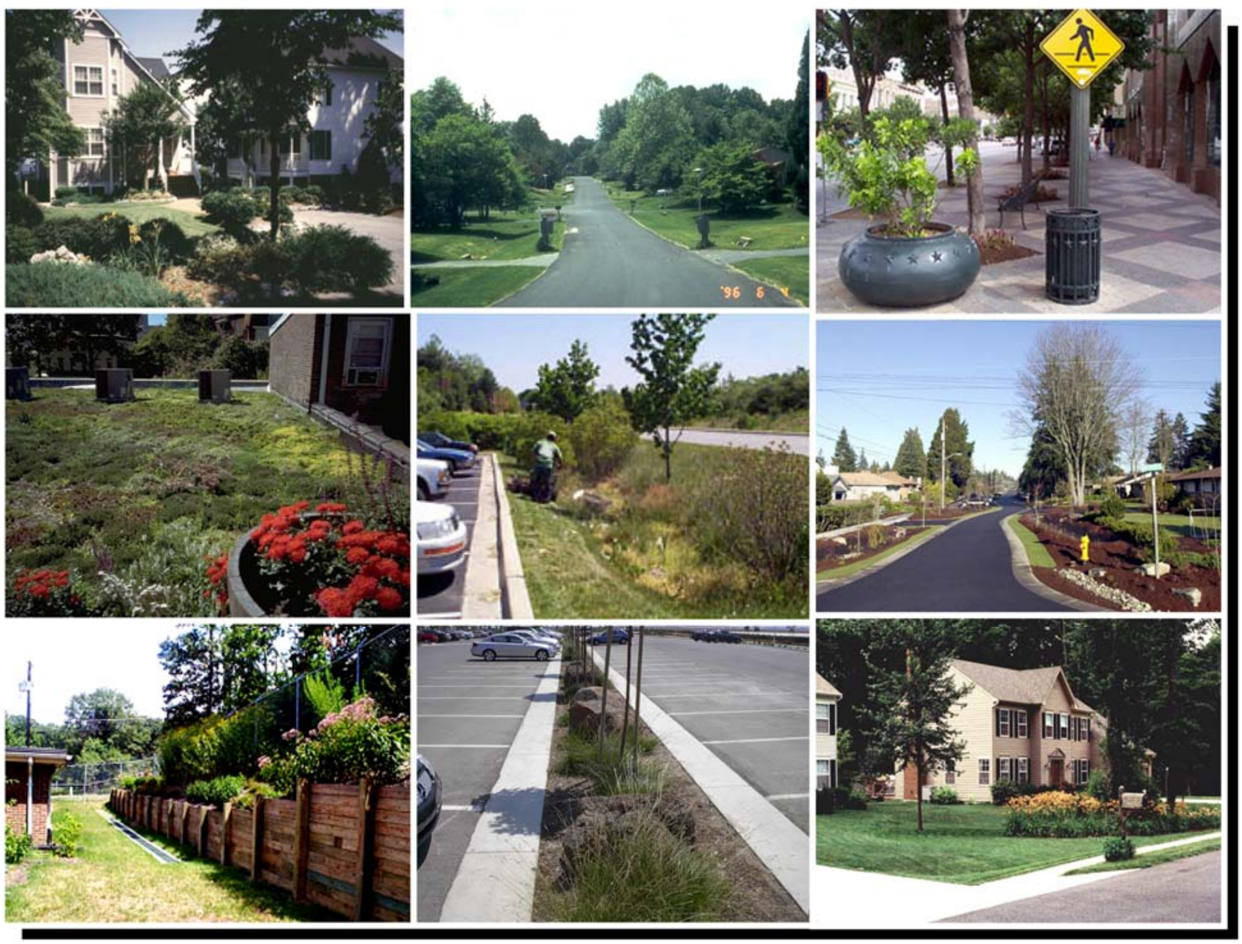
1. Charlie Miller. (2008). Extensive Green Roofs. Whole Building Design Guide (WBDG). www.wbdg.org/resources/greenroofs.php.
2. Great Lakes WATER Institute. Green Roof Project: Green Roof Installation. www.glwi.uwm.edu/research/genomics/ecoli/greenroof/roofinstall.php.
3. Paladino & Company. (2004). Green Roof Feasibility Review. King County Office Project. http://your.kingcounty.gov/solidwaste/greenbuilding/documents/KCGreenRoofStudy_Final.pdf.

Based on the above reference data, design storages to the direct determination method were assumed as follows:

- Bioretention: up to 10 inches (depending on practice used, site conditions, etc.)
- Green roof: 1 inch (2.5 inches deep media with 40% void space)
- Porous pavement: 4 inches (10 inches deep media with 40% void space)

Factors that influence total storage available include, ponding depth, available media void space, and supplemental storage if the system is designed with gravel or open pipes underneath the media.

Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices



Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices

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United States Environmental Protection Agency

Nonpoint Source Control Branch (4503T)

1200 Pennsylvania Ave., NW

Washington, DC 20460

Available for download at www.epa.gov/nps/lid

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FOREWORD

One of the most exciting new trends in water quality management today is the movement by many cities, counties, states, and private-sector developers toward the increased use of Low Impact Development (LID) to help protect and restore water quality. LID comprises a set of approaches and practices that are designed to reduce runoff of water and pollutants from the site at which they are generated. By means of infiltration, evapotranspiration, and reuse of rainwater, LID techniques manage water and water pollutants at the source and thereby prevent or reduce the impact of development on rivers, streams, lakes, coastal waters, and ground water.

Although the increase in application of these practices is growing rapidly, data regarding both the effectiveness of these practices and their costs remain limited. This document is focused on the latter issue, and the news is good. In the vast majority of cases, the U.S. Environmental Protection Agency (EPA) has found that implementing well-chosen LID practices saves money for developers, property owners, and communities while protecting and restoring water quality.

While this study focuses on the cost reductions and cost savings that are achievable through the use of LID practices, it is also the case that communities can experience many amenities and associated economic benefits that go beyond cost savings. These include enhanced property values, improved habitat, aesthetic amenities, and improved quality of life. This study does not monetize and consider these values in performing the cost calculations, but these economic benefits are real and significant. For that reason, EPA has included a discussion of these economic benefits in this document and provided references for interested readers to learn more about them.

Readers interested in increasing their knowledge about LID and Green Infrastructure, which encompasses LID along with other aspects of green development, should see www.epa.gov/npdes/greeninfrastructure and www.epa.gov/nps/lid. It is EPA's hope that as professionals and citizens continue to become more knowledgeable about the effectiveness and costs of LID, the use of LID practices will continue to increase at a rapid pace.

EXECUTIVE SUMMARY

This report summarizes 17 case studies of developments that include Low Impact Development (LID) practices and concludes that applying LID techniques can reduce project costs and improve environmental performance. In most cases, LID practices were shown to be both fiscally and environmentally beneficial to communities. In a few cases, LID project costs were higher than those for conventional stormwater management practices. However, in the vast majority of cases, significant savings were realized due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with a few exceptions in which LID project costs were higher than conventional stormwater management costs.

EPA has identified several additional areas that will require further study. First, in all cases, there were benefits that this study did not monetize and did not factor into the project's bottom line. These benefits include improved aesthetics, expanded recreational opportunities, increased property values due to the desirability of the lots and their proximity to open space, increased total number of units developed, increased marketing potential, and faster sales. Second, more research is also needed to quantify the environmental benefits that can be achieved through the use of LID techniques and the costs that can be avoided. Examples of environmental benefits include reduced runoff volumes and pollutant loadings to downstream waters, and reduced incidences of combined sewer overflows. Finally, more research is needed to monetize the cost reductions that can be achieved through improved environmental performance, reductions in long-term operation and maintenance costs, and/or reductions in the life cycle costs of replacing or rehabilitating infrastructure.

INTRODUCTION

BACKGROUND

Most stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development. The addition of impervious surfaces, soil compaction, and tree and vegetation removal result in alterations to the movement of water through the environment. As interception, evapotranspiration, and infiltration are reduced and precipitation is converted to overland flow, these modifications affect not only the characteristics of the developed site but also the watershed in which the development is located. Stormwater has been identified as one of the leading sources of pollution for all waterbody types in the United States. Furthermore, the impacts of stormwater pollution are not static; they usually increase with more development and urbanization.

Extensive development in the United States is a relatively recent phenomenon. For the past two decades, the rate of land development across the country has been twice the rate of population growth. Approximately 25 million acres were developed between 1982 and 1997, resulting in a 34 percent increase in the amount of developed land with only a 15 percent increase in population.[1,2] The 25 million acres developed during this 15-year period represent nearly 25 percent of the total amount of developed land in the contiguous states. The U.S. population is expected to increase by 22 percent from 2000 to 2025. If recent development trends continue, an additional 68 million acres of land will be developed during this 25-year period.[3]

Water quality protection strategies are often implemented at three scales: the region or large watershed area, the community or neighborhood, and the site or block. Different stormwater approaches are used at different scales to afford the greatest degree of protection to waterbodies because the influences of pollution are often found at all three scales. For example, decisions about where and how to grow are the first and perhaps most important decisions related to water quality. Growth and development can give a community the resources needed to revitalize a downtown, refurbish a main street, build new schools, and develop vibrant places to live, work, shop, and play. The environmental impacts of development, however, can pose challenges for communities striving to protect their natural resources. Development that uses land efficiently and protects undisturbed natural lands allows a community to grow and still protect its water resources.

Strategies related to these broad growth and development issues are often implemented at the regional or watershed scale. Once municipalities have determined where to grow and where to preserve, various stormwater management techniques are applied at the neighborhood or community level. These measures, such as road width requirements, often transcend specific development sites and can be applied throughout a neighborhood. Finally, site-specific stormwater strategies, such as rain gardens and infiltration areas, are incorporated within a particular development. Of course, some stormwater management strategies can be applied at several scales. For example, opportunities to maximize infiltration can occur at the neighborhood and site levels.

Many smart growth approaches can decrease the overall amount of impervious cover associated with a development's footprint. These approaches include directing development to already degraded land; using narrower roads; designing smaller parking lots; integrating retail, commercial, and residential uses; and designing more compact residential lots. These development approaches, combined with other techniques aimed at reducing the impact of development, can offer communities superior stormwater management.

Stormwater management programs have struggled to provide adequate abatement and treatment of stormwater at the current levels of development. Future development will create even greater challenges for maintaining and improving water quality in the nation's waterbodies. The past few decades of stormwater management have resulted in the current convention of control-and-treatment strategies. They are largely engineered, end-of-pipe practices that have been focused on controlling peak flow rate and suspended solids concentrations. Conventional practices, however, fail to address the widespread and cumulative hydrologic modifications within the watershed that increase stormwater volumes and runoff rates and cause excessive erosion and stream channel degradation. Existing practices also fail to adequately treat for other pollutants of concern, such as nutrients, pathogens, and metals.

LOW IMPACT DEVELOPMENT

Low Impact Development (LID)[4] is a stormwater management strategy that has been adopted in many localities across the country in the past several years. It is a stormwater management approach and set of practices that can be used to reduce runoff and pollutant loadings by managing the runoff as close to its source(s) as possible. A set or system of small-scale practices, linked together on the site, is often used. LID approaches can be used to reduce the impacts of development and redevelopment activities on water resources. In the case of new development, LID is typically used to achieve or pursue the goal of maintaining or closely replicating the predevelopment hydrology of the site. In areas where development has already occurred, LID can be used as a retrofit practice to reduce runoff volumes, pollutant loadings, and the overall impacts of existing development on the affected receiving waters.

In general, implementing integrated LID practices can result in enhanced environmental performance while at the same time reducing development costs when compared to traditional stormwater management approaches. LID techniques promote the use of natural systems, which can effectively remove nutrients, pathogens, and metals from stormwater. Cost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimized through infiltration and evapotranspiration. By working to mimic the natural water cycle, LID practices protect downstream resources from adverse pollutant and hydrologic impacts that can degrade stream channels and harm aquatic life.

It is important to note that typical, real-world LID designs usually incorporate more than one type of practice or technique to provide integrated treatment of runoff from a site. For example, in lieu of a treatment pond serving a new subdivision, planners might incorporate a bioretention area in each yard, disconnect downspouts from driveway surfaces, remove curbs, and install grassed swales in common areas. Integrating small practices throughout a site instead of using extended detention wet ponds to control runoff from a subdivision is the basis of the LID approach.

When conducting cost analyses of these practices, examples of projects where actual practice-by-practice costs were considered separately were found to be rare because material and labor costs are typically calculated for an entire site rather than for each element within a larger system. Similarly, it is difficult to calculate the economic benefits of individual LID practices on the basis of their effectiveness in reducing runoff volume and rates or in treating pollutants targeted for best management practice (BMP) performance monitoring.

The following is a summary of the different categories of LID practices, including a brief description and examples of each type of practice.

Conservation designs can be used to minimize the generation of runoff by preserving open space. Such designs can reduce the amount of impervious surface, which can cause increased runoff volumes. Open space can also be used to treat the increased runoff from the built environment through infiltration or evapotranspiration. For example, developers can use conservation designs to preserve important features on the site such as wetland and riparian areas, forested tracts, and areas of porous soils. Development plans that outline the smallest site disturbance area can minimize the stripping of topsoil and compaction of subsoil that result from grading and equipment use. By preserving natural areas and not clearing and grading the entire site for housing lots, less total runoff is generated on the development parcel. Such simplistic, nonstructural methods can reduce the need to build large structural runoff controls like retention ponds and stormwater conveyance systems and thereby decrease the overall infrastructure costs of the project. Reducing the total area of impervious surface by limiting road widths, parking area, and sidewalks can also reduce the volume of runoff that must be treated. Residential developments that incorporate conservation design principles also can benefit residents and their quality of life due to increased access and proximity to communal open space, a greater sense of community, and expanded recreational opportunities.

Examples of Conservation Design

- Cluster development
- Open space preservation
- Reduced pavement widths (streets, sidewalks)
- Shared driveways
- Reduced setbacks (shorter driveways)
- Site fingerprinting during construction

Infiltration practices are engineered structures or landscape features designed to capture and infiltrate runoff. They can be used to reduce both the volume of runoff discharged from the site and the infrastructure needed to convey, treat, or control runoff. Infiltration practices can also be used to recharge ground water. This benefit is especially important in areas where maintaining drinking water supplies and stream baseflow is of special concern because of limited precipitation or a high ratio of withdrawal to recharge rates. Infiltration of runoff can also help to maintain stream temperatures because the infiltrated water that moves laterally to replenish stream baseflow typically has a lower temperature than overland flows, which might be subject

Examples of Infiltration Practices

- Infiltration basins and trenches
- Porous pavement
- Disconnected downspouts
- Rain gardens and other vegetated treatment systems

to solar radiation. Another advantage of infiltration practices is that they can be integrated into landscape features in a site-dispersed manner. This feature can result in aesthetic benefits and, in some cases, recreational opportunities; for example, some infiltration areas can be used as playing fields during dry periods.

Runoff storage practices. Impervious surfaces are a central part of the built environment, but runoff from such surfaces can be captured and stored for reuse or gradually infiltrated, evaporated, or used to irrigate plants. Using runoff storage practices has several benefits. They can reduce the volume of runoff discharged to surface waters, lower the peak flow hydrograph to protect streams from the erosive forces of high flows, irrigate landscaping, and provide aesthetic benefits such as landscape islands, tree boxes, and rain gardens. Designers can take advantage of the void space beneath paved areas like parking lots and sidewalks to provide additional storage. For example, underground vaults can be used to store runoff in both urban and rural areas.

Examples of Runoff Storage Practices

- Parking lot, street, and sidewalk storage
- Rain barrels and cisterns
- Depressional storage in landscape islands and in tree, shrub, or turf depressions
- Green roofs

Runoff conveyance practices. Large storm events can make it difficult to retain all the runoff generated on-site by using infiltration and storage practices. In these situations, conveyance systems are typically used to route excess runoff through and off the site. In LID designs, conveyance systems can be used to slow flow velocities, lengthen the runoff time of concentration, and delay peak flows that are discharged off-site. LID conveyance practices can be used as an alternative to curb-and-gutter systems, and from a water quality perspective they have advantages over conventional approaches designed to rapidly convey runoff off-site and alleviate on-site flooding. LID conveyance practices often have rough surfaces, which slow runoff and increase evaporation and settling of solids. They are typically permeable and vegetated, which promotes infiltration, filtration, and some biological uptake of pollutants. LID conveyance practices also can perform functions similar to those of conventional curbs, channels, and gutters. For example, they can be used to reduce flooding around structures by routing runoff to landscaped areas for treatment, infiltration, and evapotranspiration.

Examples of Runoff Conveyance Practices

- Eliminating curbs and gutters
- Creating grassed swales and grass-lined channels
- Roughening surfaces
- Creating long flow paths over landscaped areas
- Installing smaller culverts, pipes, and inlets
- Creating terraces and check dams

Filtration practices are used to treat runoff by filtering it through media that are designed to capture pollutants through the processes of physical filtration of solids and/or cation exchange of dissolved pollutants. Filtration practices offer many of the same benefits as infiltration, such as reductions in the volume of runoff transported off-site, ground water recharge, increased stream baseflow, and reductions in thermal impacts to receiving waters. Filtration practices also have the added advantage of providing increased pollutant removal benefits. Although pollutant build-up and removal may be of concern, pollutants are typically captured in the upper soil horizon and can be removed by replacing the topsoil.

Examples of Filtration Practices

- Bioretention/rain gardens
- Vegetated swales
- Vegetated filter strips/buffers

Low impact landscaping. Selection and distribution of plants must be carefully planned when designing a functional landscape. Aesthetics are a primary concern, but it is also important to consider long-term maintenance goals to reduce inputs of labor, water, and chemicals. Properly preparing soils and selecting species adapted to the microclimates of a site greatly increases the success of plant establishment and growth, thereby stabilizing soils and allowing for biological uptake of pollutants. Dense, healthy plant growth offers such benefits as pest resistance (reducing the need for pesticides) and improved soil infiltration from root growth. Low impact landscaping can thus reduce impervious surfaces, improve infiltration potential, and improve the aesthetic quality of the site.

Examples of Low Impact Landscaping

- Planting native, drought-tolerant plants
- Converting turf areas to shrubs and trees
- Reforestation
- Encouraging longer grass length
- Planting wildflower meadows rather than turf along medians and in open space
- Amending soil to improve infiltration

EVALUATIONS OF BENEFITS AND COSTS

To date, the focus of traditional stormwater management programs has been concentrated largely on structural engineering solutions to manage the hydraulic consequences of the increased runoff that results from development. Because of this emphasis, stormwater management has been considered primarily an engineering endeavor. Economic analyses regarding the selection of solutions that are not entirely based on pipes and ponds have not been a significant factor in management decisions. Where costs have been considered, the focus has been primarily on determining capital costs for conventional infrastructure, as well as operation and maintenance costs in dollars per square foot or dollars per pound of pollutant removed.

Little attention has been given to the benefits that can be achieved through implementing LID practices. For example, communities rarely attempt to quantify and monetize the pollution prevention benefits and avoided treatment costs that might accrue from the use of conservation designs or LID techniques. To be more specific, the benefits of using LID practices to decrease the need for combined sewer overflow (CSO) storage and conveyance systems should be factored into the economic analyses. One of the major factors preventing LID practices from receiving equal consideration in the design or selection process is the difficulty of monetizing the environmental benefits of these practices. Without good data and relative certainty that these alternatives will work and not increase risk or cost, current standards of practice are difficult to change.

This report is an effort to compare the projected or known costs of LID practices with those of conventional development approaches. At this point, monetizing the economic and environmental benefits of LID strategies is much more difficult than monetizing traditional infrastructure costs or changes in property values due to improvements in existing utilities or transportation systems. Systems of practices must be analyzed to determine net performance and monetary benefits based on the capacity of the systems to both treat for pollutants and reduce impacts through pollution prevention. For example, benefits might come in the form of reduced stream channel degradation, avoided stream restoration costs, or reduced drinking water treatment costs.

One of the chief impediments to getting useful economic data to promote more widespread use of LID techniques is the lack of a uniform baseline with which to compare the costs and benefits of LID practices against the costs of conventional stormwater treatment and control. Analyzing benefits is further complicated in cases where the environmental performance of the conservation design or LID system exceeds that of the conventional runoff management system, because such benefits are not easily monetized. The discussion below is intended to provide a general discussion of the range of economic benefits that may be provided by LID practices in a range of appropriate circumstances.

OVERVIEW OF BENEFITS

The following is a brief discussion of some of the actual and assumed benefits of LID practices. Note that environmental and ancillary benefits typically are not measured as part of development projects, nor are they measured as part of pilot or demonstration projects, because they can be difficult to isolate and quantify. Many of the benefits described below are assumed on the basis of limited studies and anecdotal evidence.

The following discussion is organized into three categories: (1) environmental benefits, which include reductions in pollutants, protection of downstream water resources, ground water recharge, reductions in pollutant treatment costs, reductions in the frequency and severity of CSOs, and habitat improvements; (2) land value benefits, which include reductions in downstream flooding and property damage, increases in real estate value, increased parcel lot yield, increased aesthetic value, and improvement of quality of life by providing open space for recreation; and (3) compliance incentives.

Environmental Benefits

Pollution abatement. LID practices can reduce both the volume of runoff and the pollutant loadings discharged into receiving waters. LID practices result in pollutant removal through settling, filtration, adsorption, and biological uptake. Reductions in pollutant loadings to receiving waters, in turn, can improve habitat for aquatic and terrestrial wildlife and enhance recreational uses. Reducing pollutant loadings can also decrease stormwater and drinking water treatment costs by decreasing the need for regional stormwater management systems and expansions in drinking water treatment systems.

Protection of downstream water resources. The use of LID practices can help to prevent or reduce hydrologic impacts on receiving waters, reduce stream channel degradation from erosion and sedimentation, improve water quality, increase water supply, and enhance the recreational and aesthetic value of our natural resources. LID practices can be used to protect water resources that are downstream in the watershed. Other potential benefits include reduced incidence of illness from contact recreation activities such as swimming and wading, more robust and safer seafood supplies, and reduced medical treatment costs.

Ground water recharge. LID practices also can be used to infiltrate runoff to recharge ground water. Growing water shortages nationwide increasingly indicate the need for water resource management strategies designed to integrate stormwater, drinking water, and wastewater programs to maximize benefits and minimize costs. Development pressures typically result in increases in the amount of impervious surface and volume of runoff. Infiltration practices can be used to replenish ground water and increase stream baseflow. Adequate baseflow to streams during dry weather is important because low ground water levels can lead to greater fluctuations in stream depth, flows, and temperatures, all of which can be detrimental to aquatic life.

Water quality improvements/reduced treatment costs. It is almost always less expensive to keep water clean than it is to clean it up. The Trust for Public Land[5] noted Atlanta's tree cover has saved more than $883 million by preventing the need for stormwater retention facilities. A study of 27 water suppliers conducted by the Trust for Public Land and the American Water Works Association[6] found a direct relationship between forest cover in a watershed and water supply treatment costs. In other words, communities with higher percentages of forest cover had lower treatment costs. According to the study, approximately 50 to 55 percent of the variation in treatment costs can be explained by the percentage of forest cover in the source area. The researchers also found that for every 10 percent increase in forest cover in the source area, treatment and chemical costs decreased approximately 20 percent, up to about 60 percent forest cover.

Reduced incidence of CSOs. Many municipalities have problems with CSOs, especially in areas with aging infrastructure. Combined sewer systems discharge sanitary wastewater during storm events. LID techniques, by retaining and infiltrating runoff, reduce the frequency and amount of CSO discharges to receiving waters. Past management efforts typically have been concentrated on hard engineering approaches focused on treating the total volume of sanitary waste together with the runoff that is discharged to the combined system. Recently, communities like Portland (Oregon), Chicago, and Detroit have been experimenting with watershed approaches aimed at reducing the total volume of runoff generated that must be handled by the combined system. LID techniques have been the primary method with which they have experimented to reduce runoff. A Hudson Riverkeeper report concluded, based on a detailed technical analysis, that New York City could reduce its CSO's more cost-effectively with LID practices than with conventional, hard infrastructure CSO storage practices. [7]

Habitat improvements. Innovative stormwater management techniques like LID or conservation design can be used to improve natural resources and wildlife habitat, maintain or increase land value, or avoid expensive mitigation costs.

Land Value and Quality of Life Benefits

Reduced downstream flooding and property damage. LID practices can be used to reduce downstream flooding through the reduction of peak flows and the total amount or volume of runoff. Flood prevention reduces property damage and can reduce the initial capital costs and the operation and maintenance costs of stormwater infrastructure. Strategies designed to manage runoff on-site or as close as possible to its point of generation can reduce erosion and sediment transport as well as reduce flooding and downstream erosion. As a result, the costs for cleanups and streambank restoration can be reduced or avoided altogether. The use of LID techniques also can help protect or restore floodplains, which can be used as park space or wildlife habitat.[8]

Real estate value/property tax revenue. Homeowners and property owners are willing to pay a premium to be located next to or near aesthetically pleasing amenities like water features, open space, and trails. Some stormwater treatment systems can be beneficial to developers because they can serve as a "water" feature or other visual or recreational amenity that can be used to market the property. These designs should be visually attractive and safe for the residents and should be considered an integral part of planning the development. Various LID projects and smart growth studies have shown that people are willing to pay more for clustered homes than conventionally designed subdivisions. Clustered housing with open space appreciated at a higher rate than conventionally designed subdivisions. EPA's *Economic Benefits of Runoff Controls*[9] describes numerous examples where developers and subsequent homeowners have received premiums for proximity to attractive stormwater management practices.

Lot yield. LID practices typically do not require the large, contiguous areas of land that are usually necessary when traditional stormwater controls like ponds are used. In cases where LID practices are incorporated on individual house lots and along roadsides as part of the landscaping, land that would normally be dedicated for a stormwater pond or other large structural control can be developed with additional housing lots.

Aesthetic value. LID techniques are usually attractive features because landscaping is an integral part of the designs. Designs that enhance a property's aesthetics using trees, shrubs, and flowering plants that complement other landscaping features can be selected. The use of these designs may increase property values or result in faster sale of the property due to the perceived value of the "extra" landscaping.

Public spaces/quality of life/public participation. Placing water quality practices on individual lots provides opportunities to involve homeowners in stormwater management and enhances public awareness of water quality issues. An American Lives, Inc., real estate study found that 77.7 percent of potential homeowners rated natural open space as "essential" or "very important" in planned communities.[10]

Compliance Incentives

Regulatory compliance credits. Many states recognize the positive benefits LID techniques offer, such as reduced wetland impacts. As a result, they might offer regulatory compliance credits, streamlined or simpler permit processes, and other incentives similar to those offered for other green practices. For example, in Maryland the volume required for the permanent pool of a wet pond can be reduced if rooftop runoff is infiltrated on-site using LID practices. This procedure allows rooftop area to be subtracted from the total impervious area, thereby reducing the required size of the permanent pool. In addition, a LID project can have less of an environmental impact than a conventional project, thus requiring smaller impact fees.

Cost Considerations

Traditional approaches to stormwater management involve conveying runoff off-site to receiving waters, to a combined sewer system, or to a regional facility that treats runoff from multiple sites. These designs typically include hard infrastructure, such as curbs, gutters, and piping. LID-based designs, in contrast, are designed to use natural drainage features or engineered swales and vegetated contours for runoff conveyance and treatment. In terms of costs, LID techniques like conservation design can reduce the amount of materials needed for paving roads and driveways and for installing curbs and gutters. Conservation designs can be used to reduce the total amount of impervious surface, which results in reduced road and driveway lengths and reduced costs. Other LID techniques, such as grassed swales, can be used to infiltrate roadway runoff and eliminate or reduce the need for curbs and gutters, thereby reducing infrastructure costs. Also, by infiltrating or evaporating runoff, LID techniques can reduce the size and cost of flood-control structures. Note that more research is needed to determine the optimal combination of LID techniques and detention practices for flood control.

It must be stated that the use of LID techniques might not always result in lower project costs. The costs might be higher because of the costs of plant material, site preparation, soil amendments, underdrains and connections to municipal stormwater systems, and increased project management.

Another factor to consider when comparing costs between traditional and LID designs is the amount of land required to implement a management practice. Land must be set aside for both traditional stormwater management practices and LID practices, but the former require the use of land *in addition to* individual lots and other community areas, whereas bioretention areas and swales can be incorporated into the landscaping of yards, in rights-of-way along roadsides, and in or adjacent to parking lots. The land that would have been set aside for ponds or wetlands can in many cases be used for additional housing units, yielding greater profits.

Differences in maintenance requirements should also be considered when comparing costs. According to a 1999 EPA report, maintenance costs for retention basins and constructed wetlands were estimated at 3 to 6 percent of construction costs, whereas maintenance costs for swales and bioretention practices were estimated to be 5 to 7 percent of construction costs.[11] However, much of the maintenance for bioretention areas and swales can be accomplished as part of routine landscape maintenance and does not require specialized equipment. Wetland and pond maintenance, on the other hand, involves heavy equipment to remove accumulated sediment, oils, trash, and vegetation in forebays and open ponds.

Finally, in some circumstances LID practices can offset the costs associated with regulatory requirements for stormwater control. In urban redevelopment projects where land is not likely to be available for large stormwater management practices, developers can employ site-dispersed BMPs in sidewalk areas, in courtyards, on rooftops, in parking lots, and in other small outdoor spaces, thereby avoiding the fees that some municipalities charge when stormwater mitigation requirements cannot otherwise be met. In addition, stormwater utilities often provide credits for installing runoff management practices such as LID practices.[12]

CASE STUDIES

The case studies presented below are not an exhaustive list of LID projects nationwide. These examples were selected on the basis of the quantity and quality of economic data, quantifiable impacts, and types of LID practices used. Economic data are available for many other LID installations, but those installations often cannot be compared with conventional designs because of the unique nature of the design or the pilot status of the project. Table 1 presents a summary of the LID practices employed in each case study.

Table 1. Summary of LID Practices Employed in the Case Studies

Name	LID Techniques							
	Biore-tention	Cluster Building	Reduced Impervious Area	Swales	Permeable Pavement	Vegetated Landscaping	Wetlands	Green Roofs
2nd Avenue SEA Street	✓		✓	✓				
Auburn Hills	✓		✓	✓		✓	✓	
Bellingham Parking Lot Retrofits	✓							
Central Park Commercial Redesigns	✓			✓				
Crown Street	✓		✓	✓				
Gap Creek			✓			✓		
Garden Valley	✓	✓		✓	✓		✓	
Kensington Estates		✓	✓		✓	✓	✓	
Laurel Springs	✓	✓	✓	✓				
Mill Creek		✓	✓	✓				
Poplar Street Apartments	✓			✓			✓	
Portland Downspout Disconnection*			✓					
Prairie Crossing	✓		✓	✓		✓		
Prairie Glen	✓	✓	✓	✓		✓	✓	
Somerset	✓			✓				
Tellabs Corporate Campus	✓			✓		✓	✓	
Toronto Green Roofs								✓

*Although impervious area stays the same, the disconnection program reduces directly connected impervious area.

The case studies contain an analysis of development costs, which are summarized in Table 2. Note that some case study results do not lend themselves well to a traditional vs.

LID cost comparison and therefore are not included in Table 2 (as noted). *Conventional development cost* refers to costs incurred or estimated for a traditional stormwater management approach, whereas *LID cost* refers to costs incurred or estimated for using LID practices. *Cost difference* is the difference between the conventional development cost and the LID cost. *Percent difference* is the cost savings relative to the conventional development cost.

Table 2. Summary of Cost Comparisons Between Conventional and LID Approaches[a]

Project	Conventional Development Cost	LID Cost	Cost Difference[b]	Percent Difference[b]
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Kensington Estates	$765,700	$1,502,900	–$737,200	-96%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[c]	$12,510	$9,099	$3,411	27%
Prairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

[a] The Central Park Commercial Redesigns, Crown Street, Poplar Street Apartments, Prairie Crossing, Portland Downspout Disconnection, and Toronto Green Roofs study results do not lend themselves to display in the format of this table.
[b] Negative values denote increased cost for the LID design over conventional development costs.
[c] Mill Creek costs are reported on a per-lot basis.

2ND AVENUE SEA STREET, SEATTLE, WASHINGTON

The 2nd Avenue Street Edge Alternative (SEA) Street project was a pilot project undertaken by Seattle Public Utilities to redesign an entire 660-foot block with a number of LID techniques. The goals were to reduce stormwater runoff and to provide a more "livable" community. Throughout the design and construction process, Seattle Public Utilities worked collaboratively with street residents to develop the final street design.[13]

The design reduced imperviousness, included retrofits of bioswales to treat and manage stormwater, and added 100 evergreen trees and 1,100 shrubs.[14] Conventional curbs and gutters were replaced with bioswales in the rights-of-way on both sides of the street, and the street width was reduced from 25 feet to 14 feet. The final constructed design reduced imperviousness by more than 18 percent. An estimate for the final total project cost was $651,548. A significant amount of community outreach was involved, which raised the level of community acceptance. Community input is important for any project, but because this was a pilot study, much more was spent on communication and redesign than what would be spent for a typical project.

The costs for the LID retrofit were compared with the estimated costs of a conventional street retrofit (Table 3). Managing stormwater with LID techniques resulted in a cost savings of 29 percent. Also, the reduction in street width and sidewalks reduced paving costs by 49 percent.

Table 3. Cost Comparison for 2nd Avenue SEA Street [15]

Item	Conventional Development Cost	SEA Street Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$65,084	$88,173	–$23,089	–35%	–11%
Stormwater management	$372,988	$264,212	$108,776	29%	50%
Site paving and sidewalks	$287,646	$147,368	$140,278	49%	65%
Landscaping	$78,729	$113,034	–$34,305	–44%	–16%
Misc. (mobilization, etc.)	$64,356	$38,761	$25,595	40%	12%
Total	$868,803	$651,548	$217,255	—	—

* Negative values denote increased cost for the LID design over conventional development costs.

The avoided cost for stormwater infrastructure and reduced cost for site paving accounted for much of the overall cost savings. The nature of the design, which included extensive use of bioswales and vegetation, contributed to the increased cost for site preparation and landscaping. Several other SEA Street projects have been completed or are under way, and cost evaluations are expected to be favorable.

For this site, the environmental performance has been even more significant than the cost savings. Hydrologic monitoring of the project indicates a 99 percent reduction in total potential surface runoff, and runoff has not been recorded at the site since December 2002, a period that included the highest-ever 24-hour recorded rainfall at Seattle-Tacoma Airport.[16] The site is retaining more than the original design estimate of 0.75 inch of rain. A modeling analysis indicates that if a conventional curb-and-gutter system had been installed along 2nd Avenue instead of the SEA Street design, 98 times more stormwater would have been discharged from the site.[17]

Auburn Hills Subdivision, Southwestern Wisconsin

Auburn Hills in southwestern Wisconsin is a residential subdivision developed with conservation design principles. Forty percent of the site is preserved as open space; this open space includes wetlands, green space and natural plantings, and walking trails. The subdivision was designed to include open swales and bioretention for stormwater management. To determine potential savings from using conservation design, the site construction costs were compared with the estimated cost of building the site as a conventional subdivision.[18] Reduced stormwater management costs accounted for approximately 56 percent of the total cost savings. A cost comparison is provided in Table 4. Other savings not shown in Table 4 were realized as a result of reduced sanitary sewer, water distribution, and utility construction costs.

Table 4. Cost Comparison for Auburn Hills Subdivision [19]

Item	Conventional Development Cost	Auburn Hills LID Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$699,250	$533,250	$166,000	24%	22%
Stormwater management	$664,276	$241,497	$422,779	64%	56%
Site paving and sidewalks	$771,859	$584,242	$187,617	24%	25%
Landscaping	$225,000	$240,000	–$15,000	-7%	-2%
Total	$2,360,385	$1,598,989	$761,396	—	—

* Negative values denote increased cost for the LID design over conventional development costs.

The clustered design used in the development protected open space and reduced clearing and grading costs. Costs for paving and sidewalks were also decreased because the cluster design reduced street length and width. Stormwater savings were realized primarily through the use of vegetated swales and bioswales. These LID practices provided stormwater conveyance and treatment and also lowered the cost of conventional stormwater infrastructure. The increase in landscaping costs resulted from additional open space present on-site compared to a conventional design, as well as increased street sweeping. Overall, the subdivision's conservation design retained more natural open space for the benefit and use of the homeowners and aided stormwater management by preserving some of the site's natural hydrology.[20]

Bellingham, Washington, Parking Lot Retrofits

The City of Bellingham, Washington, retrofitted two parking lots—one at City Hall and the other at Bloedel Donovan Park—with rain gardens in lieu of installing underground vaults to manage stormwater.[21] At City Hall, 3 parking spaces out of a total of 60 were used for the rain garden installation. The Bloedel Donovan Park retrofit involved converting to a rain garden a 550-square-foot area near a catch basin. Both installations required excavation, geotextile fabric, drain rock, soil amendments, and native plants. Flows were directed to the rain gardens by curbs. An overflow system was installed to accommodate higher flows during heavy rains.

The City compared actual rain garden costs to estimates for conventional underground vaults based on construction costs for similar projects in the area ($12.00 per cubic foot of storage). Rain garden costs included labor, vehicle use/rental, and materials. Table 5 shows that the City Hall rain garden saved the City $22,000, or 80 percent, over the underground vault option; the Bloedel Donovan Park installation saved $40,000, or 76 percent.

Table 5. Cost Comparison for Bellingham's Parking Lot Rain Garden Retrofits[22]

Project	Conventional Vault Cost	Rain Garden Cost	Cost Savings	Percent Savings
City Hall	$27,600	$5,600	$22,000	80%
Bloedel Donovan Park	$52,800	$12,800	$40,000	76%

CENTRAL PARK COMMERCIAL REDESIGNS, FREDERICKSBURG, VA (A MODELING STUDY)

The Friends of the Rappahannock undertook a cost analysis involving the redesign of site plans for several stores in a large commercial development in the Fredericksburg, Virginia, area called Central Park.[23,24] Table 6 contains a side-by-side analysis of the cost additions and reductions for each site for scenarios where LID practices (bioretention areas and swales) were incorporated into the existing, traditional site designs. In five of the six examples, the costs for the LID redesigns were higher than those for the original designs, although they never exceeded $10,000, or 10 percent of the project. One example yielded a $5,694 savings. The fact that these projected costs for LID were comparable to the costs for traditional designs convinced the developer to begin incorporating LID practices into future design projects.[25]

Table 6. Site Information and Cost Additions/Reductions Using LID Versus Traditional Designs

Name	Total BMP Area (ft^2)	Total Impervious Area Treated (ft^2)	Percent of Impervious Area Treated	Cost Additions[a]	Cost Reductions[b]	Change in Cost After Redesign
Breezewood Station Alternative 1	4,800	64,165	98.4%	$36,696	$34,785	+ $1,911
Breezewood Station Alternative 2	3,500	38,775	59.5%	$24,449	$21,060	+ $3,389
Olive Garden	1,780	31,900	59.1%	$14,885	$11,065	+ $3,790
Kohl's, Best Buy, & Office Depot	14,400	354,238	56.3%	$89,433	$80,380	+ $9,053
First Virginia Bank	1,310	20,994	97.7%	$6,777	$1,148	+ $5,629
Chick-Fil-A[c]	1,326	28,908	82.2%	$6,846	$12,540	– $5,694

[a] Additional costs for curb, curb blocks, storm piping, inlets, underdrains, soil, mulch, and vegetation as a result of the redesign.
[b] Reduced cost for curb, storm piping, roof drain piping, and inlets as a result of the redesign.
[c] Cost reduction value includes the cost of a Stormceptor unit that is not needed as part of the redesign.

CROWN STREET, VANCOUVER, BRITISH COLUMBIA

In 1995 the Vancouver City Council adopted a Greenways program that is focused on introducing pedestrian-friendly green space into the City to connect trails, environmental areas, and urban space. As a part of this program, the City has adopted strategies to manage stormwater runoff from roadways. Two initiatives are discussed here.

The Crown Street redevelopment project, completed in 2005, retrofitted a 1,100-foot block of traditional curb-and-gutter street with a naturalized streetscape modeled after the Seattle SEA Street design. Several LID features were incorporated into the design. The total imperviousness of the street was decreased by reducing the street width from 28 feet to 21 feet with one-way sections of the road narrowed to 10 feet. Roadside swales that use vegetation and structural grass (grass supported by a grid and soil structure that prevents soil compaction and root damage) were installed to collect and treat stormwater through infiltration.[26]

Modeling predicts that the redesigned street will retain 90 percent of the annual rainfall volume on-site; the remaining 10 percent of runoff will be treated by the system of vegetated swales before discharging.[27,28] The City chose to use the LID design because stormwater runoff from Crown Street flows into the last two salmon-bearing creeks in Vancouver.[29] Monitoring until 2010 will assess the quality of stormwater runoff and compare it with both the modeling projections and the runoff from a nearby curb-and-gutter street.

The cost of construction for the Crown Street redevelopment was $707,000. Of this, $311,000 was attributed to the cost of consultant fees and aesthetic design features, which were included in the project because it was the first of its kind in Vancouver. These added costs would not be a part of future projects. Discounting the extra costs, the $396,000 construction cost is 9 percent higher than the estimated $364,000 conventional curb-and-gutter design cost.[30] The City has concluded that retrofitting streets that have an existing conventional stormwater system with naturalized designs will cost marginally more than making curb-and-gutter improvements, but installing naturalized street designs in new developments will be less expensive than installing conventional drainage systems.[31,32]

One goal of Vancouver's Greenways program is to make transportation corridors more pedestrian-friendly. A method used to achieve this goal is to extend curbs at intersections out into the street to lessen the crossing distance and improve the line of sight for pedestrians. When this initiative began, the City relocated stormwater catch basins that would have been enclosed within the extended curb. Now, at certain intersections, the City uses the new space behind the curb to install "infiltration bulges" to collect and infiltrate roadway runoff. The infiltration bulges are constructed of permeable soils and vegetation. (The City of Portland, Oregon, has installed similar systems, which they call "vegetated curb extensions.") The catch basins are left in place, and any stormwater that does not infiltrate into the soil overflows into the storm drain system.[33]

The infiltration bulges have resulted in savings for the City. Because the stormwater infiltration bulges are installed in conjunction with planned roadway improvements, the only additional costs associated with the stormwater project are the costs of a steel curb insert to allow stormwater to enter the bulge and additional soil excavation costs. These additional costs are more than offset by the $2,400 to $4,000 cost that would have been required to relocate the catch basins. To date, the City has installed nine infiltration bulges, three of which are maintained by local volunteers as part of a Green Streets program in which local residents adopt city green space.[34]

GAP CREEK SUBDIVISION, SHERWOOD, ARKANSAS

Gap Creek's original subdivision plan was revised to include LID concepts. The revised design increased open space from the originally planned 1.5 acres to 23.5 acres. Natural drainage areas were preserved and buffered by greenbelts. Traffic-calming circles were used, allowing the developer to reduce street widths from 36 to 27 feet. In addition, trees were kept close to the curb line. These design techniques allowed the development of 17 additional lots.

The lots sold for $3,000 more and cost $4,800 less to develop than comparable conventional lots. A cost comparison is provided in Table 7. For the entire development, the combination of cost savings and lot premiums resulted in an additional profit to the developer of $2.2 million.[35,36]

Table 7. Cost Comparison for Gap Creek Subdivision[37]

Total Cost of Conventional Design	Gap Creek LID Cost	Cost Savings	Percent Savings	Savings per Lot
$4,620,600	$3,942,100	$678,500	15%	$4,800

GARDEN VALLEY, PIERCE COUNTY, WASHINGTON (A MODELING STUDY)

The Garden Valley subdivision is a 9.7-acre site in Pierce County, Washington. A large wetland on the eastern portion of the site and a 100-foot buffer account for 43 percent of the site area. Designers evaluated a scenario in which roadway widths were reduced and conventional stormwater management practices were replaced with swales, bioretention, and soil amendments. The use of these LID elements would have allowed the cost for stormwater management on the site to be reduced by 72 percent. A cost comparison is provided in Table 8.[38] Other costs expected with the LID design were a $900 initial cost for homeowner education with $170 required annually thereafter. Annual maintenance costs for the LID design (not included above) were expected to be $600 more than those for the conventional design, but a $3,000 annual savings in the stormwater utility bill was expected to more than offset higher maintenance costs.

Table 8. Cost Comparison for Garden Valley Subdivision[39]

Item	Conventional Development Cost	Garden Valley LID Cost	Cost Savings*	Percent Savings*
Stormwater management	$214,000	$59,800	$154,200	72%
Site paving	$110,400	$200,900	–$90,500	–82%
Total	$324,400	$260,700	$63,700	—

* Negative values denote increased cost for the LID design over conventional development costs.

The design incorporated the use of narrower roadways coupled with Grasscrete parking along the roadside, which increased the overall site paving costs. However, this added cost was more than offset by the savings realized by employing LID for stormwater management. The LID practices were expected to increase infiltration and reduce stormwater discharge rates, which can improve the health and quality of receiving streams.

KENSINGTON ESTATES, PIERCE COUNTY, WASHINGTON (A MODELING STUDY)

A study was undertaken to evaluate the use of LID techniques at the Kensington Estates subdivision, a proposed 24-acre development consisting of single-family homes on 103 lots. The study assumed that conventional stormwater management practices would be replaced entirely by LID techniques, including reduced imperviousness, soil amendments, and bioretention areas. The design dictated that directly connected impervious areas on-site were to be minimized. Three wetlands and an open space tract would treat stormwater discharging from LID installations. Open space buffers were included in the design. The LID proposal also included rooftop rainwater collection systems on each house.[40,41]

The proposed LID design reduced effective impervious area from 30 percent in the conventional design to approximately 7 percent, and it was approximately twice as expensive as the traditional design. A cost comparison is provided in Table 9.

Table 9. Cost Comparison for Kensington Estates Subdivision[42]

Item	Conventional Development Cost	Kensington Estate LID Cost	Additional Cost
Stormwater management	$243,400	$925,400	$ 682,000
Site paving	$522,300	$577,500	$55,200
Total	$765,700	$1,502,900	$737,200

Although the study assumed that roadways in the LID design would be narrower than those in the conventional design, site paving costs increased because the LID design assumed that Grasscrete parking would be included along the roadside to allow infiltration. The use of Grasscrete increased the overall site paving costs.

The avoidance of conventional stormwater infrastructure with the use of LID afforded significant cost savings. The LID measures eliminated the need for a detention pond and made more lots available for development. The significant cost for the rooftop rainwater collection systems was assumed to be offset somewhat by savings on stormwater utility bills.[43]

The study also anticipated that the use of LID would reduce stormwater peak flow discharge rates and soil erosion. Furthermore, greater on-site infiltration increases ground water recharge, resulting in increased natural baseflows in streams and a reduction in dry channels. Proposed clustering of buildings would allow wetlands and open space to be preserved and create a more walkable community. The reduced road widths were anticipated to decrease traffic speeds and accident rates.

LAUREL SPRINGS SUBDIVISION, JACKSON, WISCONSIN

The Laurel Springs subdivision in Jackson, Wisconsin, is a residential subdivision that was developed as a conservation design community. The use of cluster design helped to preserve open space and minimize grading and paving. The use of bioretention and vegetated swales lowered the costs for stormwater management.

The costs of using conservation design to develop the subdivision were compared with the estimated cost of developing the site with conventional practices (Table 10).[44] The total savings realized with conservation design were just over $504,469, or approximately 30 percent of the estimated conventional construction cost. Savings from stormwater management accounted for 60 percent of the total cost savings. Other project savings were realized with reduced sanitary sewer, water distribution, and utility construction costs.

Table 10. Cost Comparison for Laurel Springs Subdivision[45]

Item	Conventional Development Cost	Laurel Springs LID Cost	Cost Savings	Percent Savings	Percent of Total Savings
Site preparation	$441,600	$342,000	$99,600	23%	20%
Stormwater management	$439,956	$136,797	$303,159	69%	60%
Site paving and sidewalks	$607,465	$515,755	$91,710	15%	18%
Landscaping	$165,000	$155,000	$10,000	6%	2%
Total	$1,654,021	$1,149,552	$504,469	—	—

In addition to preserving open space and reducing the overall amount of clearing and grading, the cluster design also reduced street lengths and widths, thereby lowering costs for paving and sidewalks. Vegetated swales and bioswales largely were used to replace conventional stormwater infrastructure and led to significant savings. Each of these factors helped to contribute to a more hydrologically functional site that reduced the total amount of stormwater volume and managed stormwater through natural processes.

Mill Creek Subdivision, Kane County, Illinois

The Mill Creek subdivision is a 1,500-acre, mixed-use community built as a conservation design development. Approximately 40 percent of the site is identified as open space; adjacent land use is mostly agricultural. The subdivision was built using cluster development. It uses open swales for stormwater conveyance and treatment, and it has a lower percentage of impervious surface than conventional developments. An economic analysis compared the development cost for 40 acres of Mill Creek with the development costs of 30 acres of a conventional development with similar building density and location.[46]

When compared with the conventional development, the conservation site design techniques used at Mill Creek saved approximately $3,411 per lot. Nearly 70 percent of these savings resulted from reduced costs for stormwater management, and 28 percent of the savings were found in reduced costs for site preparation. A cost comparison is provided in Table 11. Other savings not included in the table were realized with reduced construction costs for sanitary sewers and water distribution.

Table 11. Cost Comparison for Mill Creek Subdivision[47]

Item	Conventional Development Cost per Lot	Mill Creek LID Cost per Lot	Cost Savings per Lot	Percent Savings per Lot	Percent of Total Savings
Site preparation	$2,045	$1,086	$959	47%	28%
Stormwater management	$4,535	$2,204	$2,331	51%	68%
Site paving and sidewalks	$5,930	$5,809	$121	2%	4%
Total	$12,510	$9,099	$3,411	—	—

The use of cluster development and open space preservation on the site decreased site preparation costs. The majority of the cost savings were achieved by avoiding the removal and stockpiling of topsoil. In addition to cost savings from avoided soil disturbance, leaving soils intact also retains the hydrologic function of the soils and aids site stormwater management by reducing runoff volumes and improving water quality. The site's clustered design was also responsible for a decrease in costs for paving and sidewalks because the designers intentionally aimed to decrease total road length and width.

The designers used open swales as the primary means for stormwater conveyance. Coupled with other site techniques to reduce runoff volumes and discharge rates, significant savings in stormwater construction were avoided because of reduced storm sewer installation; sump pump connections; trench backfill; and catch basin, inlet, and cleanout installation.

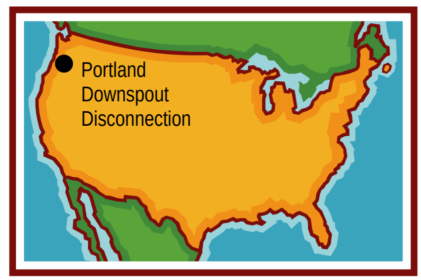
In addition to the cost savings, the conservation design at Mill Creek had a positive effect on property values: lots adjacent to walking/biking trails include a $3,000 premium, and lots adjacent to or with views of open space include a $10,000 to $17,500 premium. The

600 acres of open space on the site include 127 acres of forest preserve with quality wetlands, 195 acres of public parks, and 15 miles of walking/biking trails.[48]

Poplar Street Apartments, Aberdeen, North Carolina

The use of bioretention, topographical depressions, grass channels, swales, and stormwater basins at the 270-unit Poplar Street Apartment complex improved stormwater treatment and lowered construction costs. The design allowed almost all conventional underground storm drains to be eliminated from the design. The design features created longer flow paths, reduced runoff volume, and filtered pollutants from runoff. According to the U.S. Department of Housing and Urban Development, use of LID techniques resulted in a $175,000 savings (72 percent).[49]

Portland Downspout Disconnection Program, Portland, Oregon

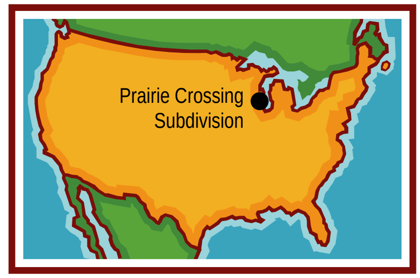


The City of Portland, Oregon, implemented a Downspout Disconnection Program as part of its CSO elimination program. Every year, billions of gallons of stormwater mixed with sewage pour into the Willamette River and Columbia Slough through CSOs. When roof runoff flows into Portland's combined sewer system, it contributes to CSOs. The City has reduced the frequency of CSOs to the Columbia Slough and hopes to eliminate 94 percent of the overflows to the Willamette River by 2011.[50]

The Downspout Disconnection Program gives homeowners, neighborhood associations, and community groups the chance to work as partners with the Bureau of Environmental Services and the Office of Neighborhood Involvement to help reduce CSOs. Residents of selected neighborhoods disconnect their downspouts from the combined sewer system and allow their roof water to drain to gardens and lawns. Residents can do the work themselves and earn $53 per downspout, or they can have community groups and local contractors disconnect for them. Community groups earn $13 for each downspout they disconnect. (Materials are provided by the City.)

More than 44,000 homeowners have disconnected their downspouts, removing more than 1 billion gallons of stormwater per year from the combined sewer system. The City estimates that removing the 1 billion gallons will result in a $250 million reduction in construction costs for an underground pipe to store CSOs by reducing the capacity needed to handle the flows. The City has spent $8.5 million so far to implement this program and will continue to encourage more homeowners and businesses to disconnect their downspouts to achieve additional CSO and water quality benefits.

PRAIRIE CROSSING SUBDIVISION, GRAYSLAKE, ILLINOIS



The Prairie Crossing subdivision is a conservation development on 678 acres, of which 470 acres is open space. The site was developed as a mixed-use community with 362 residential units and 73 acres of commercial property, along with schools, a community center, biking trails, a lakefront beach, and a farm. The site uses bioretention cells and vegetated swales to manage stormwater.[51]

A cost analysis was performed to compare the actual construction costs of Prairie Crossing with the estimated costs of a conventional design on the site with the same layout. Cost savings with conservation design were realized primarily in four areas: stormwater management, curb and gutter installation, site paving, and sidewalk installation. The total savings were estimated to be almost $1.4 million, or nearly $4,000 per lot (Table 12). Savings from stormwater management accounted for approximately 15 percent of the total savings. The cost savings shown are relative to the estimated construction cost for the items in a conventional site design based on local codes and standards.

Table 12. Cost Comparison for Prairie Crossing Subdivision[52]

Item	Cost Savings	Percent Savings
Reduced Road Width	$178,000	13%
Stormwater Management	$210,000	15%
Decreased Sidewalks	$648,000	47%
Reduced Curb and Gutter	$339,000	25%
Total	$1,375,000	—

Reduced costs for sidewalks accounted for nearly half of the total cost savings. This savings is attributed in part to the use of alternative materials rather than concrete for walkways in some locations. In addition, the design and layout of the site, which retained a very high percentage of open space, contributed to the cost savings realized from reducing paving, the length and number of sidewalks, and curbs and gutters. The use of alternative street edges, vegetated swales, and bioretention and the preservation of natural areas all reduced the need for and cost of conventional stormwater infrastructure.[53] Benefits are associated with the mixed-use aspect of the development as well: residents can easily access schools, commercial areas, recreation, and other amenities with minimal travel. Proximity to these resources can reduce traffic congestion and transportation costs. Also, mixed-use developments can foster a greater sense of community and belonging than other types of development. All of these factors tend to improve quality of life.

PRAIRIE GLEN SUBDIVISION, GERMANTOWN, WISCONSIN

The Prairie Glen subdivision is nationally recognized for its conservation design approach. A significant portion of the site (59 percent) was preserved as open space. Wetlands were constructed to manage stormwater runoff, and the open space allowed the reintroduction of native plants and wildlife habitat. The site layout incorporated hiking trails, which were designed to allow the residents to have easy access to natural areas.[54]

To evaluate the cost benefits of Prairie Glen's design, the actual construction costs were compared with the estimated costs of developing the site conventionally. When compared with conventional design, the conservation design at Prairie Glen resulted in a savings of nearly $600,000. Savings for stormwater management accounted for 25 percent of the total savings. Table 13 provides a cost comparison. Other savings not included in the table were realized with reduced sanitary sewer, water distribution, and utility construction costs.

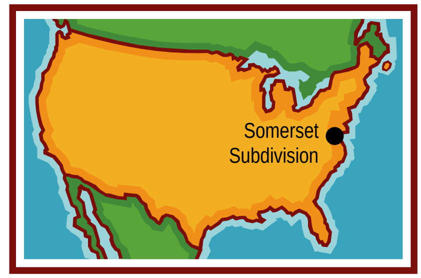
Table 13. Cost Comparison for Prairie Glen Subdivision[55]

Item	Conventional Development Cost	Prairie Glen LID Cost	Cost Savings*	Percent Savings*	Percent of Total Savings*
Site preparation	$277,043	$188,785	$88,258	32%	22%
Stormwater management	$215,158	$114,364	$100,794	47%	25%
Site paving and sidewalks	$462,547	$242,707	$219,840	48%	54%
Landscaping	$50,100	$53,680	–$3,580	–7%	–1%
Total	$1,004,848	$599,536	$405,312	—	—

* Negative values denote increased cost for the LID design over conventional development costs.

The cluster design and preservation of a high percentage of open space resulted in a significant reduction in costs for paving and sidewalks. These reduced costs accounted for 54 percent of the cost savings for the overall site. Reduced costs for soil excavation and stockpiling were also realized. The use of open-channel drainage and bioretention minimized the need for conventional stormwater infrastructure and accounted for the bulk of the savings in stormwater management. Landscaping costs increased due to the added amount of open space on the site.

Somerset Subdivision, Prince George's County, Maryland



The Somerset subdivision, outside Washington, D.C., is an 80-acre site consisting of nearly 200 homes. Approximately half of the development was built using LID techniques; the other half was conventionally built using curb-and-gutter design with detention ponds for stormwater management. Bioretention cells and vegetated swales were used in the LID portion of the site to replace conventional stormwater infrastructure. Sidewalks were also eliminated from the design. To address parking concerns, some compromises were made: because of local transportation department concern that roadside parking would damage the swales, roads were widened by 10 feet.[56] (Note that there are alternative strategies to avoid increasing impervious surface to accommodate parking, such as installing porous pavement parking lanes next to travel lanes.)

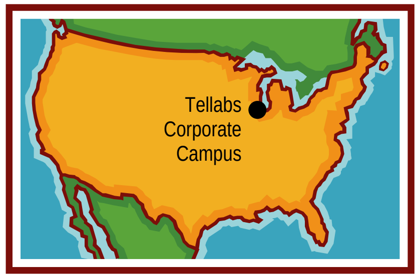
Most of the 0.25-acre lots have a 300- to 400-square-foot bioretention cell, also called a rain garden. The cost to install each cell was approximately $500—$150 for excavation and $350 for plants. The total cost of bioretention cell installation in the LID portion of the site was $100,000 (swale construction was an additional cost). The construction cost for the detention pond in the conventionally designed portion of the site was $400,000, excluding curbs, gutters, and sidewalks.[57,58] By eliminating the need for a stormwater pond, six additional lots could be included in the LID design. A comparison of the overall costs for the traditional and LID portions of the site is shown in Table 14.

Table 14. Cost Comparison for Somerset Subdivision

Conventional Development Cost	Somerset LID Cost	Cost Savings	Percent Savings	Savings per Lot
$2,456,843	$1,671,461	$785,382	32%	$4,000

In terms of environmental performance, the LID portion of the subdivision performed better than the conventional portion.[59] A paired watershed study compared the runoff between the two portions of the site, and monitoring indicated that the average annual runoff volume from the LID watershed was approximately 20 percent less than that from the conventional watershed. The number of runoff-producing rain events in the LID watershed also decreased by 20 percent. Concentrations of copper were 36 percent lower; lead, 21 percent lower; and zinc, 37 percent lower in LID watershed runoff than in conventional watershed runoff. The homeowners' response to the bioretention cells was positive; many perceived the management practices as a free landscaped area.

TELLABS CORPORATE CAMPUS, NAPERVILLE, ILLINOIS



The Tellabs corporate campus is a 55-acre site with more than 330,000 square feet of office space. After reviewing preliminary planning materials that compared the costs of conventional and conservation design, the company chose to develop the site with conservation design approaches. Because the planning process included estimating costs for the two development approaches, this particular site provides good information on commercial/industrial use of LID.[60]

Development of the site included preserving trees and some of the site's natural features and topography. For stormwater management, the site uses bioswales, as well as other infiltration techniques, in parking lots and other locations. The use of LID techniques for stormwater management accounted for 14 percent of the total cost savings for the project. A cost comparison is provided in Table 15. Other cost savings not shown in Table 15 were realized with reduced construction contingency costs, although design contingency costs were higher.

Table 15. Cost Comparison for Tellabs Corporate Campus[61]

Item	Conventional Development Cost	Tellabs LID Cost	Cost Savings	Percent Savings	Percent of Total Savings
Site preparation	$2,178,500	$1,966,000	$212,500	10%	46%
Stormwater management	$480,910	$418,000	$62,910	13%	14%
Landscape development	$502,750	$316,650	$186,100	37%	40%
Total	$3,162,160	$2,700,650	$461,510	—	—

Savings in site preparation and landscaping had the greatest impact on costs. Because natural drainage pathways and topography were maintained to the greatest extent possible, grading and earthwork were minimized; 6 fewer acres were disturbed using the conservation design approach. Landscaping at the site maximized natural areas and restored native prairies and wetland areas. The naturalized landscape eliminated the need for irrigation systems and lowered maintenance costs when compared to turf grass, which requires mowing and regular care. In the end, the conservation approach preserved trees and open space and provided a half acre of wetland mitigation. The bioswales used for stormwater management complemented the naturalized areas and allowed the site to function as a whole; engineered stormwater techniques augmented the benefits of the native areas and wetlands.[62]

TORONTO GREEN ROOFS, TORONTO, ONTARIO (A MODELING STUDY)

Toronto is home to more than 100 green roofs. To evaluate the benefits of greatly expanded use of green roofs in the city, a study was conducted using a geographic information system to model the effects of installing green roofs on all flat roofs larger than 3,750 square feet. (The model assumed that each green roof would cover at least 75 percent of the roof area.) If the modeling scenario were implemented, 12,000 acres of green roofs (8 percent of the City's land area) would be installed.[63] The study quantified five primary benefits from introducing the green roofs: (1) reduced stormwater flows into the separate storm sewer system, (2) reduced stormwater flows into the combined sewer system, (3) improved air quality, (4) mitigation of urban heat island effects, and (5) reduced energy consumption.[64]

The study predicted economic benefits of nearly $270 million in municipal capital cost savings and more than $30 million in annual savings. Of the total savings, more than $100 million was attributed to stormwater capital cost savings, $40 million to CSO capital cost savings, and nearly $650,000 to CSO annual cost savings. The cost of installing the green roofs would be largely borne by private building owners and developers; the cost to Toronto would consist of the cost of promoting and overseeing the program and would be minimal. Costs for green roof installations in Canada have averaged $6 to $7 per square foot. The smallest green roof included in the study, at 3,750 square feet, would cost between $22,000 and $27,000. The total cost to install 12,000 acres of green roofs would be $3 billion to $3.7 billion.[65,66] Although the modeled total costs exceed the monetized benefits, the costs would be spread across numerous private entities.

CONCLUSION

The 17 case studies presented in this report show that LID practices can reduce project costs and improve environmental performance. In most cases, the case studies indicate that the use of LID practices can be both fiscally and environmentally beneficial to communities. As with almost all such projects, site-specific factors influence project outcomes, but in general, for projects where open space was preserved and cluster development designs were employed, infrastructure costs were lower. In some cases, initial costs might be higher because of the cost of green roofs, increased site preparation costs, or more expensive landscaping practices and plant species. However, in the vast majority of cases, significant savings were realized during the development and construction phases of the projects due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Total capital cost savings ranged from 15 to 80 percent when LID methods were used, with a few exceptions in which LID project costs were higher than conventional stormwater management costs.

EPA has identified several additional areas that will require further study. First, in all the cases, there were benefits that this study did not monetize and factor into the project's bottom line. These benefits include improved aesthetics, expanded recreational opportunities, increased property values due to the desirability of the lots and their proximity to open space, increased number of total units developed, the value of increased marketing potential, and faster sales.

Second, more research is also needed to quantify the environmental benefits that can be achieved through the use of LID techniques and the costs that can be avoided by using these practices. For example, substantial downstream benefits can be realized through the reduction of the peak flows, discharge volumes, and pollutant loadings discharged from the site. Downstream benefits also might include reductions in flooding and channel degradation, costs for water quality improvements, costs of habitat restoration, costs of providing CSO abatement, property damage, drinking water treatment costs, costs of maintaining/dredging navigable waterways, and administrative costs for public outreach and involvement.

Finally, additional research is needed monetize the cost reductions that can be achieved through improved environmental performance, reductions in long-term operation and maintenance costs and/or reductions in the life cycle costs of replacing or rehabilitating infrastructure.

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[1] D. Beach, *Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States* (Arlington, VA: Pew Ocean Commission, 2002).

[2] USDA, *Summary Report: 1997 National Resources Inventory* (Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service, 1999 [revised 2000]).

[3] Beach, 2002.

[4] The term *LID* is one of many used to describe the practices and techniques employed to provide advanced stormwater management; *green infrastructure*, *conservation design*, and *sustainable stormwater management* are other common terms. However labeled, each of the

identified practices seeks to maintain and use vegetation and open space, optimize natural hydrologic processes to reduce stormwater volumes and discharge rates, and use multiple treatment mechanisms to remove a large range of pollutants. In the context of this report, case studies ascribing to one of the above, or similar, labels were evaluated, and these terms are used interchangeably throughout the report.

[5] Trust for Public Land, *The Economic Benefits of Open Space* (Trust for Public Land, 1999), http://www.tpl.org/tier3_cd.cfm?content_item_id=1195&folder_id=727 (accessed March 29, 2006).

[6] Trust for Public Land and American Water Works Association. *Protecting the Source* (San Francisco, CA: Trust for Public Land, 2004).

[7] Riverkeeper, *Sustainable Raindrops: Cleaning New York Harbor by Greening The Urban Landscape* (accessed Nov. 30, 2007).

[8] Trust for Public Land, 1999.

[9] USEPA, *Economic Benefits of Runoff Controls* (Washington, DC: U.S. Environmental Protection Agency, Office of Water, 1995).

[10] National Park Service, *Economic Impacts of Protecting Rivers, Trails, and Greenway Corridors: A Resource Book* (National Park Service, 1995), http://www.nps.gov/pwro/rtca/econindx.htm (accessed June 1, 2006).

[11] USEPA, *Preliminary Data Summary of Urban Stormwater Best Management Practices*, EPA-821-R-99-012 (Washington, DC: U.S. Environmental Protection Agency, 1999), http://www.epa.gov/OST/stormwater (accessed March 1, 2006).

[12] Water Environment Federation, Credits Bring Economic Incentives for Onsite Stormwater Management, *Watershed & Wet Weather Technical Bulletin* (January 1999).

[13] C. Kloss and C. Calarusse, *GI Report* (New York, NY:, Natural Resources Defense Council, April 2006).

[14] R.R. Horner, H. Lim, and S.J. Burges, *Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects: Summary of the 2000–2003 Water Years*, Water Resources Series: Technical Report No. 181 (Seattle, WA: University of Washington, Department of Civil and Environmental Engineering, 2004), http://www.ci.seattle.wa.us/util/stellent/groups/public/@spu/@esb/documents/webcontent/hydrologic_200406180904017.pdf. (accessed November 19, 2007).

[15] J. Haugland, *Changing Cost Perceptions: An Analysis of Conservation Development* (Elmhurst, IL: Conservation Research Institute, 2005), http://www.nipc.org/environment/sustainable/conservationdesign/cost_analysis (accessed March 1, 2006).

[16] Horner et al., 2004.

[17] Horner et al., 2004.

[18] Haugland, 2005.

[19] Haugland, 2005.

[20] Haugland, 2005.

[21] Puget Sound Action Team, *Reining in the Rain: A Case Study of the City of Bellingham's Use of Rain Gardens to Manage Stormwater* (Puget Sound Action Team, 2004), www.psat.wa.gov/Publications/Rain_Garden_book.pdf (accessed September 11, 2007).

[22] Puget Sound Action Team, 2004.

[23] Friends of the Rappahannock, *Example LID Commercial Re-designs* and *Costs Spreadsheets for Re-designs* (Friends of the Rappahannock, 2006), http://www.riverfriends.org/Publications/LowImpactDevelopment/tabid/86/Default.aspx. (accessed November 19, 2007).

[24] C.S. Ingles, Stafford County Helps Pioneer Low Impact Design Movement, *Virginia Town & City* 39, no. 8 (2004).

[25] Ingles, 2004.

[26] Kloss and Calarusse, 2006.

[27] A. Steed, *Naturalized Streetscapes: A Case Study of Crown Street, Vancouver* (City of Vancouver Greenways, Vancouver, BC: City of Vancouver Greenways, no date), http://www.sustainability.ca/Docs/Naturalized%20Streetscapes-AS.pdf?CFID=19075623&CFTOKEN=60214114 (accessed March 31, 2006).

[28] Personal communication with Otto Kauffmann, Engineering Project Coordinator, City of Vancouver Streets Division, April 2005.

[29] Scott Deveau, Street in for Crowning Touch, *The Vancouver Courier* (September 22, 2004) http://spec.bc.ca/article/article.php?articleID=340 (accessed March 9, 2005).

[30] American dollars converted from Canadian equivalent based on April 25, 2005, exchange rate.

[31] City of Vancouver, British Columbia, *Crown Street: Vancouver's First Environmentally Sustainable Street* (City of Vancouver, BC, 2005), prepared for TAC's Environmental Council, Vancouver, BC, http://www.transportationassociation.ca/english/pdf/conf2005/s5/kauffman.pdf (accessed November 19, 2007).

[32] Personal communication with Otto Kauffmann, Engineering Project Coordinator, City of Vancouver Streets Division, November 2005.

[33] Kloss and Calarusse, 2006.

[34] Personal communication with David Yurkovich, Greenways Landscape Designer, City of Vancouver Greenways, April 2005.

[35] Haugland, 2005.

[36] HUD, *The Practice of Low Impact Development (LID)* (Washington, DC: U.S. Department of Housing and Urban Development, Office of Policy Development and Research, 2003), http://www.huduser.org/Publications/PDF/practLowImpctDevel.pdf (accessed March 1, 2006).

[37] Haugland, 2005.

[38] CH2MHill, *Pierce County Low Impact Development Study—Final Report* (Belleview, WA: CH2MHill, 2001), http://www.co.pierce.wa.us/xml/services/home/environ/water/CIP/LID/final-lid-report.pdf (accessed March 1, 2006).

[39] CH2MHill, 2001.

[40] USEPA, Low-Impact Development Pays Off, *Nonpoint Source News-Notes* 75 (May 2005): 7–10, http://www.epa.gov/owow/info/NewsNotes/issue75/75issue.pdf (accessed March 1, 2006).

[41] CH2MHill, 2001.

[42] CH2MHill, 2001.

[43] CH2MHill, 2001.

[44] Haugland, 2005.

[45] Haugland, 2005.

[46] Haugland, 2005.

[47] Haugland, 2005.

[48] Haugland, 2005.

[49] HUD, 2003.

[50] Portland Bureau of Environmental Services, *Downspout Disconnection Program* (Portland, OR: Portland Bureau of Environmental Services, 2006), http://www.portlandonline.com/bes/index.cfm?c=31246 (accessed March 31, 2006).

[51] Haugland, 2005.

[52] Haugland, 2005.

[53] Haugland, 2005.

[54] Haugland, 2005.

[55] Haugland, 2005.

[56] USEPA, Maryland Developer Grows "Rain Gardens" to Control Residential Runoff, *Nonpoint Source News-Notes* 42 (August/September 1995), http://www.epa.gov/owow/info/NewsNotes/pdf/42issue.pdf (accessed March 1, 2006).

[57] USEPA, 2005.

[58] HUD, 2003.

[59] USEPA, 2005.

[60] Haugland, 2005.

[61] Haugland, 2005.

[62] Haugland, 2005.

[63] D. Banting, H. Doshi, J. Li, P. Missios, A. Au, B.A. Currie, and M. Verrati, *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto* (Toronto, ON: City of Toronto and Ontario Centres of Excellence—Earth and Environmental Technologies, 2005), http://www.toronto.ca/greenroofs/pdf/fullreport103105.pdf (accessed December 16, 2005).

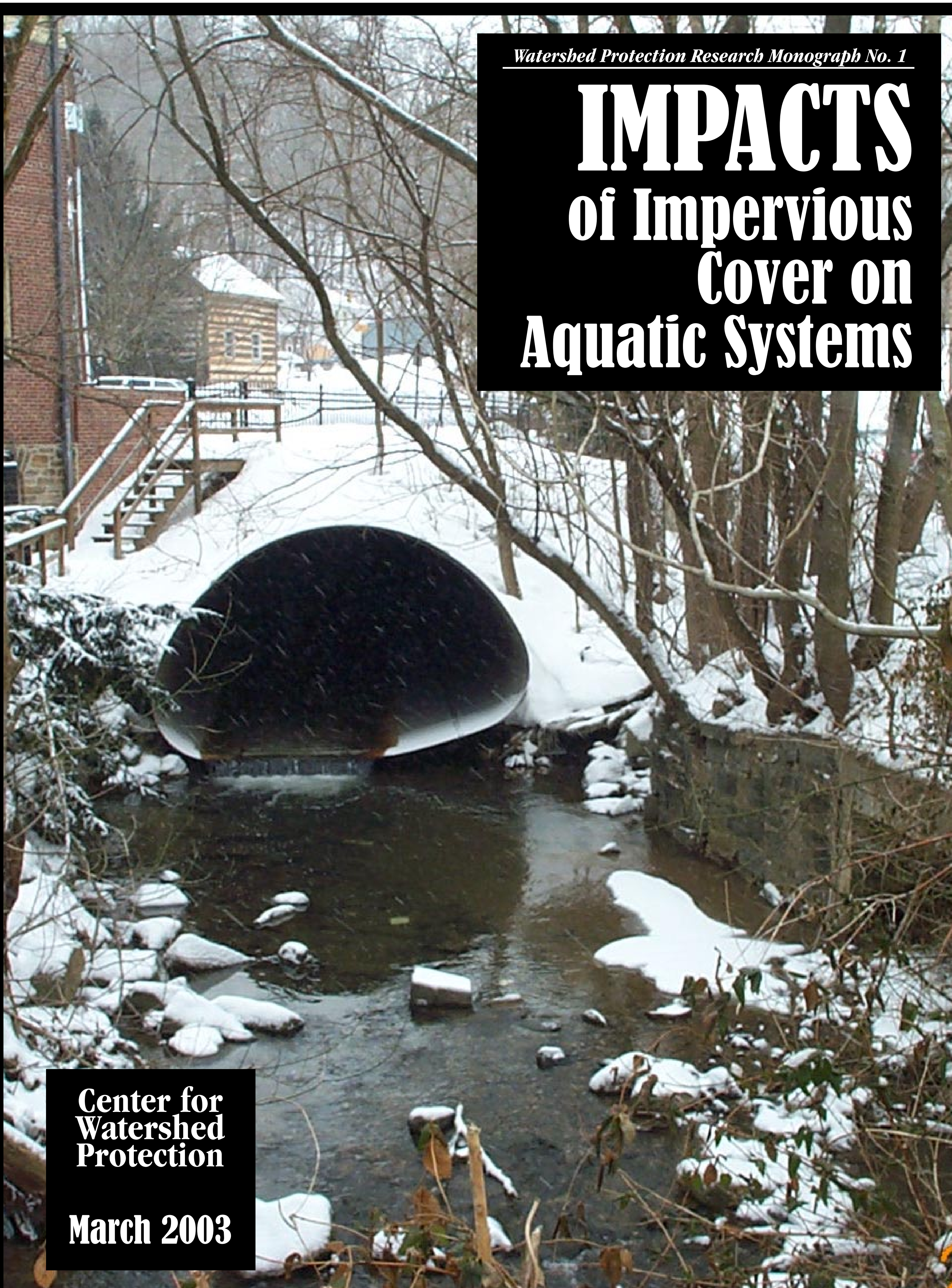
[64] Kloss and Calarusse, 2006.

[65] American dollars converted from Canadian equivalent based on December 19, 2005, exchange rate.

[66] Banting et al., 2005.

Watershed Protection Research Monograph No. 1

IMPACTS of Impervious Cover on Aquatic Systems



Center for Watershed Protection

March 2003

Cover photograph Ellicott City, Maryland 2003.
Courtesy Anne Kitchell, Center for Watershed Protection.

Watershed Protection Research Monograph No. 1

Impacts of Impervious Cover on Aquatic Systems

March 2003

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Foreword

We are extremely pleased to launch the first edition of a new series called *Watershed Protection Research Monographs*. Each monograph will synthesize emerging research within a major topical area in the practice of watershed protection. The series of periodic monographs will replace our journal *Watershed Protection Techniques,* which lapsed in 2002. We hope this new format will provide watershed managers with the science and perspectives they need to better protect and restore their local watersheds.

This monograph was written to respond to many inquiries from watershed managers and policy makers seeking to understand the scientific basis behind the relationship between impervious cover and the health of aquatic ecosystems. It reviews more than 225 research studies that have explored the impact of impervious cover and other indicators of urbanization on aquatic systems. This report comprehensively reviews the available scientific data on how urbanization influences hydrologic, physical, water quality, and biological indicators of aquatic health, as of late 2002.

Our intention was to organize the available scientific data in a manner that was accessible to watershed leaders, policy-makers and agency staff. In addition, the research itself, which spans dozens of different academic departments and disciplines, was conducted in many different eco-regions, climatic zones, and stream types. In order to communicate across such a wide audience, we have resorted to some simplifications, avoided some important particulars, refrained from some jargon, and tried, wherever possible, to use consistent terminology. Thus, the interpretations and conclusions contained in this document are ours alone, and our readers are encouraged to consult the original sources when in doubt.

We would also like to note that the Center for Watershed Protection and the University of Alabama are currently developing a major national database on stormwater quality. The database will contain nearly 4,000 station-storm events collected by municipalities as part of the U.S. EPA's National Pollutant Discharge Elimination System (NPDES) Phase I Stormwater Permit Program. We anticipate releasing a data report in late 2003 that will provide a much needed update of stormwater event mean concentrations (EMCs).

As of this writing, many research efforts are underway that will further test and refine these relationships (most notably, the U.S. Geological Survey gradients initiative, but also many other local, state and academic efforts). We hope that this report provides a useful summary of the existing science, suggests some directions for new research, and stimulates greater discussion of this important topic in watershed management. We also feel it is time for a major conference or symposium, where this diverse community can join together to discuss methods, findings and the important policy implications of their research.

Acknowledgments

Putting this first research monograph together took a lot of energy, editing and analysis, and many Center staff devoted their time and energy over the last two years to get it done. The project team consisted of Karen Cappiella, Deb Caraco, Samantha Corbin, Heather Holland, Anne Kitchell, Stephanie Linebaugh, Paul Sturm, and Chris Swann. Special thanks are extended to Tiffany Wright, who worked tirelessly to assemble, edit and otherwise polish the final draft.

I am also grateful to Michael Paul of Tetratech, Inc., who graciously provided us with an extensive literature review from his PhD days at the University of Georgia that contained many obscure and hard to find citations. Portions of this monograph were developed as part of a literature review conducted as part of a work assignment for the U.S. EPA Office of Wastewater Management in 2001, which proved indispensable in our efforts. Lastly, I would like to thank the hundreds of scientists who have contributed their time and data to explore and test the relationships between urbanization and aquatic health.

Tom Schueler
Center for Watershed Protection

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Acronyms and Abbreviations

B-IBI	Benthic Index of Biotic Integrity
BOD	Biological Oxygen Demand
BSD	Better Site Design
C-IBI	Combined Index of Biotic Integrity
cfs	cubic feet per second
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
Cu	Copper
DOC	Dissolved Organic Carbon
du/ac	dwelling units per acre
EMC	Event Mean Concentration
EPT	Ephemeroptera, Plecoptera and Trichoptera
FC	Forest Cover
GIS	Geographic Information Systems
IBI	Index of Biotic Integrity
IC	Impervious Cover
ICM	Impervious Cover Model
lbs/ac	pounds per acre
LWD	Large Woody Debris
mg/kg	milligrams per kilogram
mg/l	milligrams per liter (equal to ppm)
MPN	Most Probable Number
MTBE	Methyl Tertiary-Butyl Ether
N	Number of Studies
N/R	data not reported
NO_2	Nitrite
NO_3	Nitrate
NO_x	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Unit
NURP	National Urban Runoff Program
PAH	Polycylic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
ppb	Parts per billion (equal to ug/l)
ppm	Parts per million (equal to mg/l)
RBP	Rapid Bioassessment Protocol
SLAMM	Source Loading Assessment/ Management Model
SPMD	Semi-Permeable Membrane Device
SSO	Sanitary Sewer Overflow
STP	Stormwater Treatment Practice
TC	Turf Cover
TDS	Total Dissolved Solids
TKN	Total Kjeldhal Nitrogen
TMDL	Total Maximum Daily Load
Total N	Total Nitrogen
Total P	Total Phosphorous
TOC	Total Organic Carbon
TSS	Total Suspended Solids
ug/l	micrograms per liter (equal to ppb)
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
WLF	Water Level Fluctuation
WTP	Wastewater Treatment Plant

Chapter 1: Introduction

This research monograph comprehensively reviews the available scientific data on the impacts of urbanization on small streams and receiving waters. These impacts are generally classified according to one of four broad categories: changes in hydrologic, physical, water quality or biological indicators. More than 225 research studies have documented the adverse impact of urbanization on one or more of these key indicators. In general, most research has focused on smaller watersheds, with drainage areas ranging from a few hundred acres up to ten square miles.

Streams vs. Downstream Receiving Waters

Urban watershed research has traditionally pursued two core themes. One theme has evaluated the direct impact of urbanization on small streams, whereas the second theme has explored the more indirect impact of urbanization on downstream receiving waters, such as rivers, lakes, reservoirs, estuaries and coastal areas. This report is organized to profile recent research progress in both thematic areas and to discuss the implications each poses for urban watershed managers.

When evaluating the direct impact of urbanization on streams, researchers have emphasized hydrologic, physical and biological indicators to define urban stream quality. In recent years, impervious cover (IC) has emerged as a key paradigm to explain and sometimes predict how severely these stream quality indicators change in response to different levels of watershed development. The Center for Watershed Protection has integrated these research findings into a general watershed planning model, known as the impervious cover model (ICM). The ICM predicts that most stream quality indicators decline when watershed IC exceeds 10%, with severe degradation expected beyond 25% IC. In the first part of this review, we critically analyze the scientific basis for the ICM and explore some of its more interesting technical implications.

While many researchers have monitored the quality of stormwater runoff from small watersheds, few have directly linked these pollutants to specific water quality problems within streams (e.g., toxicity, biofouling, eutrophication). Instead, the prevailing view is that stormwater pollutants are a downstream export. That is, they primarily influence downstream receiving water quality. Therefore, researchers have focused on how to estimate stormwater pollutant loads and then determine the water quality response of the rivers, lakes and estuaries that receive them. To be sure, there is an increasing recognition that runoff volume can influence physical and biological indicators within some receiving waters, but only a handful of studies have explored this area. In the second part of this review, we review the impacts of urbanization on downstream receiving waters, primarily from the standpoint of stormwater quality. We also evaluate whether the ICM can be extended to predict water quality in rivers, lakes and estuaries.

This chapter is organized as follows:

1.1 A Review of Recent Urban Stream Research and the ICM
1.2 Impacts of Urbanization on Downstream Receiving Waters
1.3 Implications of the ICM for Watershed Managers

1.1 A Review of Recent Urban Stream Research and the ICM

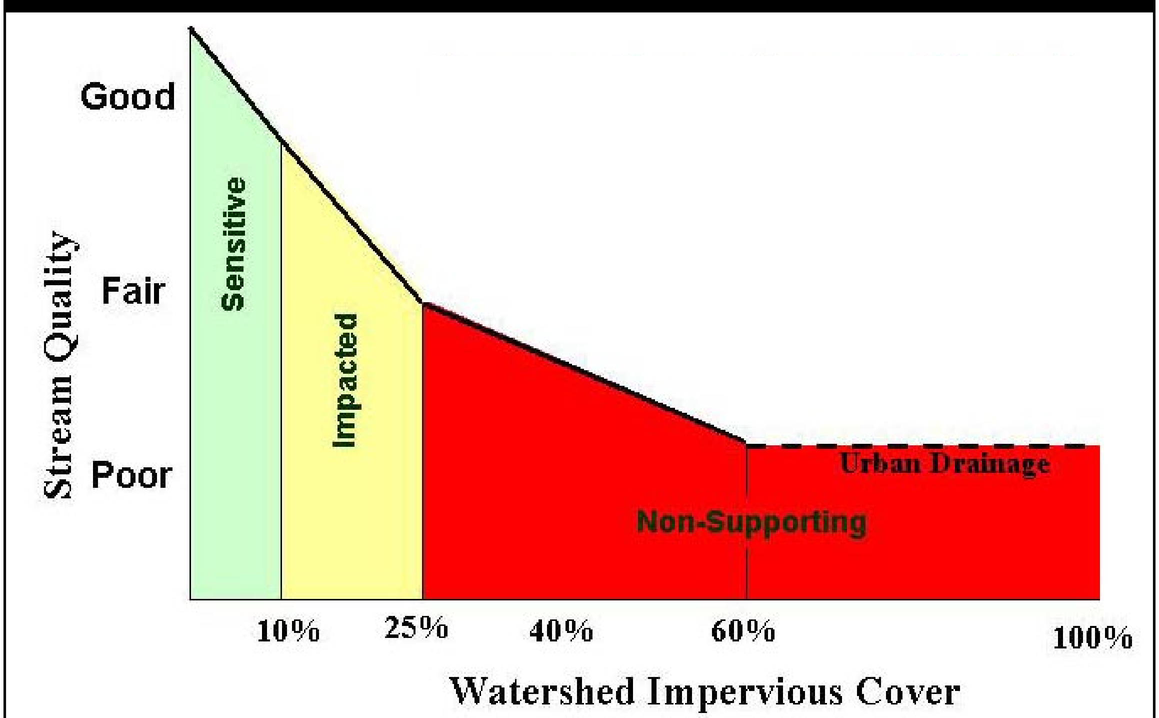
In 1994, the Center published "The Importance of Imperviousness," which outlined the scientific evidence for the relationship between IC and stream quality. At that time, about two dozen research studies documented a reasonably strong relationship between watershed IC and various indicators of stream quality. The research findings were subsequently integrated into the ICM (Schueler, 1994a and CWP, 1998). A brief summary of the basic assumptions of the ICM can be found in Figure 1. The ICM has had a major influence in watershed planning, stream classification and land use regulation in many communities. The ICM is a deceptively simple model that raises extremely complex and profound policy implications for watershed managers.

The ICM has been widely applied in many urban watershed settings for the purposes of small watershed planning, stream classification, and supporting restrictive development regulations and watershed zoning. As such, the ICM has stimulated intense debate among the planning, engineering and scientific communities. This debate is likely to soon spill over into the realm of politics and the courtroom, given its potential implications for local land use and environmental regulation. It is no wonder that the specter of scientific uncertainty is frequently invoked in the ICM debate, given the land use policy issues at stake. In this light, it is helpful to review the current strength of the evidence for and against the ICM.

The ICM is based on the following assumptions and caveats:

- Applies only to 1st, 2nd and 3rd order streams.
- Requires accurate estimates of percent IC, which is defined as the total amount of impervious cover over a subwatershed area.
- Predicts potential rather than actual stream quality. It can and should be expected that some streams will depart from the predictions of the model. For example, monitoring indicators may reveal poor water quality in a stream classified as "sensitive" or a surprisingly high biological diversity

Figure 1: Impervious Cover Model



score in a "non-supporting" one. Consequently, while IC can be used to initially diagnose stream quality, supplemental field monitoring is recommended to actually confirm it.

- Does not predict the precise score of an individual stream quality indicator but rather predicts the average behavior of a group of indicators over a range of IC. Extreme care should be exercised if the ICM is used to predict the fate of individual species (e.g., trout, salmon, mussels).

- "Thresholds" defined as 10 and 25% IC are not sharp "breakpoints," but instead reflect the expected transition of a composite of individual indicators in that range of IC. Thus, it is virtually impossible to distinguish real differences in stream quality indicators within a few percentage points of watershed IC (e.g., 9.9 vs. 10.1%).

- Should only be applied within the ecoregions where it has been tested, including the mid-Atlantic, Northeast, Southeast, Upper Midwest, and Pacific Northwest.

- Has not yet been validated for non-stream conditions (e.g., lakes, reservoirs, aquifers and estuaries).

- Does not currently predict the impact of watershed treatment.

In this section, we review available stream research to answer four questions about the ICM:

1. Does recent stream research still support the basic ICM?
2. What, if any, modifications need to be made to the ICM?
3. To what extent can watershed practices shift the predictions of the ICM?
4. What additional research is needed to test the ICM?

1.1.1 Strength of the Evidence for the ICM

Many researchers have investigated the IC/stream quality relationship in recent years. The Center recently undertook a comprehensive analysis of the literature to assess the scientific basis for the ICM. As of the end of 2002, we discovered more than 225 research studies that measured 26 different urban stream indicators within many regions of North America. We classified the research studies into three basic groups.

The first and most important group consists of studies that directly test the IC/stream quality indicator relationship by monitoring a large population of small watersheds. The second and largest group encompasses secondary studies that indirectly support the ICM by showing significant differences in stream quality indicators between urban and non-urban watersheds. The third and last group of studies includes widely accepted engineering models that explicitly use IC to directly predict stream quality indicators. Examples include engineering models that predict peak discharge or stormwater pollutant loads as a direct function of IC. In most cases, these relationships were derived from prior empirical research.

Table 1 provides a condensed summary of recent urban stream research, which shows the impressive growth in our understanding of urban streams and the watershed factors that influence them. A negative relationship between watershed development and nearly all of the 26 stream quality indicators has been established over many regions and scientific disciplines. About 50 primary studies have tested the IC/stream quality indicator relationship, with the largest number looking at biological indicators of stream health, such as the diversity of aquatic insects or fish. Another 150 or so secondary studies provide evidence that stream quality indicators are significantly different between urban and non-urban watersheds, which lends at least indirect support for the ICM and suggests that additional research to directly test the IC/stream quality indicator

Table 1: The Strength of Evidence:
A Review of the Current Research on Urban Stream Indicators

Stream Quality Indicator	#	IC	UN	EM	RV	Notes
Increased Runoff Volume	2	Y	Y	Y	N	extensive national data
Increased Peak Discharge	7	Y	Y	Y	Y	type of drainage system key
Increased Frequency of Bankfull Flow	2	?	Y	N	N	hard to measure
Diminished Baseflow	8	?	Y	N	Y	inconclusive data
Stream Channel Enlargement	8	Y	Y	N	Y	stream type important
Increased Channel Modification	4	Y	Y	N	?	stream enclosure
Loss of Riparian Continuity	4	Y	Y	N	?	can be affected by buffer
Reduced Large Woody Debris	4	Y	Y	N	?	Pacific NW studies
Decline in Stream Habitat Quality	11	Y	Y	N	?	
Changes in Pool Riffle/Structure	4	Y	Y	N	?	
Reduced Channel Sinuosity	1	?	Y	N	?	straighter channels
Decline in Streambed Quality	2	Y	Y	N	?	embeddedness
Increased Stream Temperature	5	Y	Y	N	?	buffers and ponds also a factor
Increased Road Crossings	3	?	Y	N	?	create fish barriers
Increased Nutrient Load	30+	?	Y	Y	N	higher stormwater EMCs
Increased Sediment Load	30+	?	Y	N	Y	higher EMCs in arid regions
Increased Metals & Hydrocarbons	20+	?	Y	Y	N	related to traffic/VMT
Increased Pesticide Levels	7	?	Y	N	Y	may be related to turf cover
Increased Chloride Levels	5	?	Y	N	Y	related to road density
Violations of Bacteria Standards	9	Y	Y	N	Y	indirect association
Decline in Aquatic Insect Diversity	33	Y	Y	N	N	IBI and EPT
Decline in Fish Diversity	19	Y	Y	N	N	regional IBI differences
Loss of Coldwater Fish Species	6	Y	Y	N	N	trout and salmon
Reduced Fish Spawning	3	Y	Y	N	?	
Decline in Wetland Plant Diversity	2	N	Y	N	?	water level fluctuation
Decline in Amphibian Community	5	Y	Y	N	?	few studies

***#**: total number of all studies that evaluated the indicator for urban watersheds*
***IC**: does balance of studies indicate a progressive change in the indicator as IC increases? Answers: Yes, No or No data (?)*
***UN**: If the answer to IC is no, does the balance of the studies show a change in the indicator from non-urban to urban watersheds? Yes or No*
***EM** Is the IC/stream quality indicator relationship implicitly assumed within the framework of widely accepted engineering models? Yes, No or No models yet exist (?)*
***RV**: If the relationship has been tested in more than one eco-region, does it generally show major differences between ecoregions? Answers: Yes, No, or insufficient data (?)*

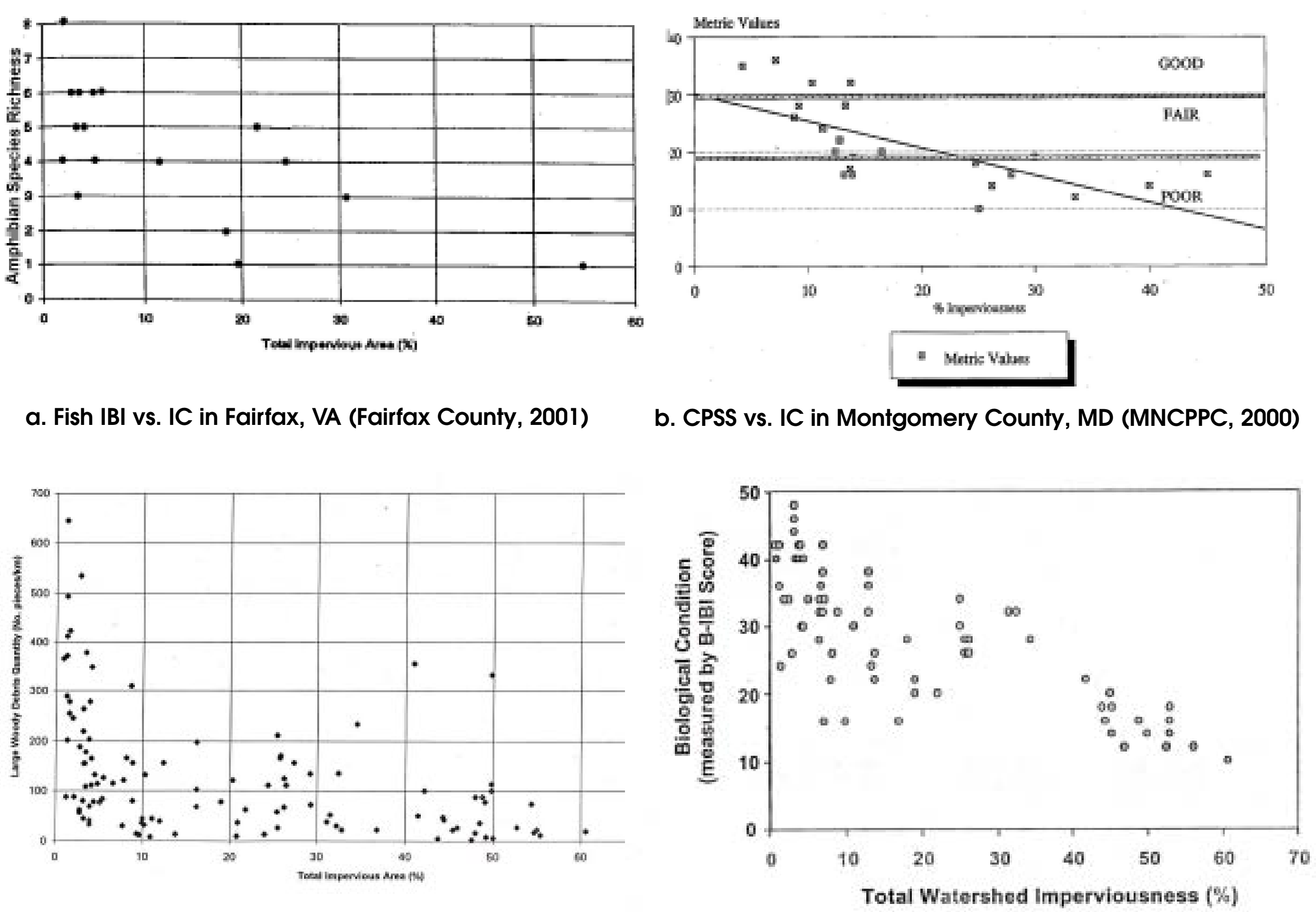
relationship is warranted. In some cases, the IC/stream quality indicator relationship is considered so strongly established by historical research that it has been directly incorporated into accepted engineering models. This has been particularly true for hydrological and water quality indicators.

1.1.2 Reinterpretation of the ICM

Although the balance of recent stream research generally supports the ICM, it also offers several important insights for interpreting and applying the ICM, which are discussed next.

Statistical Variability
Scatter is a common characteristic of most IC/ stream quality indicator relationships. In most cases, the overall trend for the indicator is down, but considerable variation exists along the trend line. Often, linear regression equations between IC and individual stream quality indicators produce relatively modest correlation coefficients (reported r^2 of 0.3 to 0.7 are often considered quite strong).

Figure 2 shows typical examples of the IC/ stream quality indicator relationship that illustrate the pattern of statistical variability. Variation is always encountered when dealing with urban stream data (particularly so for biological indicators), but several patterns exist that have important implications for watershed managers.



a. Fish IBI vs. IC in Fairfax, VA (Fairfax County, 2001)

b. CPSS vs. IC in Montgomery County, MD (MNCPPC, 2000)

c. Large Woody Debris vs. IC (Booth *et al.*, 1997)

d. Biological Condition vs. Total Watershed IC (Booth, 2000)

Figure 2: Typical Scatter Found in IC/Stream Quality Indicator Research

The first pattern to note is that the greatest scatter in stream quality indicator scores is frequently seen in the range of one to 10% IC. These streams, which are classified as "sensitive" according to the ICM, often exhibit low, moderate or high stream quality indicator scores, as shown in Figure 2. The key interpretation is that sensitive streams have the potential to attain high stream quality indicator scores, but may not always realize this potential.

Quite simply, the influence of IC in the one to 10% range is relatively weak compared to other potential watershed factors, such as percent forest cover, riparian continuity, historical land use, soils, agriculture, acid mine drainage or a host of other stressors. Consequently, watershed managers should never rely on IC alone to classify and manage streams in watersheds with less than 10% IC. Rather, they should evaluate a range of supplemental watershed variables to measure or predict actual stream quality within these lightly developed watersheds.

The second important pattern is that variability in stream quality indicator data is usually dampened when IC exceeds 10%, which presumably reflects the stronger influence of stormwater runoff on stream quality indicators. In particular, the chance that a stream quality indicator will attain a high quality score is sharply diminished at higher IC levels. This trend becomes pronounced within the 10 to 25% IC range and almost inevitable when watershed IC exceeds 25%. Once again, this pattern suggests that IC is a more robust and reliable indicator of overall stream quality beyond the 10% IC threshold.

Other Watershed Variables and the ICM

Several other watershed variables can potentially be included in the ICM. They include forest cover, riparian forest continuity and turf cover.

Forest cover (FC) is clearly the main rival to IC as a useful predictor of stream quality in urban watersheds, at least for humid regions of North America. In some regions, FC is simply the reciprocal of IC. For example, Horner and May (1999) have demonstrated a strong interrelationship between IC and FC for subwatersheds in the Puget Sound region (Figure 3). In other regions, however, "pre-

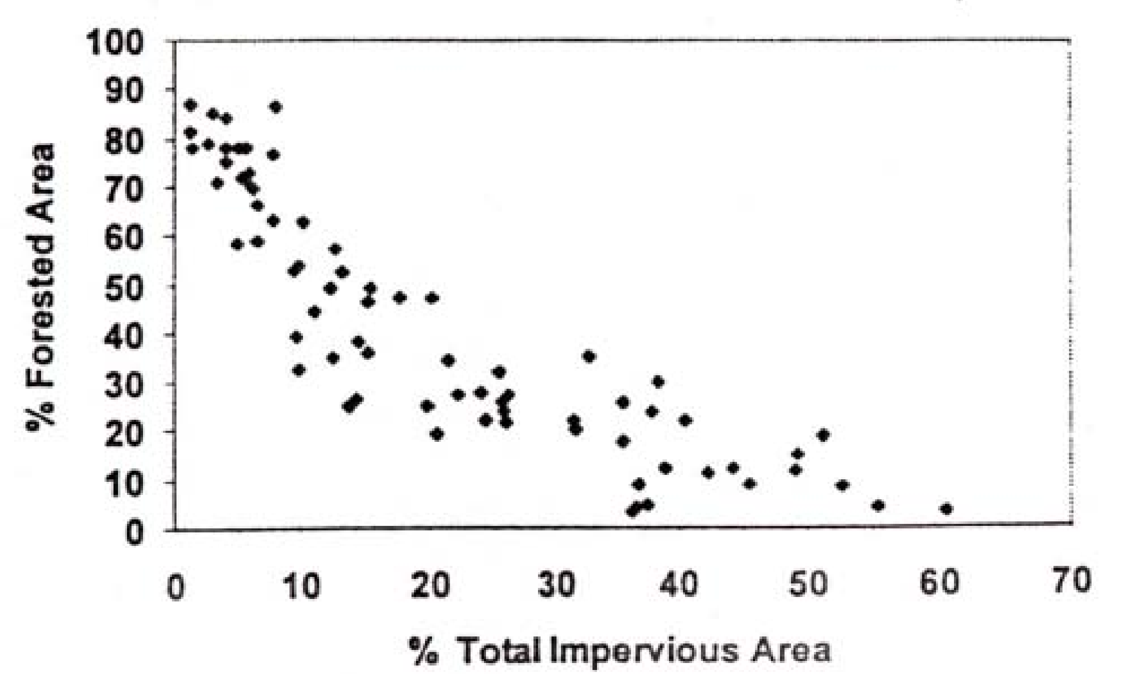


Figure 3: Relationship of IC and FC in Puget Sound Subwatersheds (Horner and May, 1999)

development" land use represents a complex mosaic of crop land, pasture and forest. Therefore, an inverse relationship between FC and IC may not be universal for subwatersheds that have witnessed many cycles of deforestation and cultivation.

It should come as little surprise that the progressive loss of FC has been linked to declining stream quality indicators, given that forested watersheds are often routinely used to define natural reference conditions for streams (Booth, 2000 and Horner *et al.*, 2001). Mature forest is considered to be the main benchmark for defining pre-development hydrology within a subwatershed, as well. Consequently, FC is perhaps the most powerful indicator to predict the quality of streams within the "sensitive" category (zero to 10% IC).

To use an extreme example, one would expect that stream quality indicators would respond quite differently in a subwatershed that had 90% FC compared to one that had 90% crop cover. Indeed, Booth (1991) suggests that stream quality can only be maintained when IC is limited to less than 10% <u>and</u> at least 65% FC is retained within a subwatershed. The key management implication then is that stream health is best managed by simultaneously minimizing the creation of IC and maximizing the preservation of native FC.

FC has also been shown to be useful in predicting the quality of terrestrial variables in a subwatershed. For example, the Mid-Atlantic Integrated Assessment (USEPA, 2000) has documented that watershed FC can reliably predict the diversity of bird, reptile and amphibian communities in the mid-Atlantic region. Moreover, the emerging discipline of landscape ecology provides watershed managers with a strong scientific foundation for deciding where FC should be conserved in a watershed. Conservation plans that protect and connect large forest fragments have been shown to be effective in conserving terrestrial species.

Riparian forest continuity has also shown considerable promise in predicting at least some indicators of stream quality for urban watersheds. Researchers have yet to come up with a standard definition of riparian continuity, but it is usually defined as the proportion of the perennial stream network in a subwatershed that has a fixed width of mature streamside forest. A series of studies indicates that aquatic insect and fish diversity are associated with high levels of riparian continuity (Horner *et al.,* 2001; May *et al.*, 1997; MNCPPC, 2000; Roth *et al.,* 1998). On the other hand, not much evidence has been presented to support the notion that riparian continuity has a strong influence on hydrology or water quality indicators.

One watershed variable that received little attention is the fraction of watershed area maintained in turf cover (TC). Grass often comprises the largest fraction of land area within low-density residential development and could play a significant role in streams that fall within the "impacted" category (10 to 25% IC). Although lawns are pervious, they have sharply different properties than the forests and farmlands they replace (i.e., irrigation, compacted soils, greater runoff, and much higher input of fertilizers and pesticides, etc.). It is interesting to speculate whether the combined area of IC and TC might provide better predictions about stream health than IC area alone, particularly within impacted subwatersheds.

Several other watershed variables might have at least supplemental value in predicting stream quality. They include the presence of extensive wetlands and/or beaverdam complexes in a subwatershed; the dominant form of drainage present in the watershed (tile drains, ditches, swales, curb and gutters, storm drain pipes); the average age of development; and the proximity of sewer lines to the stream. As far as we could discover, none of these variables has been systematically tested in a controlled population of small watersheds. We have observed that these factors could be important in our field investigations and often measure them to provide greater insight into subwatershed behavior.

Lastly, several watershed variables that are closely related to IC have been proposed to predict stream quality. These include population, percent urban land, housing density, road density and other indices of watershed development. As might be expected, they generally track the same trend as IC, but each has some significant technical limitations and/or difficulties in actual planning applications (Brown, 2000).

Individual vs. Multiple Indicators
The ICM does not predict the precise score of individual stream quality indicators, but rather predicts the average behavior of a group of indicators over a range of IC. Extreme care should be exercised if the ICM is used to predict the fate of individual indicators and/or species. This is particularly true for sensitive aquatic species, such as trout, salmon, and freshwater mussels. When researchers have examined the relationship between IC and individual species, they have often discovered lower thresholds for harm. For example, Boward *et al.* (1999) found that brook trout were not found in subwatersheds that had more than 4% IC in Maryland, whereas Horner and May (1999) asserted an 8% threshold for sustaining salmon in Puget Sound streams.

The key point is that if watershed managers want to maintain an individual species, they should be very cautious about adopting the 10% IC threshold. The essential habitat requirements for many sensitive or endangered species are probably determined by the *most sensitive* stream quality indicators, rather than the *average behavior* of all stream quality indicators.

Direct Causality vs. Association
A strong relationship between IC and declining stream quality indicators does not always mean that the IC is directly responsible for the decline. In some cases, however, causality can be demonstrated. For example, increased stormwater runoff volumes are directly caused by the percentage of IC in a subwatershed, although other factors such as conveyance, slope and soils may play a role.

In other cases, the link is much more indirect. For these indicators, IC is merely an index of the cumulative amount of watershed development, and more IC simply means that a greater number of known or unknown pollutant sources or stressors are present. In yet other cases, a causal link appears likely but has not yet been scientifically demonstrated. A good example is the more than 50 studies that have explored how fish or aquatic insect diversity changes in response to IC. While the majority of these studies consistently shows a very strong negative association between IC and biodiversity, they do not really establish which stressor or combination of stressors contributes most to the decline. The widely accepted theory is that IC changes stream hydrology, which degrades stream habitat, and in turn leads to reduced stream biodiversity.

Regional Differences
Currently, the ICM has been largely confirmed within the following regions of North America: the mid-Atlantic, the Northeast, the Southeast, the upper Midwest and the Pacific Northwest. Limited testing in Northern California, the lower Midwest and Central Texas generally agrees with the ICM. The ICM has not been tested in Florida, the Rocky Mountain West, and the Southwest. For a number of reasons, it is not certain if the ICM accurately predicts biological indicators in arid and semiarid climates (Maxted, 1999).

Measuring Impervious Cover
Most researchers have relied on total impervious cover as the basic unit to measure IC at the subwatershed level. The case has repeatedly been made that effective impervious cover is probably a superior metric (e.g., only counting IC that is hydraulically connected to the drainage system). Notwithstanding, most researchers have continued to measure total IC because it is generally quicker and does not require extensive (and often subjective) engineering judgement as to whether it is connected or not. Researchers have used a wide variety of techniques to estimate subwatershed IC, including satellite imagery, analysis of aerial photographs, and derivation from GIS land use layers. Table 2 presents some standard land use/IC relationships that were developed for suburban regions of the Chesapeake Bay.

Table 2: Land Use/IC Relationships for Suburban Areas of the Chesapeake Bay (Cappiella and Brown, 2001)					
Land Use Category	**Sample Number (N)**	**Mean IC (SE)**	**Land Use Category**	**Sample Number (N)**	**Mean IC (SE)**
Agriculture	8	**1.9** – 0.3	Institutional	30	**34.4** – 3.45
Open Urban Land	11	**8.6** – 1.64	Light	20	**53.4** – 2.8
2 Acre Lot Residential	12	**10.6** – 0.65	Commercia	23	**72.2** – 2.0
1 Acre Lot Residential	23	**14.3** – 0.53	Churches	8	**39.9** – 7.8 1
1/2 Acre Lot Residential	20	**21.2** – 0.78	Schools	13	**30.3** – 4.8
1/4 Acre Lot Residential	23	**27.8** – 0.60	Municipals	9	**35.4** – 6.3
1/8 Acre Lot Residential	10	**32.6** – 1.6	Golf	4	**5.0** – 1.7
Townhome Residential	20	**40.9** – 1.39	Cemeteries	3	**8.3** – 3.5
Multifamily Residential	18	**44.4** – 2.0	Parks	4	**12.5** – 0.7

Three points are worth noting. First, it is fair to say that most researchers have spent more quality control effort on their stream quality indicator measurements than on their subwatershed IC estimates. At the current time, no standard protocol exists to estimate subwatershed IC, although Cappiella and Brown (2001) presented a useful method. At best, the different methods used to measure IC make it difficult to compare results from different studies, and at worst, it can introduce an error term of perhaps +/- 10% from the true value within an individual subwatershed. Second, it is important to keep in mind that IC is not constant over time; indeed, major changes in subwatershed IC have been observed within as few as two years. Consequently, it is sound practice to obtain subwatershed IC estimates from the most recent possible mapping data, to ensure that it coincides with stream quality indicator measurements. Lastly, it is important to keep in mind that most suburban and even rural zoning categories exceed 10% IC (see Table 2). Therefore, from a management standpoint, planners should try to project future IC, in order to determine the future stream classification for individual subwatersheds.

1.1.3 Influence of Watershed Treatment Practices on the ICM

The most hotly debated question about the ICM is whether widespread application of watershed practices such as stream buffers or stormwater management can mitigate the impact of IC, thereby allowing greater development density for a given watershed. At this point in time, there are fewer than 10 studies that directly bear on this critical question. Before these are reviewed, it is instructive to look at the difficult technical and scientific issues involved in detecting the effect of watershed treatment, given its enormous implications for land use control and watershed management.

The first tough issue is how to detect the effect of watershed treatment, given the inherent scatter seen in the IC/stream quality indicator relationship. Figure 4 illustrates the "double scatter" problem, based on three different urban stream research studies in Delaware, Maryland and Washington. A quick inspection of the three plots shows how intrinsically hard it is to distinguish the watershed treatment effect. As can be seen, stream quality indicators in subwatersheds with treatment tend to

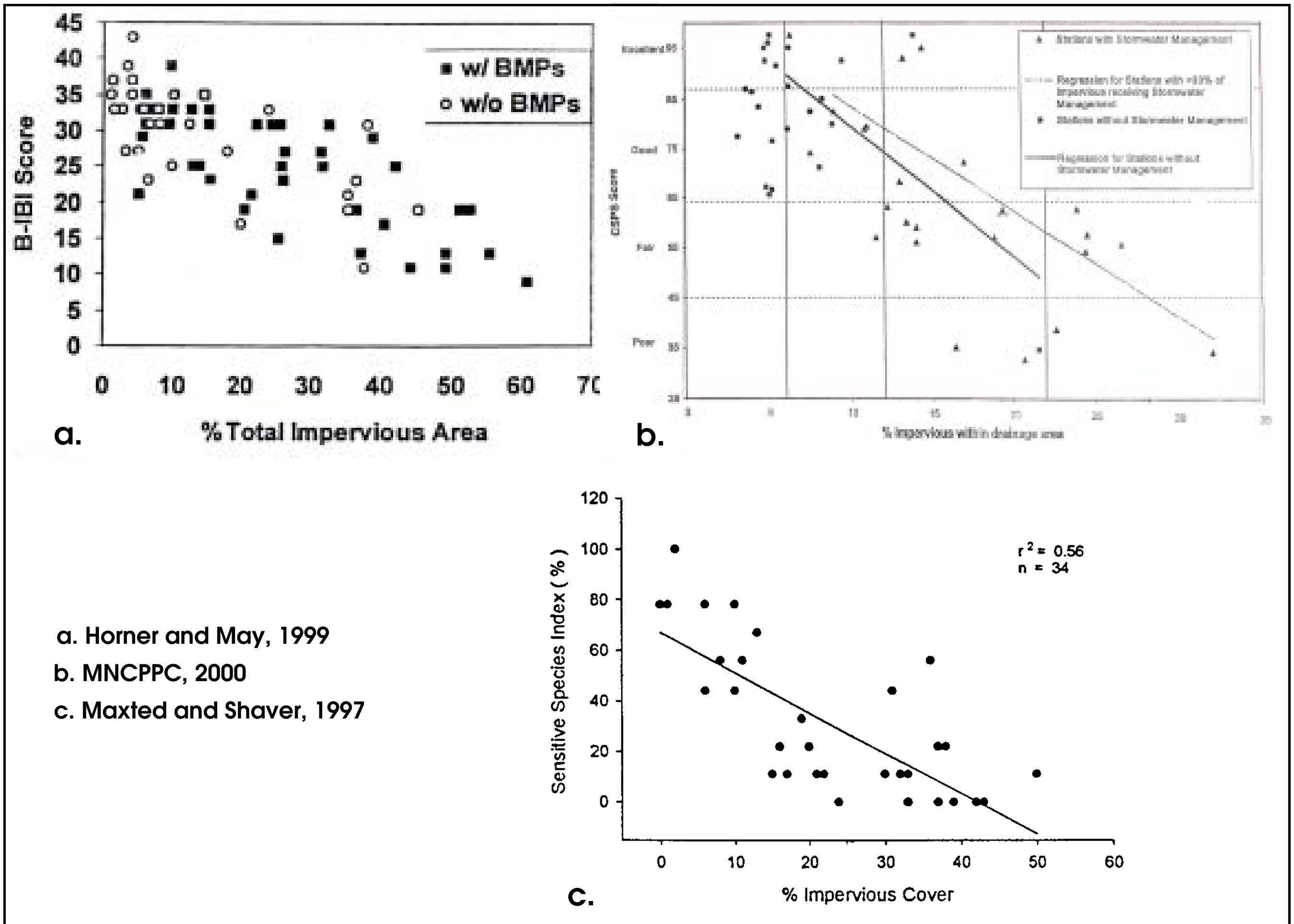


Figure 4: The Double Scatter Problem: Difficulties in Detecting the Effect of Watershed Treatment

overplot those in subwatersheds that lack treatment. While subtle statistical differences may be detected, they are not visibly evident. This suggests that the impact of watershed treatment would need to be extremely dramatic to be detected, given the inherent statistical variability seen in small watersheds (particularly so within the five to 25% IC range where scatter is considerable).

In an ideal world, a watershed study design would look at a controlled population of small urban watersheds that were developed with and without watershed practices to detect the impact of "treatment." In the real world, however, it is impossible to strictly control subwatershed variables. Quite simply, no two subwatersheds are ever alike. Each differs slightly with respect to drainage area, IC, forest cover, riparian continuity, historical land use, and percent watershed treatment. Researchers must also confront other real world issues when designing their watershed treatment experiments.

For example, researchers must carefully choose which indicator or group of indicators will be used to define stream health. IC has a negative influence on 26 stream quality indicators, yet nearly all of the watershed treatment research so far has focused on just a few biological indicators (e.g., aquatic insect or fish diversity) to define stream health. It is conceivable that watershed treatment might have no effect on biological indicators, yet have a positive influence on hydrology, habitat or water quality indicators. At this point, few of these indicators have been systematically tested in the field. It is extremely doubtful that any watershed practice can simultaneously improve or mitigate all 26 stream quality indicators, so researchers must carefully interpret the outcomes of their watershed treatment experiments.

The second issue involves how to quantify watershed treatment. In reality, watershed treatment collectively refers to dozens of practices that are installed at individual development sites in the many years or even decades it takes to fully "build out" a subwatershed. Several researchers have discovered that watershed practices are seldom installed consistently across an entire subwatershed. In some cases, less than a third of the IC in a subwatershed was actually treated by any practice, because development occurred prior to regulations; recent projects were exempted, waived or grandfathered; or practices were inadequately constructed or maintained (Horner and May, 1999 and MNCPPC, 2000).

Even when good coverage is achieved in a watershed, such as the 65 to 90% reported in studies of stormwater ponds (Jones *et al*., 1996; Maxted, 1999; Maxted and Shaver, 1997), it is still quite difficult to quantify the actual quality of treatment. Often, each subwatershed contains its own unique mix of stormwater practices installed over several decades, designed under diverse design criteria, and utilizing widely different stormwater technologies. Given these inconsistencies, researchers will need to develop standard protocols to define the extent and quality of watershed treatment.

Effect of Stormwater Ponds

With this in mind, the effect of stormwater ponds and stream buffers can be discussed. The effect of larger stormwater ponds in mitigating the impacts of IC in small watersheds has received the most scrutiny to date. This is not surprising, since larger ponds often control a large fraction of their contributing subwatershed area (e.g. 100 to 1,000 acres) and are located on the stream itself, therefore lending themselves to easier monitoring. Three studies have evaluated the impact of large stormwater ponds on downstream aquatic insect communities (Jones *et al.*, 1996; Maxted and Shaver, 1997; Stribling *et al.*, 2001). Each of these studies was conducted in small headwater subwatersheds in the mid-Atlantic Region, and none was able to detect major differences in aquatic insect diversity in streams with or without stormwater ponds.

Four additional studies statistically evaluated the stormwater treatment effect in larger populations of small watersheds with varying degrees of IC (Horner and May, 1999; Horner *et al.,* 2001; Maxted, 1999; MNCPPC, 2000). These studies generally sampled larger watersheds that had many stormwater practices but not necessarily complete watershed coverage. In general, these studies detected a small but positive effect of stormwater treatment relative to aquatic insect diversity. This positive effect was typically seen only in the range of five to 20% IC and was generally undetected beyond about 30% IC. Although each author was hesitant about interpreting his results, all generally agreed that perhaps as much as 5% IC could be added to a subwatershed while maintaining aquatic insect diversity, given effective stormwater treatment. Forest retention and stream buffers were found to be very important, as well. Horner *et al.* (2001) reported a somewhat stronger IC threshold for various species of salmon in Puget Sound streams.

Some might conclude from these initial findings that stormwater ponds have little or no value in maintaining biological diversity in small streams. However, such a conclusion may be premature for several reasons. First, the generation of stormwater ponds that was tested was not explicitly designed to protect stream habitat or to prevent downstream channel erosion, which would presumably promote aquatic diversity. Several states have recently changed their stormwater criteria to require extended detention for the express purpose of preventing downstream channel erosion, and these new criteria may exert a stronger influence on aquatic diversity. Instead, their basic design objective was to maximize pollutant removal, which they did reasonably well.

The second point to stress is that streams with larger stormwater ponds should be considered "regulated streams" (Ward and Stanford, 1979), which have a significantly altered aquatic insect community downstream of the ponds. For example, Galli (1988) has reported that on-stream wet stormwater ponds shift the trophic structure of the aquatic insect community. The insect community above the pond was dominated by shredders, while the insect community below the pond was dominated by scrapers, filterers and collectors. Of particular note, several pollution-sensitive species were eliminated below the pond. Galli reported that changes in stream temperatures, carbon supply and substrate fouling were responsible for the downstream shift in the aquatic insect community. Thus, while it is clear that large stormwater ponds can be expected to have a negative effect on aquatic insect diversity, they could still exert positive influence on other stream quality indicators.

Effect of Stream Buffers

A handful of studies have evaluated biological indicator scores for urban streams that have extensive forest buffers, compared to streams where they were mostly or completely absent (Horner and May, 1999; Horner *et al.,* 2001; May *et al.*, 1997; MNCPPC, 2000; Roth *et al.,* 1998; Steedman, 1988). Biological indicators included various indices of aquatic insect, fish and salmon diversity. Each study sampled a large population of small subwatersheds over a range of IC and derived a quantitative measure to express the continuity, width and forest cover of the riparian buffer network within each subwatershed. Riparian forests were hypothesized to have a positive influence on stream biodiversity, given the direct ways they contribute to stream habitat (e.g., shading, woody debris, leaf litter, bank stability, and organic carbon supply).

All five studies detected a small to moderate positive effect when forested stream buffers were present (frequently defined as at least two-thirds of the stream network with at least 100 feet of stream side forest). The greatest effect was reported by Horner and May (1999) and Horner *et al.* (2001) for salmon streams in the Puget Sound ecoregion. If excellent riparian habitats were preserved, they generally reported that fish diversity could be maintained up to 15% IC, and good aquatic insect diversity could be maintained with as much as 30% IC. Steedman (1988) reported a somewhat smaller effect for Ontario streams. MNCPPC (2000), May *et al.* (1997), and Roth *et al.* (1998) could not find a statistically significant relationship between riparian quality and urban stream quality indicators but did report that most outliers (defined as higher IC subwatersheds with unusually high biological indicator scores) were generally associated with extensive stream side forest.

1.1.4 Recommendations for Further ICM Research

At this point, we recommend three research directions to improve the utility of the ICM for watershed managers. The **first direction** is to expand basic research on the relationship between IC and stream quality indicators that have received little scrutiny. In particular, more work is needed to define the relationship between IC and hydrological and physical indicators such as the following:

- Physical loss or alteration of the stream network
- Stream habitat measures
- Riparian continuity
- Baseflow conditions during dry weather

In addition, more watershed research is needed in ecoregions and physiographic areas where the ICM has not yet been widely tested. Key areas include Florida, arid and semiarid climates, karst areas and mountainous regions. The basic multiple subwatershed monitoring protocol set forth by Schueler (1994a) can be used to investigate IC/stream quality relationships, although it would be wise to measure a wider suite of subwatershed variables beyond IC (e.g., forest cover, turf cover, and riparian continuity).

The **second** research direction is to more clearly define the impact of watershed treatment on stream quality indicators. Based on the insurmountable problems encountered in controlling variation at the subwatershed level, it may be necessary to abandon the multiple watershed or paired watershed sampling approaches that have been used to date. Instead, longitudinal monitoring studies within individual subwatersheds may be a more powerful tool to detect the effect of watershed treatment. These studies could track changes in stream quality indicators in individual subwatersheds over the entire development cycle: pre-development land use, clearing, construction, build out, and post construction. In most cases, longitudinal studies would take five to 10 years to complete, but they would allow watershed managers to measure and control the inherent variability at the subwatershed level and provide a "before and after" test of watershed treatment. Of course, a large population of test subwatersheds would be needed to satisfactorily answer the watershed treatment question.

The **third** research direction is to monitor more non-supporting streams, in order to provide a stronger technical foundation for crafting more realistic urban stream standards and to see how they respond to various watershed restoration treatments. As a general rule, most researchers have been more interested in the behavior of sensitive and impacted streams. The non-supporting stream category spans a wide range of IC, yet we do not really understand how stream quality indicators behave over the entire 25 to 100% IC range.

For example, it would be helpful to establish the IC level at the upper end of the range where streams are essentially transformed into an artificial conveyance system (i.e., become pipes or artificial channels). It would also be interesting to sample more streams near the lower end of the non-supporting category (25 to 35% IC) to detect whether stream quality indicators respond to past watershed treatment or current watershed restoration efforts. For practical reasons, the multiple subwatershed sampling approach is still recommended to characterize indicators in non-supporting streams. However, researchers will need to screen a large number of non-supporting subwatersheds in order to identify a few subwatersheds that are adequate for subsequent sampling (i.e., to control for area, IC, development age, percent watershed treatment, type of conveyance systems, etc.).

1.2 Impacts of Urbanization on Downstream Receiving Waters

In this section, we review the impacts of urbanization on downstream receiving waters, primarily from the standpoint of impacts caused by poor stormwater quality. We begin by looking at the relationship between IC and stormwater pollutant loadings. Next, we discuss the sensitivity of selected downstream receiving waters to stormwater pollutant loads. Lastly, we examine the effect of watershed treatment in reducing stormwater pollutant loads.

1.2.1 Relationship Between Impervious Cover and Stormwater Quality

Urban stormwater runoff contains a wide range of pollutants that can degrade downstream water quality (Table 3). Several generalizations can be supported by the majority of research conducted to date. First, the unit area pollutant load delivered by stormwater runoff to receiving waters increases in direct proportion to watershed IC. This is not altogether surprising, since pollutant load is the product of the average pollutant concentration and stormwater runoff volume. Given that runoff volume increases in direct proportion to IC, pollutant loads must automatically increase when IC increases, as long the average pollutant concentration stays the same (or increases). This relationship is a central assumption in most simple and complex pollutant loading models (Bicknell *et al.*, 1993; Donigian and Huber, 1991; Haith *et al.*, 1992; Novotny and Chester, 1981; NVPDC, 1987; Pitt and Voorhees, 1989).

The second generalization is that stormwater pollutant concentrations are generally similar

Table 3: Summary of Urban Stormwater Pollutant Loads on Quality of Receiving Waters

Pollutants in Urban Stormwater	WQ Impacts To:					Higher Unit Load?	Load a function of IC?	Other Factors Important in Loading
	R	L	E	A	W			
Suspended Sediment	Y	Y	Y	N	Y	Y (ag)	Y	channel erosion
Total Nitrogen	N	N	Y	Y	N	Y (ag)	Y	septic systems
Total Phosphorus	Y	Y	N	N	Y	Y (ag)	Y	tree canopy
Metals	Y	Y	Y	?	N	Y	Y	vehicles
Hydrocarbons	Y	Y	Y	Y	Y	Y	?	related to VMTs and hotspots
Bacteria/Pathogens	Y	Y	Y	N	Y	Y	Y	many sources
Organic Carbon	N	?	?	?	Y	Y	Y	
MTBE	N	N	N	Y	Y	Y	?	roadway, VMTs
Pesticides	?	?	?	?	Y	Y	?	turf/landscaping
Chloride	?	Y	N	Y	Y	Y	?	road density
Trash/Debris	Y	Y	Y	N	?	Y	Y	curb and gutters

Major Water Quality Impacts Reported for:
R = River, L = Lake, E = Estuary, A = Aquifer, W = Surface Water Supply
Higher Unit Area Load? Yes (compared to all land uses) (ag): with exception of cropland
Load a function of IC? Yes, increases proportionally with IC

at the catchment level, regardless of the mix of IC types monitored (e.g., residential, commercial, industrial or highway runoff). Several hundred studies have examined stormwater pollutant concentrations from small urban catchments and have generally found that the variation within a catchment is as great as the variation between catchments. Runoff concentrations tend to be log-normally distributed, and therefore the long term "average" concentration is best expressed by a median value. It should be kept in mind that researchers have discovered sharp differences in pollutant concentrations for smaller, individual components of IC (e.g., rooftops, parking lots, streets, driveways and the like). Since most urban catchments are composed of many kinds of IC, this mosaic quality tempers the variability in long term pollutant concentrations at the catchment or subwatershed scale.

The third generalization is that median concentrations of pollutants in urban runoff are usually higher than in stormwater runoff from most other non-urban land uses. Consequently, the unit area nonpoint pollutant load generated by urban land normally exceeds that of nearly all watershed land uses that it replaces (forest, pasture, cropland, open space — see Table 3). One important exception is cropland, which often produces high unit area sediment and nutrient loads in many regions of the country. In these watersheds, conversion of intensively managed crops to low density residential development may actually result in a slightly decreased sediment or nutrient load. On the other hand, more intensive land development (30% IC or more) will tend to equal or exceed cropland loadings.

The last generalization is that the effect of IC on stormwater pollutant loadings tends to be weakest for subwatersheds in the one to 10% IC range. Numerous studies have suggested that other watershed and regional factors may have a stronger influence, such as the underlying geology, the amount of carbonate rock in the watershed, physiographic region, local soil types, and most important, the relative fraction of forest and crop cover in the subwatershed (Herlihy *et al*., 1998 and Liu *et al.,* 2000). The limited influence of IC on pollutant loads is generally consistent with the finding for hydrologic, habitat and biological indicators over this narrow range of IC. Once again, watershed managers are advised to track other watershed indicators in the sensitive stream category, such as forest or crop cover.

1.2.2 Water Quality Response to Stormwater Pollution

As noted in the previous section, most ICM research has been done on streams, which are directly influenced by increased stormwater. Many managers have wondered whether the ICM also applies to downstream receiving waters, such as lakes, water supply reservoirs and small estuaries. In general, the exact water quality response of downstream receiving waters to increased nonpoint source pollutant loads depends on many factors, including the specific pollutant, the existing loading generated by the converted land use, and the geometry and hydraulics of the receiving water. Table 3 indicates the sensitivity of rivers, lakes, estuaries, aquifers and water supply reservoirs to various stormwater pollutants.

Lakes and the ICM

The water column and sediments of urban lakes are impacted by many stormwater pollutants, including sediment, nutrients, bacteria, metals, hydrocarbons, chlorides, and trash/debris. Of these pollutants, limnologists have always regarded phosphorus as the primary lake management concern, given that more than 80% of urban lakes experience symptoms of eutrophication (CWP, 2001a).

In general, phosphorus export steadily increases as IC is added to a lake watershed, although the precise amount of IC that triggers eutrophication problems is unique to each urban lake. With a little effort, it is possible to calculate the specific IC threshold for an individual lake, given its internal geometry, the size of its contributing watershed, current in-lake phosphorus concentration, degree of watershed treatment, and the desired water quality goals for the lake (CWP, 2001a). As a general rule, most lakes are extremely sensitive to increases in phosphorus loads caused by watershed IC. Exceptions include lakes that are unusually deep and/or have very small drainage area/lake area ratios. In most lakes, however, even a small amount of watershed development will result in an upward shift in trophic status (CWP, 2001a).

Reservoirs and the ICM

While surface water supply reservoirs respond to stormwater pollutant loads in the same general manner as lakes, they are subject to stricter standards because of their uses for drinking water. In particular, water supply reservoirs are particularly sensitive to increased turbidity, pathogens, total organic carbon, chlorides, metals, pesticides and hydrocarbon loads, in addition to phosphorus (Kitchell, 2001). While some pollutants can be removed or reduced through expanded filtering and treatment at drinking water intakes, the most reliable approach is to protect the source waters through watershed protection and treatment.

Consequently, we often recommend that the ICM be used as a "threat index" for most drinking water supplies. Quite simply, if current or future development is expected to exceed 10% IC in the contributing watershed, we recommend that a very aggressive watershed protection strategy be implemented (Kitchell, 2001). In addition, we contend that drinking water quality cannot be sustained once watershed IC exceeds 25% and have yet to find an actual watershed where a drinking water utility has been maintained under these conditions.

Small Tidal Estuaries and Coves and the ICM

The aquatic resources of small tidal estuaries, creeks, and coves are often highly impacted by watershed development and associated activities, such as boating/marinas, wastewater discharge, septic systems, alterations in freshwater flow and wetland degradation and loss. Given the unique impacts of eutrophication on the marine system and stringent water quality standards for shellfish harvesting, the stormwater pollutants of greatest concern in the estuarine water column are nitrogen and fecal coliform bacteria. Metals and hydrocarbons in stormwater runoff can also contaminate bottom sediments, which can prove toxic to local biota (Fortner *et al*., 1996; Fulton *et al.*, 1996; Kucklick *et al.*, 1997; Lerberg *et al.*, 2000; Sanger *et al.,* 1999; Vernberg *et al.*, 1992).

While numerous studies have demonstrated that physical, hydrologic, water quality and biological indicators differ in urban and non-urban coastal watersheds, only a handful of studies have used watershed IC as an indicator of estuarine health. These studies show significant correlations with IC, although degradation thresholds may not necessarily adhere to the ICM due to tidal dilution and dispersion. Given the limited research, it is not fully clear if the ICM can be applied to coastal systems without modification.

Atmospheric deposition is considered a primary source of nitrogen loading to estuarine watersheds. Consequently, nitrogen loads in urban stormwater are often directly linked to IC. Total nitrogen loads have also been linked to groundwater input, especially from subsurface discharges from septic systems, which are common in low density coastal development (Swann, 2001; Valiela *et al.*, 1997; Vernberg *et al.*, 1996a). Nitrogen is generally considered to be the limiting nutrient in estuarine systems, and increased loading has been shown to increase algal and phytoplankton biomass and cause shifts in the phytoplankton community and food web structure that may increase the potential for phytoplankton blooms and fish kills (Bowen and Valiela, 2001; Evgenidou *et al.*, 1997; Livingston, 1996).

Increased nitrogen loads have been linked to declining seagrass communities, finfish populations, zooplankton reproduction, invertebrate species richness, and shellfish populations (Bowen and Valiela, 2001; Rutkowski *et al.*, 1999; Short and Wyllie-Echeverria, 1996; Valiela and Costa, 1988). Multiple studies have shown significant increases in nitrogen loading as watershed land use becomes more urban (Valiela *et al.,* 1997; Vernberg *et al.* 1996a; Wahl *et al.,* 1997). While a few studies link nitrogen loads with building and population density, no study was found that used IC as an indicator of estuarine nitrogen loading.

The second key water quality concern in small estuaries is high fecal coliform levels in stormwater runoff, which can lead to the closure of shellfish beds and swimming beaches. Waterfowl and other wildlife have also been shown to contribute to fecal coliform loading (Wieskel *et al.*, 1996). Recent research has shown that fecal coliform standards are routinely violated during storm events at very low levels of IC in coastal watersheds (Mallin *et al.,* 2001; Vernberg *et al.*, 1996b; Schueler, 1999). Maiolo and Tschetter (1981) found a significant correlation between human population and closed shellfish acreage in North Carolina, and Duda and Cromartie (1982) found greater fecal coliform densities when septic tank density and IC increased, with an approximate threshold at 10% watershed IC.

Recently, Mallin *et al.* (2000) studied five small North Carolina estuaries of different land uses and showed that fecal coliform levels were significantly correlated with watershed population, developed land and IC. Percent IC was the most statistically significant indicator and could explain 95% of the variability in fecal coliform concentrations. They also found that shellfish bed closures were possible in watersheds with less than 10% IC, common in watersheds above 10% IC, and almost certain in watersheds above 20% IC. While higher fecal coliform levels were observed in developed watersheds, salinity, flushing and proximity to pollution sources often resulted in higher concentrations at upstream locations and at high tides (Mallin *et al.*, 1999). While these studies support the ICM, more research is needed to prove the reliability of the ICM in predicting shellfish bed closures based on IC.

Several studies have also investigated the impacts of urbanization on estuarine fish, macrobenthos and shellfish communities. Increased PAH accumulation in oysters, negative effects of growth in juvenile sheepshead minnows, reduced molting efficiency in copepods, and reduced numbers of grass shrimp have all been reported for urban estuaries as compared to forested estuaries (Fulton *et al.,* 1996). Holland *et al. (*1997) reported that the greatest abundance of penaid shrimp and mummichogs was observed in tidal creeks with forested watersheds compared to those with urban cover. Porter *et al.* (1997) found lower grass shrimp abundance in small tidal creeks adjacent to commercial and urban development, as compared to non-urban watersheds.

Lerberg *et al.* (2000) studied small tidal creeks and found that highly urban watersheds (50% IC) had the lowest benthic diversity and abundance as compared to suburban and forested creeks, and benthic communities were numerically dominated by tolerant oligochaetes and polychaetes. Suburban watersheds (15 to 35% IC) also showed signs of degradation and had some pollution tolerant macrobenthos, though not as markedly as urban creeks. Percent abundance of pollution-indicative species showed a marked decline at 30% IC, and the abundance of pollution-sensitive species also significantly correlated with IC (Lerberg *et al*., 2000). Holland *et al*. (1997) reported that the variety and food availability for juvenile fish species was impacted at 15 to 20% IC.

Lastly, a limited amount of research has focused on the direct impact of stormwater runoff on salinity and hypoxia in small tidal creeks. Blood and Smith (1996) compared urban and forested watersheds and found higher salinities in urban watersheds due to the increased number of impoundments. Fluctuations in salinity have been shown to affect shellfish and other aquatic populations (see Vernberg, 1996b). When urban and forested watersheds were compared, Lerberg *et al.* (2000) reported that higher salinity fluctuations occurred most often in developed watersheds; significant correlations with salinity range and IC were also determined. Lerberg *et al.* (2000) also found that the most severe and frequent hypoxia occurred in impacted salt marsh creeks and that dissolved oxygen dynamics in tidal creeks were comparable to dead-end canals common in residential marina-style coastal developments. Suburban watersheds (15 to 35% IC) exhibited signs of degradation and had some pollution-tolerant macrobenthic species, though not to the extent of urban watersheds (50% IC).

In summary, recent research suggests that indicators of coastal watershed health are linked to IC. However, more research is needed to clarify the relationship between IC and estuarine indicators in small tidal estuaries and high salinity creeks.

1.2.3 Effect of Watershed Treatment on Stormwater Quality

Over the past two decades, many communities have invested in watershed protection practices, such as stormwater treatment practices (STPs), stream buffers, and better site design, in order to reduce pollutant loads to receiving waters. In this section, we review the effect of watershed treatment on the quality of stormwater runoff.

Effect of Stormwater Treatment Practices

We cannot directly answer the question as to whether or not stormwater treatment practices can significantly reduce water quality impacts at the watershed level, simply because no controlled monitoring studies have yet been conducted at this scale. Instead, we must rely on more indirect research that has tracked the change in mass or concentration of pollutants as they travel through individual stormwater treatment practices. Thankfully, we have an abundance of these performance studies, with nearly 140 monitoring studies evaluating a diverse range of STPs, including ponds, wetlands, filters, and swales (Winer, 2000).

These studies have generally shown that stormwater practices have at least a moderate ability to remove many pollutants in urban stormwater. Table 4 provides average removal efficiency rates for a range of practices and stormwater pollutants, and Table 5 profiles the mean storm outflow concentrations for various practices. As can be seen, some groups of practices perform better than others in removing certain stormwater pollutants. Consequently, managers need to carefully choose which practices to apply to solve the primary water quality problems within their watersheds.

It is also important to keep in mind that site-based removal rates cannot be extrapolated to the watershed level without significant adjustment. Individual site practices are never implemented perfectly or consistently across a watershed. At least three discount factors need to be considered: bypassed load, treatability and loss of performance over time. For a review on how these discounts are derived, consult Schueler and Caraco (2001). Even under the most optimistic watershed implementation scenarios, overall pollutant reduc-

Table 4: The Effectiveness of Stormwater Treatment Practices in Removing Pollutants - Percent Removal Rate (Winer, 2000)

Practice	N	TSS	TP	OP	TN	NOx	Cu	Zn	Oil/ Grease[1]	Bacteria
Dry Ponds	9	47	19	N/R	25	3.5	26	26	3	44
Wet Ponds	43	80	51	65	33	43	57	66	78	70
Wetlands	36	76	49	48	30	67	40	44	85	78
Filtering Practices[2]	18	86	59	57	38	-14	49	88	84	37
Water Quality Swales	9	81	34	1.0	84	31	51	71	62	-25
Ditches[3]	9	31	-16	N/R	-9.0	24	14	0	N/R	0
Infiltration	6	95	80	85	51	82	N/R	N/R	N/R	N/R

1: Represents data for Oil and Grease and PAH
2: Excludes vertical sand filters
3: Refers to open channel practices not designed for water quality
N/R = Not Reported

Table 5: Median Effluent Concentrations from Stormwater Treatment Practices (mg/l) (Winer, 2000)								
Practice	N	TSS	TP	OP	TN	NOx	Cu[1]	Zn[1]
Dry Ponds[2]	3	28	0.18	N/R	0.86	N/R	9.0	98
Wet Ponds	25	17	0.11	0.03	1.3	0.26	5.0	30
Wetlands	19	22	0.20	0.07	1.7	0.36	7.0	31
Filtering Practices[3]	8	11	0.10	0.07	1.1	0.55	9.7	21
Water Quality Swales	7	14	0.19	0.09	1.1	0.35	10	53
Ditches[4]	3	29	0.31	N/R	2.4	0.72	18	32

1. Units for Zn and Cu are micrograms per liter (Fg/l)
2. Data available for Dry Extended Detention Ponds only
3. Excludes vertical sand filters
4. Refers to open channel practices not designed for water quality
N/R = Not Reported

tions by STPs may need to be discounted by at least 30% to account for partial watershed treatment.

Even with discounting, however, it is evident that STPs can achieve enough pollutant reduction to mimic rural background loads for many pollutants, as long as the watershed IC does not exceed 30 to 35%. This capability is illustrated in Figure 5, which shows phosphorus load as a function of IC, with and without stormwater treatment.

Effect of Stream Buffers/Riparian Areas
Forested stream buffers are thought to have very limited capability to remove stormwater pollutants, although virtually no systematic monitoring data exists to test this hypothesis. The major reason cited for their limited removal capacity is that stormwater generated from upland IC has usually concentrated before it reaches the forest buffer and therefore crosses the buffer in a channel, ditch or storm drain pipe. Consequently, the opportunity to filter runoff is lost in many forest buffers in urban watersheds.

Effect of Better Site Design
Better site design (BSD) is a term for nonstructural practices that minimize IC, conserve natural areas and distribute stormwater treatment across individual development sites. BSD is also known by many other names, including conservation development, low-impact development, green infrastructure, and sustainable urban drainage systems. While

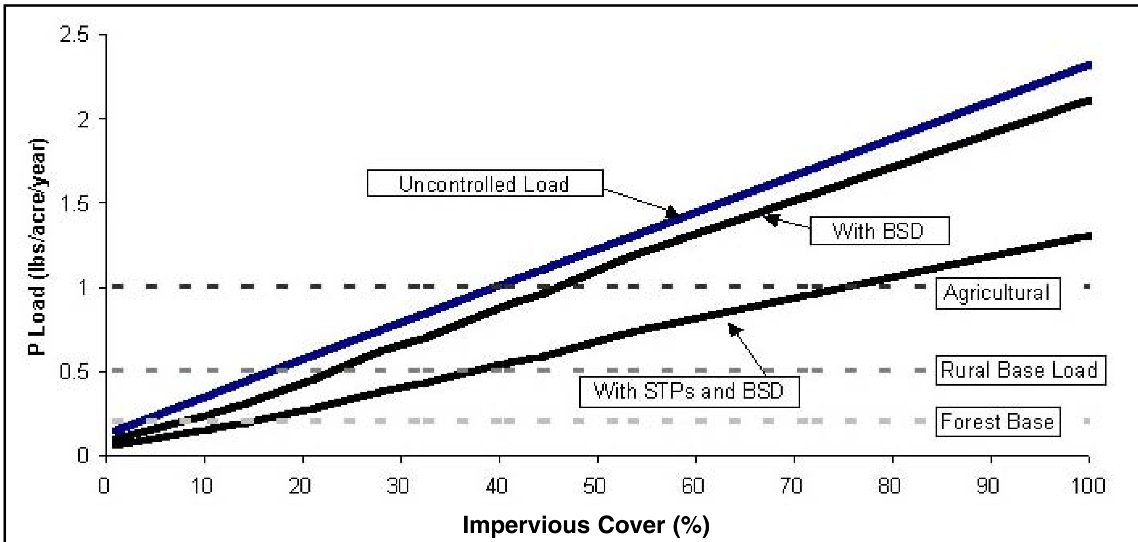


Figure 5: Estimated Phosphorus Load as a Function of Impervious Cover, Discounted Stormwater Treatment and Better Site Design (Schueler and Caraco, 2001)

some maintain that BSD is an alternative to traditional STPs, most consider it to be an important complement to reduce pollutant loads.

While BSD has become popular in recent years, only one controlled research study has evaluated its potential performance, and this is not yet complete (i.e. Jordan Cove, CT).

Indirect estimates of the potential value of BSD to reduce pollutant discharges have been inferred from modeling and redesign analyses (Zielinski, 2000). A typical example is provided in Figure 5, which shows the presumed impact of BSD in reducing phosphorus loadings. As is apparent, BSD appears to be a very effective strategy in the one to 25% IC range, but its benefits diminish beyond that point.

1.3 Implications of the ICM for Watershed Managers

One of the major policy implications of the ICM is that in the absence of watershed treatment, it predicts negative stream impacts at an extremely low intensity of watershed development. To put this in perspective, consider that a watershed zoned for two-acre lot residential development will generally exceed 10% IC, and therefore shift from a sensitive to an impacted stream classification (Cappiella and Brown, 2001). Thus, if a community wants to protect an important water resource or a highly regarded species (such as trout, salmon or an endangered freshwater mussel), the ICM suggests that there is a maximum limit to growth that is not only quite low, but is usually well below the current zoning for many suburban or even rural watersheds. Consequently, the ICM suggests the unpleasant prospect that massive down-zoning, with all of the associated political and legal carnage involving property rights and economic development, may be required to maintain stream quality.

It is not surprising, then, that the ICM debate has quickly shifted to the issue of whether or not watershed treatment practices can provide adequate mitigation for IC. How much relief can be expected from stream buffers, stormwater ponds, and other watershed practices, which might allow greater development density within a given watershed? Only a limited amount of research has addressed this question, and the early results are not reassuring (reviewed in section 1.1.3). At this early stage, researchers are still having trouble detecting the impact of watershed treatment, much less defining it. As noted earlier, both watershed research techniques and practice implementation need to be greatly improved if we ever expect to get a scientifically defensible answer to this crucial question. Until then, managers should be extremely cautious in setting high expectations for how much watershed treatment can mitigate IC.

1.3.1 Management of Non-Supporting Streams

Most researchers acknowledge that streams with more than 25% IC in their watersheds cannot support their designated uses or attain water quality standards and are severely degraded from a physical and biological standpoint. As a consequence, many of these streams are listed for non-attainment under the Clean Water Act and are subject to Total Maximum Daily Load (TMDL) regulations. Communities that have streams within this regulatory class must prepare implementation plans that demonstrate that water quality standards can ultimately be met.

While some communities have started to restore or rehabilitate these streams in recent years, their efforts have yielded only modest improvements in water quality and biological indicators. In particular, no community has yet demonstrated that they can achieve water quality standards in an urban watershed that exceeds 25% IC. Many communities are deeply concerned that non-supporting streams may never achieve water quality standards, despite massive investments in watershed restoration. The ICM suggests that water quality standards may need to be sharply revised for streams with more than 25% IC, if they are ever to come into attainment. While states have authority to create more achievable standards for non-supporting streams within the regulatory framework of the Clean Water Act (Swietlik, 2001), no state has yet exercised this authority. At this time, we are not aware of any water quality standards that are based on the ICM or similar urban stream classification techniques.

Two political perceptions largely explain why states are so reticent about revising water quality standards. The first is a concern that they will run afoul of anti-degradation provisions within the Clean Water Act or be accused of “backsliding” by the environmental community. The second concern relates to the demographics of watershed organizations across the country. According to recent surveys, slightly more than half of all watershed organizations represent moderately to highly developed watersheds (CWP, 2001a). These urban watershed organizations often have a keen interest in keeping the existing regulatory structure intact, since it is perceived to be the only lever to motivate municipalities to implement restoration efforts in non-supporting streams.

However, revised water quality standards are urgently needed to support smart growth efforts. A key premise of smart growth is that it is more desirable to locate new development within a non-supporting subwatershed rather than a sensitive or impacted one (i.e., concentrating density and IC within an existing subwatershed helps prevent sprawl from encroaching on a less developed one). Yet while smart growth is desirable on a regional basis, it will usually contribute to already serious problems in non-supporting watersheds, which makes it even more difficult to meet water quality standards.

This creates a tough choice for regulators: if they adopt stringent development criteria for non-supporting watersheds, their added costs can quickly become a powerful barrier to desired redevelopment. If, on the other hand, they relax or waive environmental criteria, they contribute to the further degradation of the watershed. To address this problem, the Center has developed a "smart watersheds" program to ensure that any localized degradation caused by development within a non-supporting subwatershed is more than compensated for by improvements in stream quality achieved through municipal restoration efforts (CWP, in press). Specifically, the smart watersheds program includes 17 public sector programs to treat stormwater runoff, restore urban stream corridors and reduce pollution discharges in highly urban watersheds. It is hoped that communities that adopt and implement smart watershed programs will be given greater flexibility to meet state and federal water quality regulations and standards within non-supporting watersheds.

1.3.2 Use of the ICM for Urban Stream Classification

The ICM has proven to be a useful tool for classifying and managing the large inventory of streams that most communities possess. It is not unusual for a typical county to have several thousand miles of headwater streams within its political boundaries, and the ICM provides a unified framework to identify and manage these subwatersheds. In our watershed practice, we use the ICM to make an initial diagnosis rather than a final determination for stream classification. Where possible, we conduct rapid stream and subwatershed assessments as a final check for an individual stream classification, particularly if it borders between the sensitive and impacted category. As noted earlier, the statistical variation in the IC/stream quality indicator makes it difficult to distinguish between a stream with 9% versus 11% IC. Some of the key criteria we use to make a final stream classification are provided in Table 6.

1.3.3 Role of the ICM in Small Watershed Planning

The ICM has also proven to be an extremely important tool for watershed planning, since it can rapidly project how streams will change in response to future land use. We routinely estimate existing and future IC in our watershed planning practice and find that it is an excellent indicator of change for subwatersheds in the zero to 30% IC range. In particular, the ICM often forces watershed planners to directly confront land use planning and land conservation issues early in the planning process.

On the other hand, we often find that the ICM has limited planning value when subwatersheds exceed 30% IC for two practical reasons. First, the ICM does not differentiate stream conditions within this very large span of IC (i.e., there is no difference in the stream quality prediction for a subwatershed that has 39.6% IC versus one that has 58.4% IC). Second, the key management question for non-supporting watersheds is whether or not they are potentially restorable. More detailed analysis and field investigations are needed to determine, in each subwatershed, the answer to this question. While a knowledge of IC is often used in these feasibility assessments, it is but one of many factors that needs to be considered.

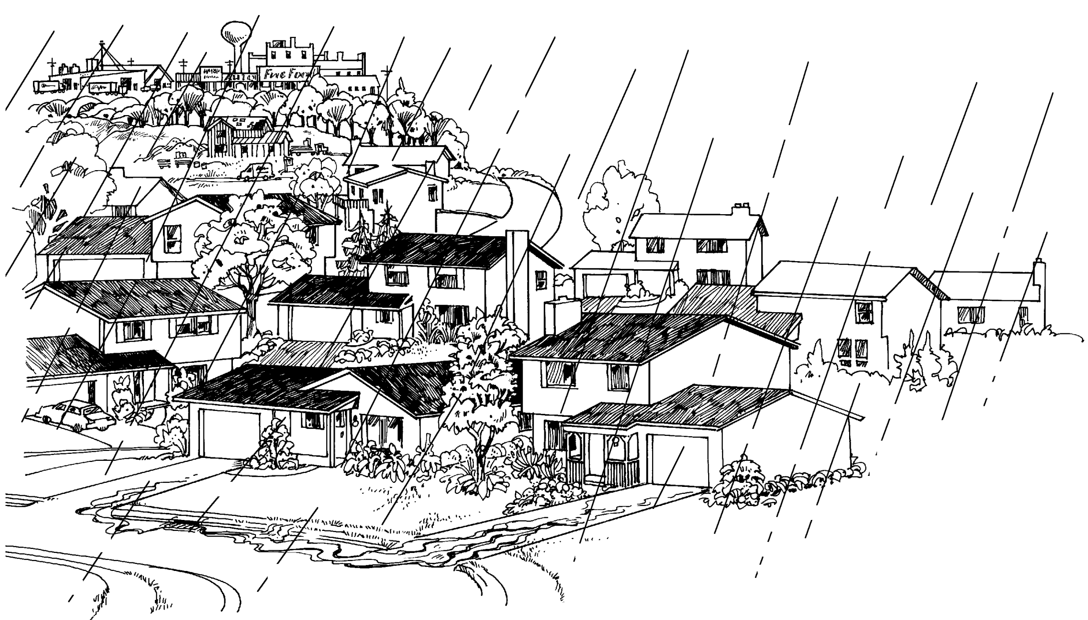
Lastly, we have come to recognize several practical factors when applying the ICM for small watershed planning. These include thoughtful delineation of subwatershed boundaries, the proper accounting of a direct drainage area in larger watersheds, and the critical need for the most recent IC data. More guidance on these factors can be found in Zielinski (2001).

Impervious cover is not a perfect indicator of existing stream quality. A number of stream and subwatershed criteria should be evaluated in the field before a final classification decision is made, particularly when the stream is on the borderline between two classifications. We routinely look at the stream and subwatershed criteria to decide whether a borderline stream should be classified as sensitive or impacted. Table 6 reviews these additional criteria.

Table 6: Additional Considerations for Urban Stream Classification
Stream Criteria
Reported presence of rare, threatened or endangered species in the aquatic community (e.g., freshwater mussels, fish, crayfish or amphibians) Confirmed spawning of cold-water fish species (e.g., trout) Fair/good, good, or good to excellent macro invertebrate scores More than 65% of EPT species present in macro-invertebrate surveys No barriers impede movement of fish between the subwatershed and downstream receiving waters Stream channels show little evidence of ditching, enclosure, tile drainage or channelization Water quality monitoring indicates no standards violations during dry weather Stream and flood plain remain connected and regularly interact Stream drains to a downstream surface water supply Stream channels are generally stable, as determined by the Rosgen level analysis Stream habitat scores are rated at least fair to good
Subwatershed Criteria
Contains terrestrial species that are documented as rare, threatened and endangered Wetlands, flood plains and/or beaver complexes make up more than 10% of subwatershed area Inventoried conservation areas comprise more than 10% of subwatershed area More than 50% of the riparian forest corridor has forest cover and is either publicly owned or regulated Large contiguous forest tracts remain in the subwatershed (more than 40% in forest cover) Significant fraction of subwatershed is in public ownership and management Subwatershed connected to the watershed through a wide corridor Farming, ranching and livestock operations in the subwatershed utilize best management practices Prior development in the subwatershed has utilized stormwater treatment practices

1.4 Summary

The remainder of this report presents greater detail on the individual research studies that bear on the ICM. Chapter 2 profiles research on hydrologic indicators in urban streams, while Chapter 3 summarizes the status of current research on the impact of urbanization on physical habitat indicators. Chapter 4 presents a comprehensive review of the impact of urbanization on ten major stormwater pollutants. Finally, Chapter 5 reviews the growing body of research on the link between IC and biological indicators within urban streams and wetlands.



Chapter 2: Hydrologic Impacts of Impervious Cover

The natural hydrology of streams is fundamentally changed by increased watershed development. This chapter reviews the impacts of watershed development on selected indicators of stream hydrology.

This chapter is organized as follows:

2.1 Introduction

Fundamental changes in urban stream hydrology occur as a result of three changes in the urban landscape that accompany land development. First, large areas of the watershed are paved, rendering them impervious. Second, soils are compacted during construction, which significantly reduces their infiltration capabilities. Lastly, urban stormwater drainage systems are installed that increase the efficiency with which runoff is delivered to the stream (i.e., curbs and gutters, and storm drain pipes). Consequently, a greater fraction of annual rainfall is converted to surface runoff, runoff occurs more quickly, and peak flows become larger. Additionally, dry weather flow in streams may actually decrease because less groundwater recharge is available. Figure 6 illustrates the change in hydrology due to increased urban runoff as compared to pre-development conditions.

Research has demonstrated that the effect of watershed urbanization on peak discharge is more marked for smaller storm events. In particular, the bankfull, or channel forming flow, is increased in magnitude, frequency and duration. Increased bankfull flows have strong ramifications for sediment transport and channel enlargement. All of these changes in the natural water balance have impacts on the physical structure of streams, and ultimately affect water quality and biological diversity.

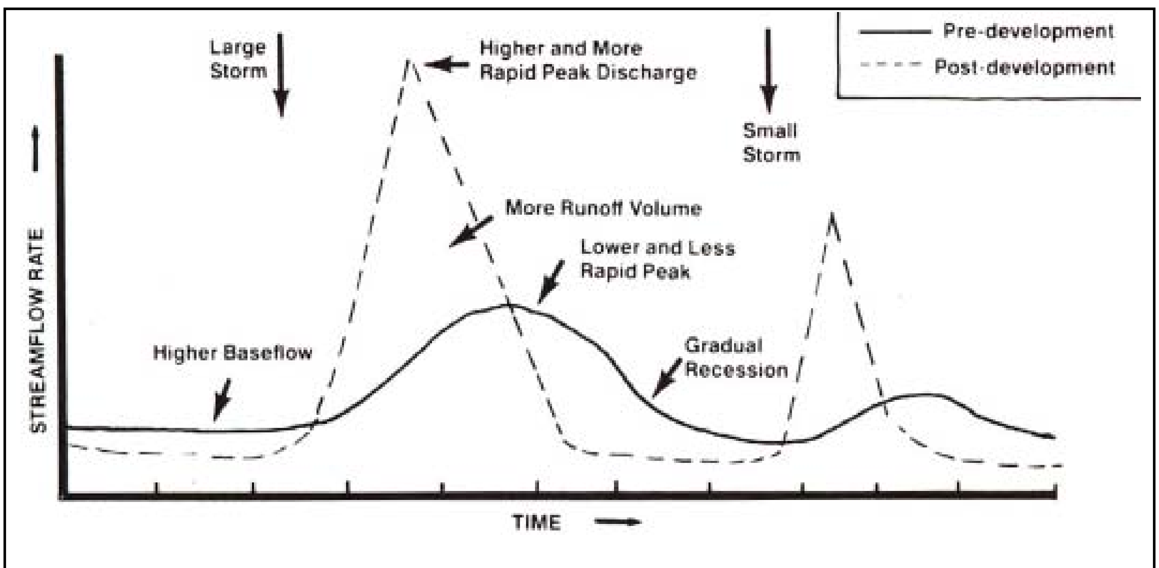


Figure 6: Altered Hydrograph in Response to Urbanization (Schueler, 1987)

The relationship between watershed IC and stream hydrology is widely accepted, and has been incorporated into many hydrologic engineering models over the past three decades. Several articles provide a good summary of these (Bicknell *et al.*, 1993; Hirsch *et al.*, 1990; HEC, 1977; Huber and Dickinson, 1988; McCuen and Moglen, 1988; Overton and Meadows, 1976; Pitt and Voorhees, 1989; Schueler, 1987; USDA, 1992; 1986).

The primary impacts of watershed development on stream hydrology are as follows:

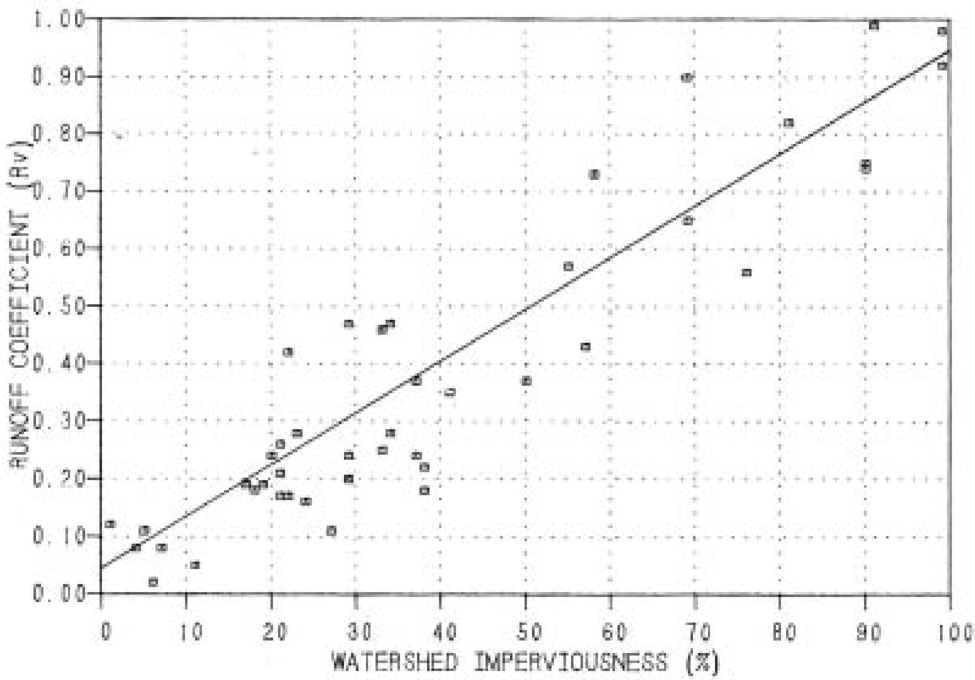
- Increased runoff volume
- Increased peak discharge rates
- Increased magnitude, frequency, and duration of bankfull flows
- Diminished baseflow

2.2 Increased Runoff Volume

Impervious cover and other urban land use alterations, such as soil compaction and storm drain construction, alter infiltration rates and increase runoff velocities and the efficiency with which water is delivered to streams. This decrease in infiltration and basin lag time can significantly increase runoff volumes. Table 7 reviews research on the impact of IC on runoff volume in urban streams. Schueler (1987) demonstrated that runoff values are directly related to subwatershed IC (Figure 7). Runoff data was derived from 44 small catchment areas across the country for EPA's Nationwide Urban Runoff Program.

Table 8 illustrates the difference in runoff volume between a meadow and a parking lot, as compiled from engineering models. The parking lot produces more than 15 times more runoff than a meadow for the same storm event.

Urban soils are also profoundly modified during the construction process. The compaction of urban soils and the removal of topsoil can decrease the infiltration capacity, causing increases in runoff volumes (Schueler, 2000). Bulk density is often used to measure soil compaction, and Table 9 illustrates how bulk density increases in many urban land uses.



Note: 44 small urban catchments monitored during the national NURP study

Figure 7: Runoff Coefficient vs. IC (Schueler, 1987)

Table 7: Research Review of Increased Runoff Volume and Peak Discharge in Urban Streams		
Reference	**Key Finding**	**Location**
	Increased Runoff Volume	
Schueler, 1987	Runoff coefficients were found to be strongly correlated with IC at 44 sites nationwide.	U.S.
Neller, 1988	Urban watershed produced more than seven times as much runoff as a similar rural watershed. Average time to produce runoff was reduced by 63% in urban watersheds compared to rural watersheds.	Australia
	Increased Peak Discharge	
Hollis, 1975	Review of data from several studies showed that floods with a return period of a year or longer are not affected by a 5% watershed IC; small floods may be increased 10 times by urbanization; flood with a return period of 100 years may be doubled in size by a 30% watershed IC.	N/A
Leopold, 1968	Data from seven nationwide studies showed that 20% IC can cause the mean annual flood to double.	U.S.
Neller, 1988	Average peak discharge from urban watersheds was 3.5 times higher than peak runoff from rural watersheds.	Australia
Doll *et al.*, 2000	Peak discharge was greater for 18 urban streams versus 11 rural Piedmont streams.	NC
Sauer *et al.*, 1983	Estimates of flood discharge for various recurrence intervals showed that less than 50% watershed IC can result in a doubling of the 2-year, 10-year, and 100-year floods.	U.S.
Leopold, 1994	Watershed development over a 29-year period caused the peak discharge of the 10-year storm to more than double.	MD
Kibler *et al.*, 1981	Rainfall/runoff model for two watersheds showed that an increase in IC caused a significant increase in mean annual flood.	PA
Konrad and Booth, 2002	Evaluated streamflow data at 11 streams and found that the fraction of annual mean discharges was exceeded and maximum annual instantaneous discharges were related to watershed development and road density for moderately and highly developed watersheds.	WA

Table 8: Hydrologic Differences Between a Parking Lot and a Meadow (Schueler, 1994a)		
Hydrologic or Water Quality Parameter	**Parking Lot**	**Meadow**
Runoff Coefficient	0.95	0.06
Time of Concentration (minutes)	4.8	14.4
Peak Discharge, two-year, 24-hour storm (cfs)	4.3	0.4
Peak Discharge Rate, 100-year storm (cfs)	12.6	3.1
Runoff Volume from one-inch storm (cu. ft)	3,450	218
Runoff Velocity @ two-year storm (ft/sec)	8	1.8

Key Assumptions:
2-yr, 24-hr storm = 3.1 in; 100-yr storm = 8.9 in.
Parking Lot: 100% imperviousness; 3% slope; 200ft flow length; hydraulic radius =.03; concrete channel; suburban Washington C values
Meadow: 1% impervious; 3% slope; 200 ft flow length; good vegetative condition; B soils; earthen channel
Source: Schueler, 1994a

Table 9: Comparison of Bulk Density for Undisturbed Soils and Common Urban Conditions (Schueler, 2000)			
Undisturbed Soil Type or Urban Condition	**Surface Bulk Density (grams/cubic centimeter)**	**Urban Condition**	**Surface Bulk Density (grams/cubic centimeter)**
Peat	0.2 to 0.3	Urban Lawns	1.5 to 1.9
Compost	1.0	Crushed Rock Parking Lot	1.5 to 1.9
Sandy Soils	1.1 to 1.3	Urban Fill Soils	1.8 to 2.0
Silty Sands	1.4	Athletic Fields	1.8 to 2.0
Silt	1.3 to 1.4	Rights-of-Way and Building Pads (85%)	1.5 to 1.8
Silt Loams	1.2 to 1.5	Rights-of-Way and Building Pads (95%)	1.6 to 2.1
Organic Silts/Clays	1.0 to 1.2	Concrete Pavement	2.2
Glacial Till	1.6 to 2.0	Rock	2.65

2.3 Increased Peak Discharge Rate

Watershed development has a strong influence on the magnitude and frequency of flooding in urban streams. Peak discharge rates are often used to define flooding risk. Doll *et al.* (2000) compared 18 urban streams with 11 rural streams in the North Carolina Piedmont and found that unit area peak discharge was always greater in urban streams (Figure 8). Data from Seneca Creek, Maryland also suggest a similar increase in peak discharge. The watershed experienced significant growth during the 1950s and 1960s. Comparison of pre- and post-development gage records suggests that the peak 10-year flow event more than doubled over that time (Leopold, 1994).

Hollis (1975) reviewed numerous studies on the effects of urbanization on floods of different recurrence intervals and found that the effect of urbanization diminishes when flood recurrence gets longer (i.e., 50 and 100 years). Figure 9 shows the effect on flood magnitude in urban watersheds with 30% IC, and shows the one-year peak discharge rate increasing by a factor of 10, compared to an undeveloped watershed. In contrast, floods with a 100-year recurrence interval only double in size under the same watershed conditions.

Sauer *et al.* (1983) evaluated the magnitude of flooding in urban watersheds throughout the United States. An equation was developed for estimating discharge for floods of two-year, 10-year, and 100-year recurrence intervals. The equations used IC to account for increased runoff volume and a basin development factor to account for sewers, curbs and gutters, channel improvements and drainage development. Sauer noted that IC is not the dominant factor in determining peak discharge rates for extreme floods because these storm events saturate the soils of undeveloped watersheds and produce high peak discharge rates. Sauer found that watersheds with 50% IC can increase peak discharge for the two-year flood by a factor of four, the 10-year flood by a factor of three, and the 100-year flood by a factor of 2.5, depending on the basin development factor (Figure 10).

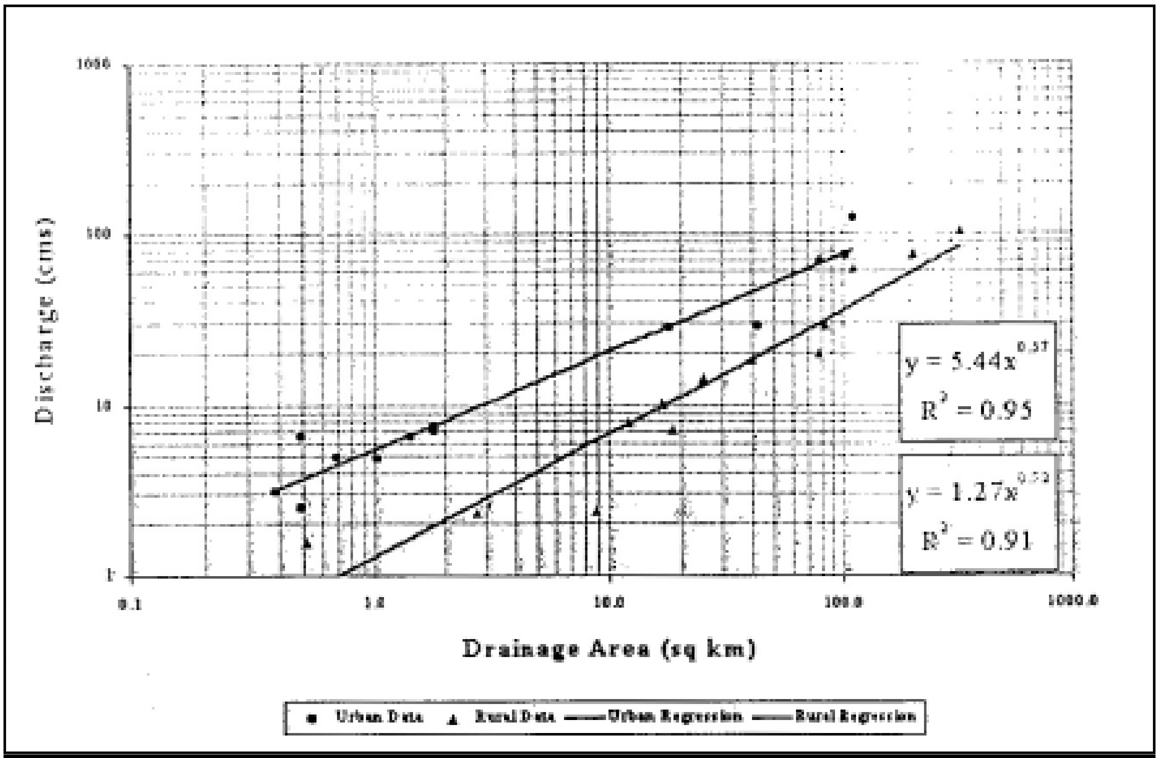


Figure 8: Peak Discharge for Urban and Rural Streams in North Carolina (Doll *et al.*, 2000)

2.4 Increased Bankfull Flow

Urbanization also increases the frequency and duration of peak discharge associated with smaller flood events (i.e., one- to two-year return storms). In terms of stream channel morphology, these more frequent bankfull flows are actually much more important than large flood events in forming the channel. In fact, Hollis (1975) demonstrated that urbanization increased the frequency and magnitude of bankfull flow events to a greater degree than the larger flood events.

An example of the increase in bankfull flow in arid regions is presented by the U.S. Geological Survey (1996), which compared the peak discharge rate from two-year storm events before and after watersheds urbanized in Parris Valley, California. Over an approximately 20-year period, watershed IC increased by 13.5%, which caused the two-year peak flow to more than double. Table 10 reviews other research studies on the relationship between watershed IC and bankfull flows in urban streams.

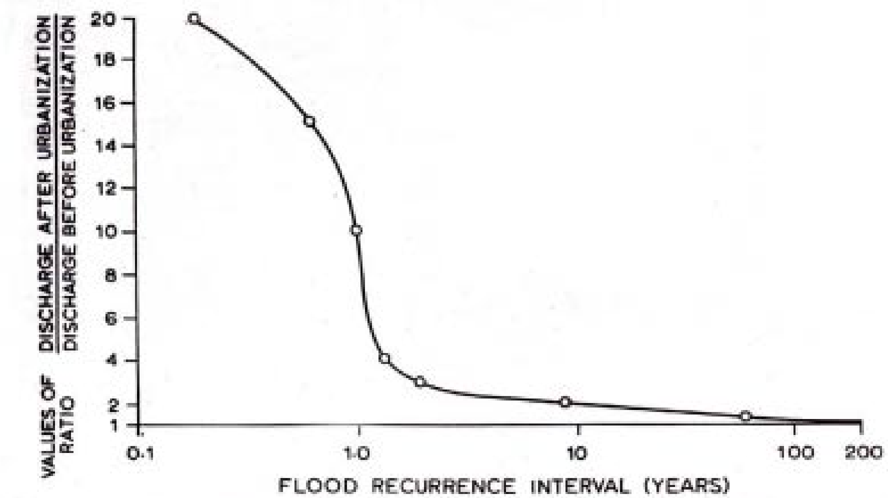


Fig. 3. Effect on flood magnitudes of paving 20% of a basin (based on Figure 2).

Figure 9: Effect on Flood Magnitudes of 30% Basin IC (Hollis, 1975)

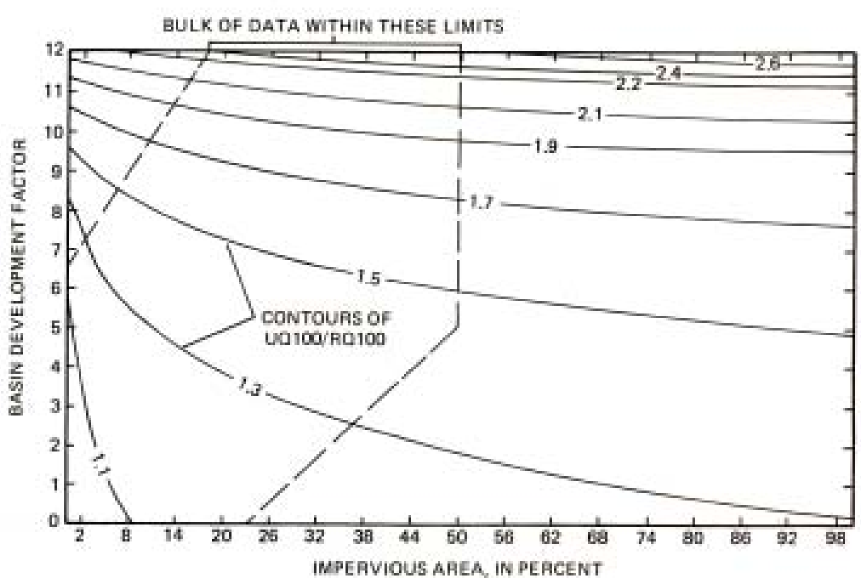


Figure 10: Relationship of Urban/Rural 100-Year Peak Flow Ratio to Basin Development Factor and IC (Sauer *et al.*, 1983)

Table 10: Research Review of Increased Bankfull Discharge in Urban Streams

Reference	Key Finding	Location
Booth and Reinelt, 1993	Using a simulation model and hydrologic data from four watersheds, it was estimated that more than 10% watershed IC may cause discharge from the two-year storm under current conditions to equal or exceed discharge from the 10-year storm under forested conditions.	WA
Fongers and Fulcher, 2001	Bankfull flow of 1200 cfs was exceeded more frequently over time with urbanization, and exceedence was three times as frequent from 1930s to 1990s.	MI
USGS, 1996	Over a 20-year period, IC increased 13.5%, and the two-year peak flow more than doubled in a semi-arid watershed.	CA
Henshaw and Booth, 2000	Two of three watersheds in the Puget Sound lowlands showed increasing flashiness over 50 years with urbanization.	WA
Leopold, 1968	Using hydrologic data from a nine-year period for North Branch Brandywine Creek, it was estimated that for a 50% IC watershed, bankfull frequency would be increased fourfold.	PA
Leopold, 1994	Bankfull frequency increased two to seven times after urbanization in Watts Branch.	MD
MacRae, 1996	For a site downstream of a stormwater pond in Markham, Ontario hours of exceedence of bankfull flows increased by 4.2 times after the watershed urbanized (34% IC)	Ontario

Leopold (1968) evaluated data from seven nationwide studies and extrapolated this data to illustrate the increase in bankfull flows due to urbanization. Figure 11 summarizes the relationship between bankfull flows over a range of watershed IC. For example, watersheds that have 20% IC increase the number of flows equal to or greater than bankfull flow by a factor of two. Leopold (1994) also observed a dramatic increase in the frequency of the bankfull event in Watts Branch, an urban subwatershed in Rockville, Maryland. This watershed experienced significant urban development during the 1950s and 1960s. Leopold compared gage records and found that the bankfull storm event frequency increased from two to seven times per year from 1958 to 1987.

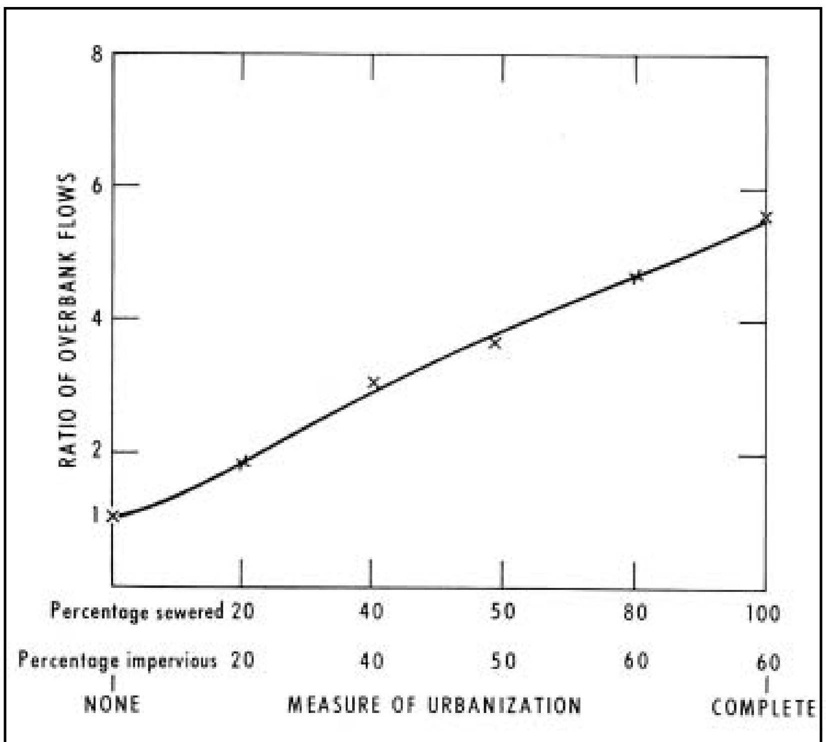


Figure 11: Increase in Bankfull Flows Due to Urbanization (Leopold, 1968)

More recent data on bankfull flow frequency was reported for the Rouge River near Detroit, Michigan by Fongers and Fulcher (2001). They noted that channel-forming flow (1200 cfs) was exceeded more frequently as urbanization increased in the watershed and had become three times more frequent between 1930 and 1990 (Figure 12).

McCuen and Moglen (1988) have documented the increase in duration of bankfull flows in response to urbanization using hydrology models. MacRae (1996), monitored a stream in Markham, Ontario downstream of a stormwater pond and found that the hours of

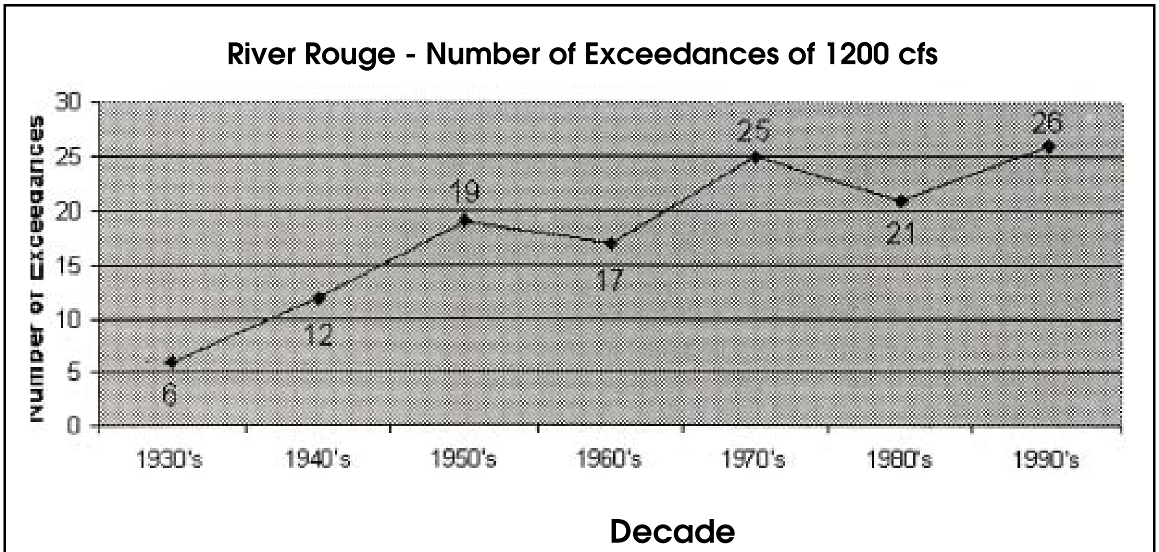


Figure 12: Increase in Number of Exceedences of Bankfull Flow Over Time With Urbanization in the Rouge River, MT (Fongers and Fulcher, 2001)

exceedence of bankfull flows increased by a factor of 4.2 once watershed IC exceeded 30%. Modeling for seven streams also downstream of stormwater ponds in Surrey, British Columbia also indicated an increase in bankfull flooding in response to watershed development (MacRae, 1996).

Watershed IC also increases the "flashiness" of stream hydrographs. Flashiness is defined here as the percent of daily flows each year that exceeds the mean annual flow. Henshaw and Booth (2000) evaluated seven urbanized watersheds in the Puget Sound lowland streams and tracked changes in flashiness over 50 years (Figure 13). The most urbanized watersheds experienced flashy discharges. Henshaw and Booth concluded that increased runoff in urban watersheds leads to higher but shorter-duration peak discharges.

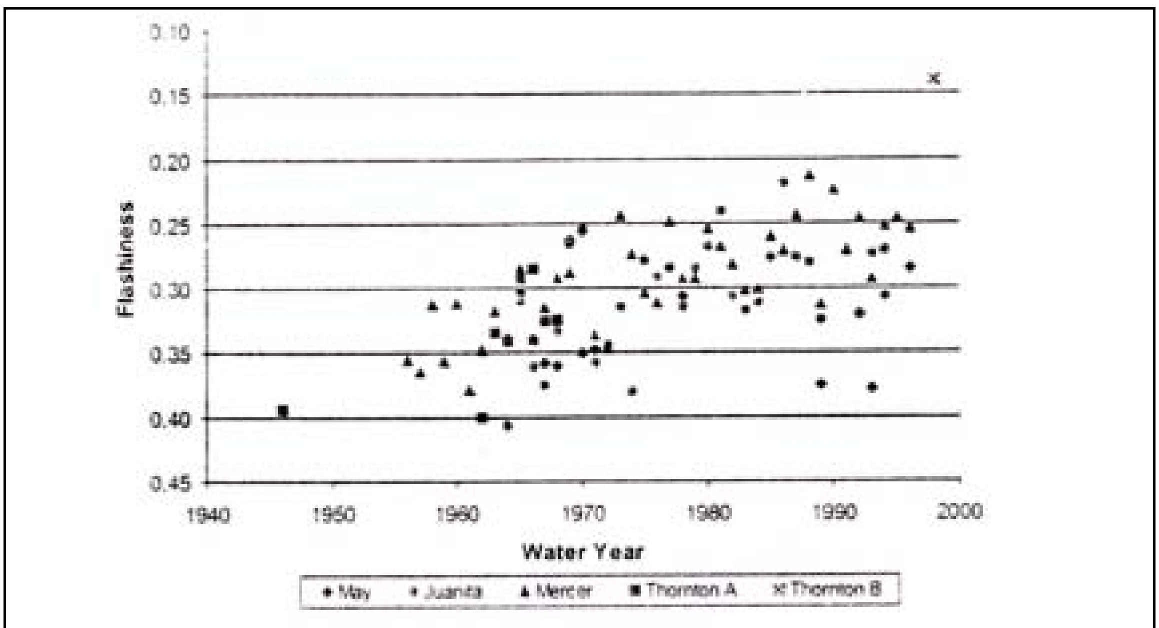


Figure 13: Percent of Gage Reading Above Mean Annual Flow for Puget Sound Lowland Streams (Henshaw and Booth, 2000)

2.5 Decreased Baseflow

As IC increases in a watershed, less groundwater infiltration is expected, which can potentially decrease stream flow during dry periods, (i.e. baseflow). Several East Coast studies provide support for a decrease in baseflow as a result of watershed development. Table 11 reviews eight research studies on baseflow in urban streams.

Klein (1979) measured baseflow in 27 small watersheds in the Maryland Piedmont and reported an inverse relationship between IC and baseflow (Figure 14). Spinello and Simmons (1992) demonstrated that baseflow in two urban Long Island streams declined seasonally as a result of urbanization (Figure 15). Saravanapavan (2002) also found that percentage of baseflow decreased in direct proportion to percent IC for 13 subwatersheds of the Shawsheen River watershed in Massachusetts (Figure 16).

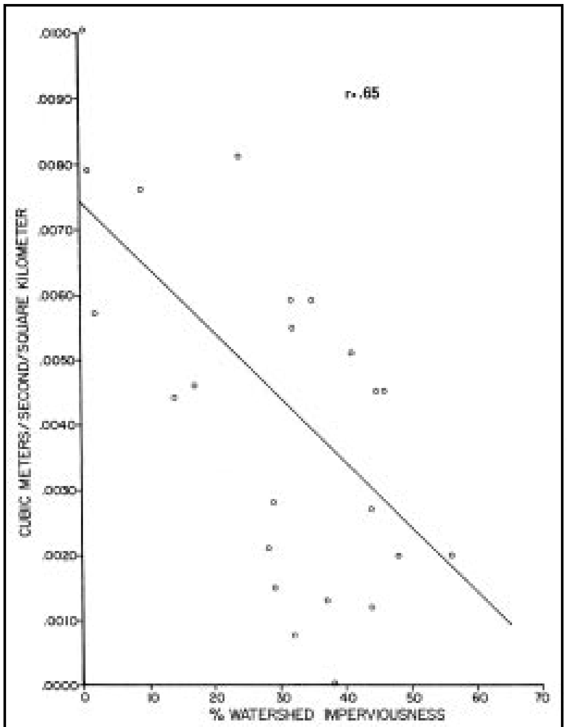
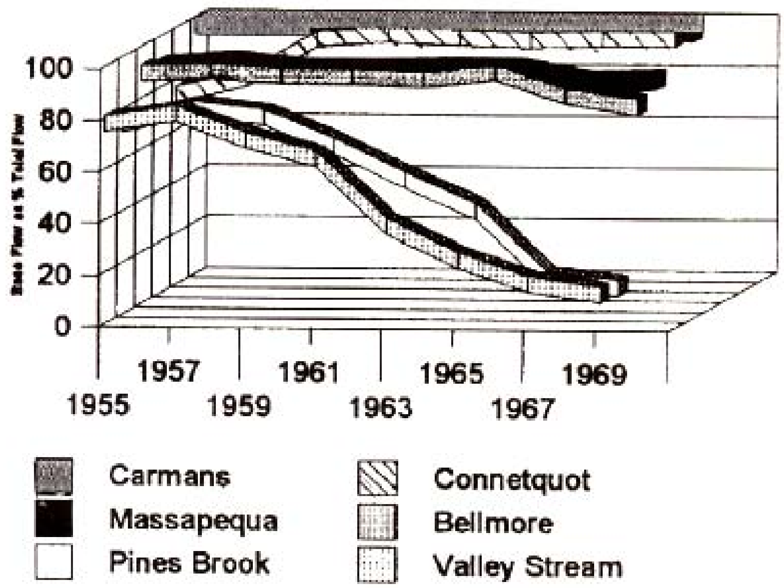


Figure 14: Relationship Between Baseflow and Watershed IC in the Streams on Maryland Piedmont (Klein, 1979)

Table 11: Research Review of Decreased Baseflow in Urban Streams

Reference	Key Finding	Location
Finkenbine *et al.*, 2000	Summer base flow was uniformly low in 11 streams when IC reached 40% or greater.	Vancouver
Klein, 1979	Baseflow decreased as IC increased in Piedmont streams.	MD
Saravanapavan, 2002	Percentage of baseflow decreased linearly as IC increased for 13 subwatersheds of Shawsheen River watershed.	MA
Simmons and Reynolds, 1982	Dry weather flow dropped 20 to 85% after development in several urban watersheds on Long Island.	NY
Spinello and Simmons, 1992	Baseflow in two Long Island streams went dry as a result of urbanization.	NY
Konrad and Booth, 2002	No discernable trend over many decades in the annual seven day low flow discharge for 11 Washington streams.	WA
Wang *et al.*, 2001	Stream baseflow was negatively correlated with watershed IC in 47 small streams, with an apparent breakpoint at 8 to 12% IC.	WI
Evett *et al.*, 1994	No clear relationship between dry weather flow and urban and rural streams in 21 larger watersheds.	NC



Notes:

Carmans and Connetquot: Rural/suburban, watersheds are unsewered

Bellmore and Massapequa: Moderately urbanized, not sewered until 1989

Valley Stream and Pine Brook: Urbanized and densely populated watersheds, sewer systems completed in 1960s

1953-1964: Period of sanitary sewer construction in eastern Nassau County

1962-1966: Drought years

Figure 15: Baseflow Response to Urbanization in Long Island Streams (Spinello and Simmons, 1992)

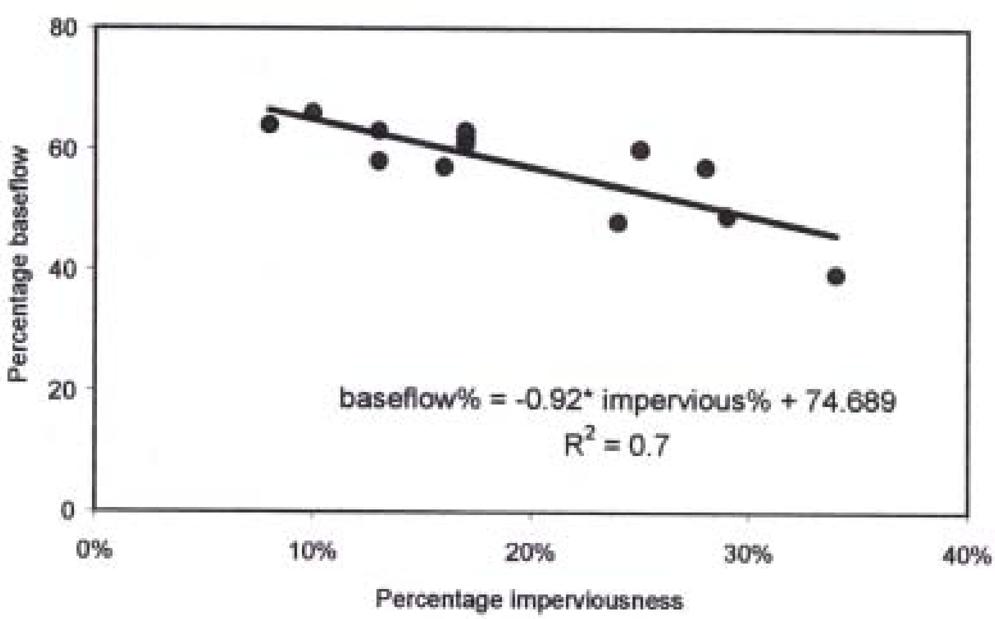


Figure 16: Relationship Between Percentage Baseflow and Percent IC in Massachusetts Streams (Saravanapan, 2002)

Finkebine *et al.* (2000) monitored summer baseflow in 11 streams near Vancouver, British Columbia and found that stream base flow was uniformly low due to decreased groundwater recharge in watersheds with more than 40% IC (Figure 17). Baseflow velocity also consistently decreased when IC increased (Figure 18). The study cautioned that other factors can affect stream baseflow, such as watershed geology and age of development.

Other studies, however, have not been able to establish a relationship between IC and declining baseflow. For example, a study in North Carolina could not conclusively determine that urbanization reduced baseflow in larger urban and suburban watersheds in that area (Evett *et al.*, 1994). In some cases, stream baseflow is supported by deeper aquifers or originate in areas outside the surface watershed boundary. In others, baseflow is augmented by leaking sewers, water pipes and irrigation return flows.

This appears to be particularly true in arid and semi-arid areas, where baseflow can actually increase in response to greater IC (Hollis, 1975). For instance, Crippen and Waananen (1969) found that Sharon Creek near San Francisco changed from an ephemeral stream into a perennial stream after urban development. Increased infiltration from lawn watering and return flow from sewage treatment plants are two common sources of augmented baseflows in these regions (Caraco, 2000a).

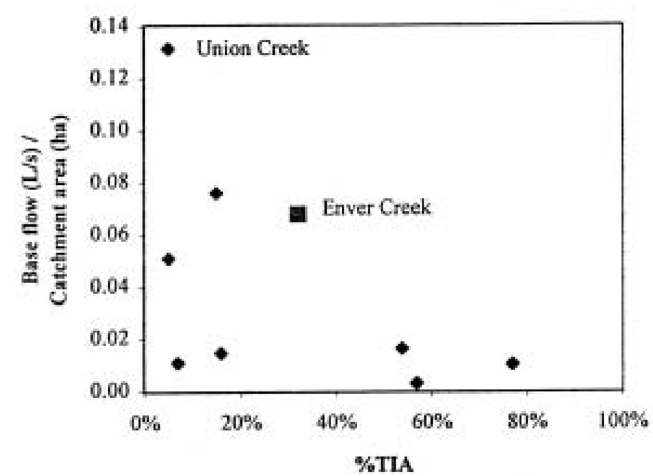


Figure 17: Effect of IC on Summer Baseflow in Vancouver Streams (Finkerbine *et al.*, 2000)

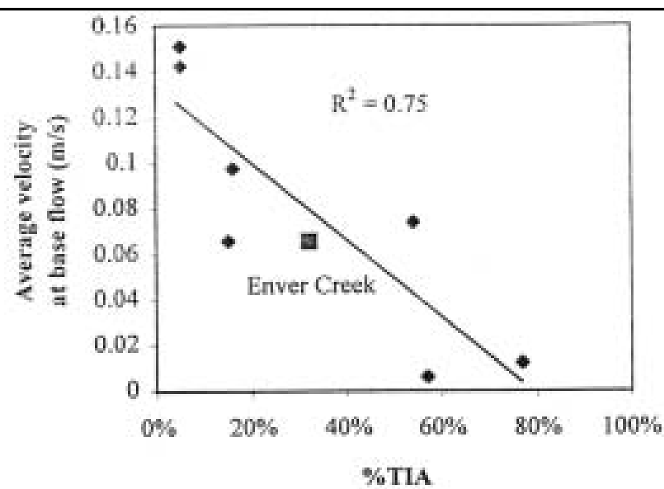


Figure 18: Effect of Watershed IC on Summer Stream Velocity in Vancouver Streams (Finkerbine *et al.*, 2000)

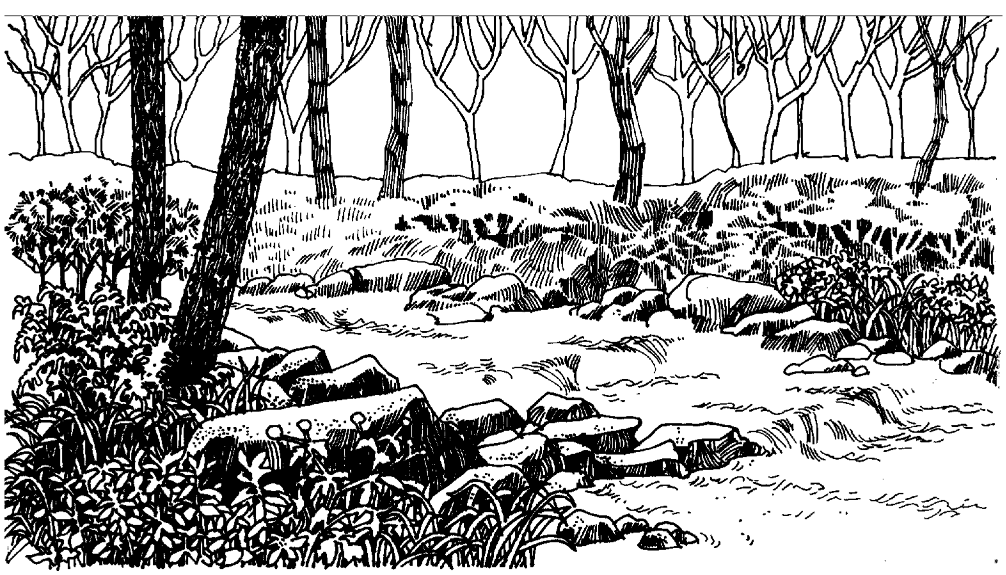
2.6 Conclusions

The changes in hydrology indicators caused by watershed urbanization include increased runoff volume; increased peak discharge; increased magnitude, frequency and duration of bankfull flows; flashier/less predictable flows; and decreased baseflow. Many studies support the direct relationship between IC and these indicators. However, at low levels of watershed IC, site-specific factors such as slope, soils, types of conveyance systems, age of development, and watershed dimensions often play a stronger role in determining a watershed's hydrologic response.

Overall, the following conclusions can be drawn from the relationship between watershed IC and hydrology indicators:

- Strong evidence exists for the direct relationship between watershed IC and increased stormwater runoff volume and peak discharge. These relationships are considered so strong that they have been incorporated into widely accepted engineering models.
- The relationship between IC and bankfull flow frequency has not been extensively documented, although abundant data exists for differences between urban and non-urban watersheds.
- The relationship between IC and declining stream flow is more ambiguous and appears to vary regionally in response to climate and geologic factors, as well as water and sewer infrastructure.

The changes in hydrology indicators caused by watershed urbanization directly influence physical and habitat characteristics of streams. The next chapter reviews how urban streams physically respond to the major changes to their hydrology.



Chapter 3: Physical Impacts of Impervious Cover

A growing body of scientific literature documents the physical changes that occur in streams undergoing watershed urbanization. This chapter discusses the impact of watershed development on various measures of physical habitat in urban stream channels and is organized as follows:

This chapter reviews the available evidence on stream habitat. We begin by looking at geomorphological research that has examined how the geometry of streams changes in response to altered urban hydrology. The typical response is an enlargement of the cross-sectional area of the stream channel through a process of channel incision, widening, or a combination of both. This process triggers an increase in bank and/or bed erosion that increases sediment transport from the stream, possibly for several decades or more.

Next, we examine the handful of studies that have evaluated the relationship between watershed development and composite indicators of stream habitat (such as the habitat Rapid Bioassessment Protocol, or RBP). In the fourth section, we examine the dozen studies that have evaluated how individual habitat elements respond to watershed development. These studies show a consistent picture. Generally, streams with low levels of IC have stable banks, contain considerable large woody debris (LWD) and possess complex habitat structure. As watershed IC increases, however, urban streambanks become increasingly unstable, streams lose LWD, and they develop a more simple and uniform habitat structure. This is typified by reduced pool depths, loss of pool and riffle sequences, reduced channel roughness and less channel sinuosity.

Water temperature is often regarded as a key habitat element, and the fifth section describes the stream warming effect observed in urban streams in six studies. The last section looks at the effect of watershed development on the stream channel network as a whole, in regard to headwater stream loss and the creation of fish barriers.

3.1 Difficulty in Measuring Habitat

The physical transformation of urban streams is perhaps the most conspicuous impact of watershed development. These dramatic physical changes are easily documented in sequences of stream photos with progressively greater watershed IC (see Figure 19). Indeed, the network of headwater stream channels generally disappears when watershed IC exceeds 60% (CWP).

3.1.1 The Habitat Problem

It is interesting to note that while the physical impacts of urbanization on streams are widely accepted, they have rarely been documented by the research community. As a consequence, no predictive models exist to quantify how physical indicators of stream habitat will decline in response to watershed IC, despite the fact that most would agree that some kind of decline is expected (see Table 12).

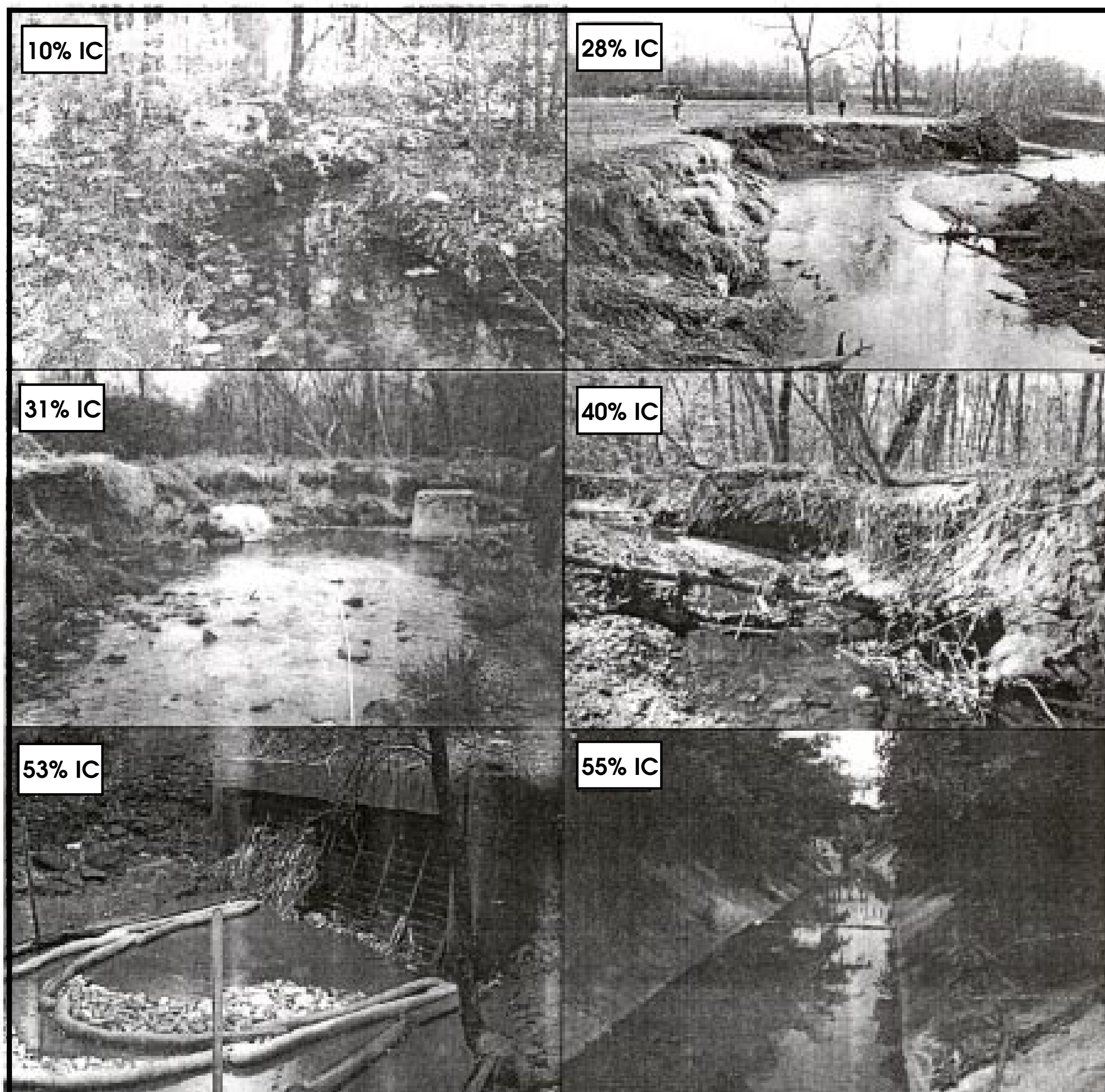


Figure 19: Urban Stream Channels with Progressively Greater IC

The main reason for this gap is that "habitat" is extremely hard to define, and even more difficult to measure in the field. Most indices of physical habitat involve a visual and qualitative assessment of 10 or more individual habitat elements that are perceived by fishery and stream biologists to contribute to quality stream habitat. Since these indices include many different habitat elements, each of which is given equal weight, they have not been very useful in discriminating watershed effects (Wang *et al.*, 2001).

Researchers have had greater success in relating individual habitat elements to watershed conditions, such as large woody debris (LWD), embeddedness, or bank stability. Even so, direct testing has been limited, partly because individual habitat elements are hard to measure and are notoriously variable in both space and time. Consider bank stability for a moment. It would be quite surprising to see a highly urban stream that did not have unstable banks. Yet, the hard question is exactly how would bank instability be quantitatively measured? Where would it be measured — at a point, a cross-section, along a reach, on the left bank or the right?

Geomorphologists stress that no two stream reaches are exactly alike, due to differences in gradient, bed material, sediment transport, hydrology, watershed history and many other factors. Consequently, it is difficult to make controlled comparisons among different streams. Indeed, geomorphic theory stresses that individual stream reaches respond in a highly dynamic way to changes in watershed hydrology and sediment transport, and can take several decades to fully adjust to a new equilibrium.

Table 12: Physical Impacts of Urbanization on Streams
Specific Impacts
Sediment transport modified
Channel enlargement
Channel incision
Stream embeddedness
Loss of large woody debris
Changes in pool/riffle structure
Loss of riparian cover
Reduced channel sinuosity
Warmer in-stream temperatures
Loss of cold water species and diversity
Channel hardening
Fish blockages
Loss of 1st and 2nd order streams through storm drain enclosure

Returning to our example of defining bank stability, how might our measure of bank instability change over time as its watershed gradually urbanizes, is built out, and possibly reaches a new equilibrium over several decades? It is not very surprising that the effect of watershed development on stream habitat is widely observed, yet rarely measured.

3.2 Changes in Stream Geometry

As noted in the last chapter, urbanization causes an increase in the frequency and duration of bankfull and sub-bankfull flow events in streams. These flow events perform more "effective work" on the stream channel, as defined by Leopold (1994). The net effect is that an urban stream channel is exposed to more shear stress above the critical threshold needed to move bank and bed sediments (Figure 20). This usually triggers a cycle of active bank erosion and greater sediment transport in urban streams. As a consequence, the stream channel adjusts by expanding its cross-sectional area, in order to effectively accommodate greater flows and sediment supply. The stream channel can expand by incision, widening, or both. Incision refers to stream down-cutting through the streambed, whereas widening refers to lateral erosion of the stream bank and its flood plain (Allen and Narramore, 1985; Booth, 1990; Morisawa and LaFlure, 1979).

3.2.1 Channel Enlargement

A handful of research studies have specifically examined the relationship between watershed development and stream channel enlargement (Table 13). These studies indicate that stream cross-sectional areas can enlarge by as much as two to eight times in response to urbanization, although the process is complex and may take several decades to complete (Pizzuto *et al*., 2000; Caraco, 2000b; Hammer, 1972). An example of channel enlargement is provided in Figure 21, which shows how a stream cross-section in Watts Branch near Rockville, Maryland has expanded in response to nearly five decades of urbanization (i.e., watershed IC increased from two to 27%).

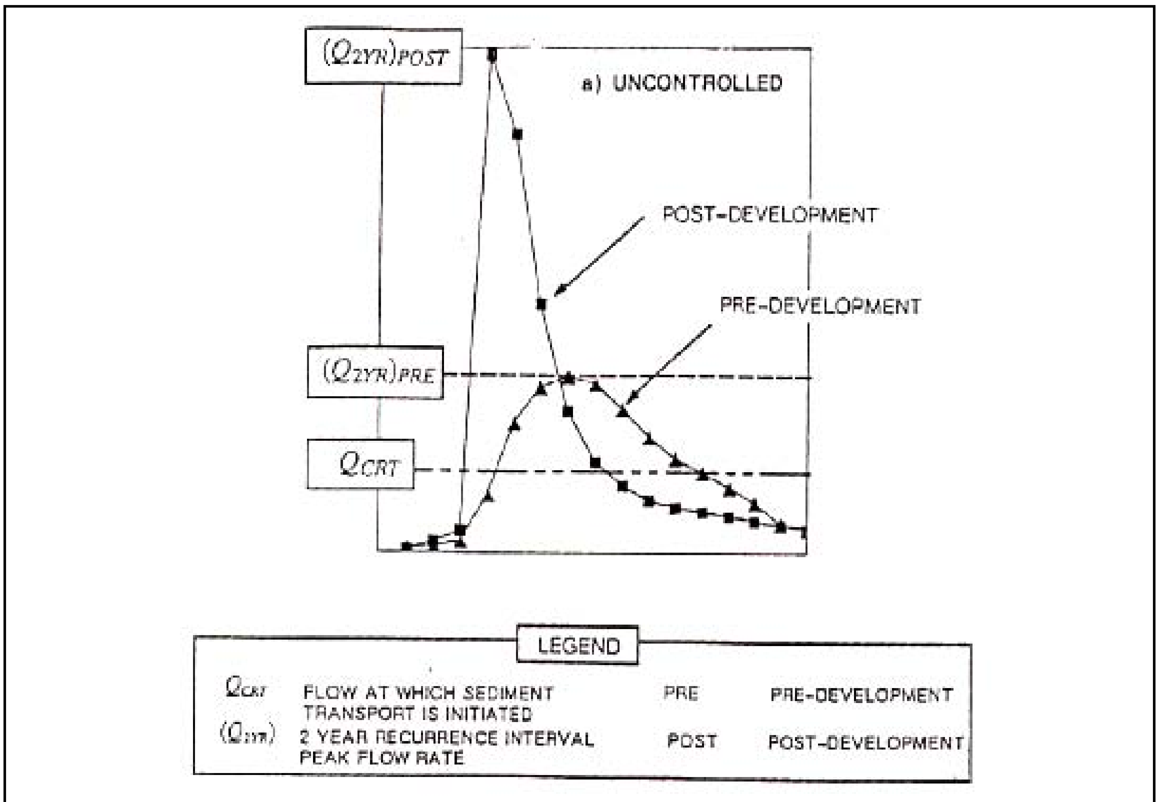


Figure 20: Increased Shear Stress from a Hydrograph (MacRae and Rowney, 1992)

Table 13: Research Review of Channel Enlargement and Sediment Transport in Urban Streams		
Reference	**Key Finding**	**Location**
% IC used as Indicator		
Caraco, 2000b	Reported enlargement in ratios of 1.5 to 2.2 for 10 stream reaches in Watts Branch and computed ultimate enlargement ratios of 2.0	MD
MacCrae and De Andrea, 1999	Introduced the concept of ultimate channel enlargement based on watershed IC and channel characteristics.	Ontario, TX
Morse, 2001	Demonstrated increased erosion rates with increases in IC (channels were generally of the same geomorphic type).	ME
Urbanization Used as Indicator		
Allen and Narramore, 1985	Enlargement ratios in two urban streams ranged from 1.7 to 2.4.	TX
Bledsoe, 2001	Reported that channel response to urbanization depends on other factors in addition to watershed IC including geology, vegetation, sediment and flow regimes.	N/A
Booth and Henshaw, 2001	Evaluated channel cross section erosion rates and determined that these rates vary based on additional factors including the underlying geology, age of development and gradient.	WA
Hammer, 1972	Enlargement ratios ranged from 0.7 to 3.8 in urban watersheds.	PA
Neller, 1989	Enlargement ratios in small urban catchments ranged from two to 7.19, the higher enlargement ratios were primarily from incision occurring in small channels.	Australia
Pizzuto *et al.*, 2000	Evaluated channel characteristics of paired urban and rural streams and demonstrated median bankfull cross sectional increase of 180%. Median values for channel sinuosity were 8% lower in urban streams; Mannings N values were found to be 10% lower in urban streams.	PA
Hession *et al.*, *in press*	Bankfull widths for urban streams were significantly wider than non-urban streams in 26 paired streams. Forested reaches were consistently wider than non-forested reaches in urban streams.	MD, DE, PA
Dartiguenave *et al.*, 1997	Bank erosion accounted for up to 75% of the sediment transport in urban watersheds.	TX
Trimble, 1997	Demonstrated channel enlargement over time in an urbanizing San Diego Creek; Bank erosion accounted for over 66% of the sediment transport.	CA

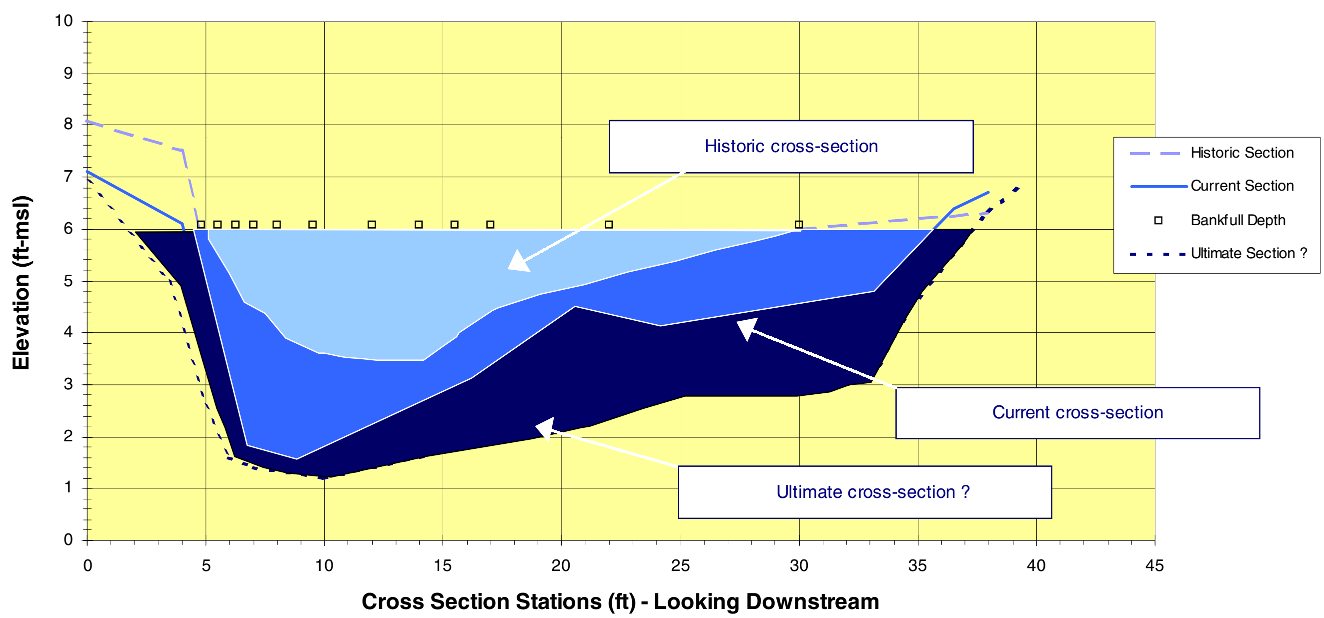


Figure 21: Stream Channel Enlargement in Watts Branch, MD 1950-2000 (Caraco, 2000b)

Some geomorphologists suggest that urban stream channels will reach an "ultimate enlargement" relative to pre-developed channels (MacRae and DeAndrea, 1999) and that this can be predicted based on watershed IC, age of development, and the resistance of the channel bed and banks. A relationship between ultimate stream channel enlargement and watershed IC has been developed for alluvial streams in Texas, Vermont and Maryland (Figure 22). Other geomorphologists such as Bledsoe (2001) and Booth and Henshaw (2001) contend that channel response to urbanization is more complex, and also depends on geology, grade control, stream gradient and other factors.

Channel incision is often limited by grade control caused by bedrock, cobbles, armored substrates, bridges, culverts and pipelines. These features can impede the downward erosion of the stream channel and thereby limit the incision process. Stream incision can become severe in streams that have softer substrates such as sand, gravel and clay (Booth, 1990). For example, Allen and Narramore (1985) showed that channel enlargement in chalk channels was 12 to 67% greater than in shale channels near Dallas, Texas. They attributed the differences to the softer substrate, greater velocities and higher shear stress in the chalk channels.

Neller (1989) and Booth and Henshaw (2001) also report that incised urban stream channels possess cross-sectional areas that are larger than would be predicted based on watershed area or discharge alone. This is due to the fact that larger floods are often contained within the stream channel rather than the floodplain. Thus, incised channels often result in greater erosion and geomorphic change. In general, stream conditions that can foster incision include erodible substrates, moderate to high stream gradients, and an absence of grade control features.

Channel widening occurs more frequently when streams have grade control and the stream has cut into its bank, thereby expanding its cross-sectional area. Urban stream channels often have artificial grade controls caused by frequent culverts and road crossings. These grade controls often cause localized sediment deposition that can reduce the capacity of culverts and bridge crossings to pass flood waters.

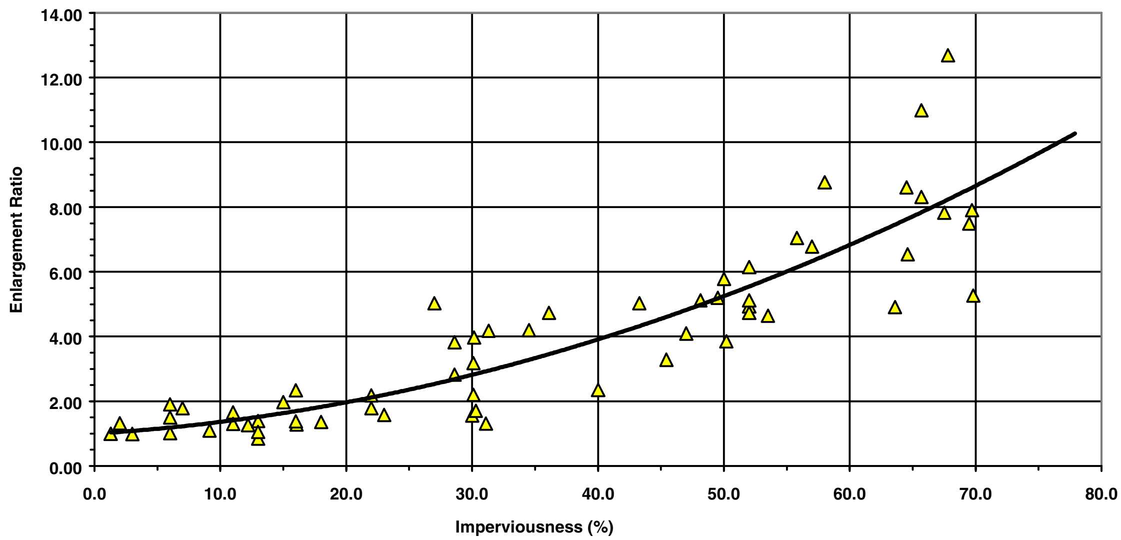


Figure 22: Ultimate Channel Enlargement in MD, UT and TX Alluvial Streams (MacRae and DeAndrea, 1999 and CWP, 2001b)

The loss of flood plain and riparian vegetation has been strongly associated with watershed urbanization (May *et al.*, 1997). A few studies have shown that the loss of riparian trees can result in increased erosion and channel migration rates (Beeson and Doyle, 1995 and Allmendinger *et al.*, 1999). For example, Beeson and Doyle (1995) found that meander bends with vegetation were five times less likely to experience significant erosion from a major flood than non-vegetated meander bends.Hession *et al.* (in press) observed that forested reaches consistently had greater bankfull widths than non-forested reaches in a series of urban streams in Pennsylvania, Maryland and Delaware.

3.2.2 Effect of Channel Enlargement on Sediment Yield

Regardless of whether a stream incises, widens, or does both, it will greatly increase sediment transport from the watershed due to erosion. Urban stream research conducted in California and Texas suggests that 60 to 75% of the sediment yield of urban watersheds can be derived from channel erosion (Trimble, 1997 and Dartingunave *et al.*, 1997) This can be compared to estimates for rural streams where channel erosion accounts for only five to 20% of the annual sediment yield (Collins *et al.*, 1997 and Walling and Woodward, 1995).

Some geomorphologists speculate that urban stream channels will ultimately adjust to their post-development flow regime and sediment supply. Finkenbine *et al.* (2000) observed these conditions in Vancouver streams, where study streams eventually stabilized two decades after the watersheds were fully developed. In older urban streams, reduced sediment transport can be expected when urbanization has been completed. At this point, headwater stream channels are replaced by storm drains and pipes, which can transport less sediment. The lack of available sediment may cause downstream channel erosion, due to the diminished sediment supply found in the stream.

3.3 Effect on Composite Measures of Stream Habitat

Composite measures of stream habitat refer to assessments such as EPA's Habitat Rapid Bioassessment Protocol (RBP) that combine multiple habitat elements into a single score or index (Barbour *et al*., 1999). For example, the RBP requires visual assessment of 10 stream habitat elements, including embeddedness, epifaunal substrate quality, velocity/depth regime, sediment deposition, channel flow status, riffle frequency, bank stabilization, streambank vegetation and riparian vegetation width. Each habitat element is qualitatively scored on a 20 point scale, and each element is weighted equally to derive a composite score for the stream reach.

To date, several studies have found a relationship between declining composite habitat indicator scores and increasing watershed IC in different eco-regions of the United States. A typical pattern in the composite habitat scores is provided for headwater streams in Maine (Morse, 2001; Figure 23). This general finding has been reported in the mid-Atlantic, Northeast and the Northwest (Black and Veatch, 1994; Booth and Jackson, 1997; Hicks and Larson, 1997; Maxted and Shaver, 1997; Morse, 2001; Stranko and Rodney, 2001).

However, other researchers have found a much weaker relationship between composite habitat scores and watershed IC. Wang and his colleagues (2001) found that composite habitat scores were not correlated with watershed IC in Wisconsin streams, although it was correlated with individual habitat elements, such as streambank erosion. They noted that many agricultural and rural streams had fair to poor composite habitat scores, due to poor riparian management and sediment deposition. The same basic conclusion was also reported for streams of the Maryland Piedmont (MNCPPC, 2000).

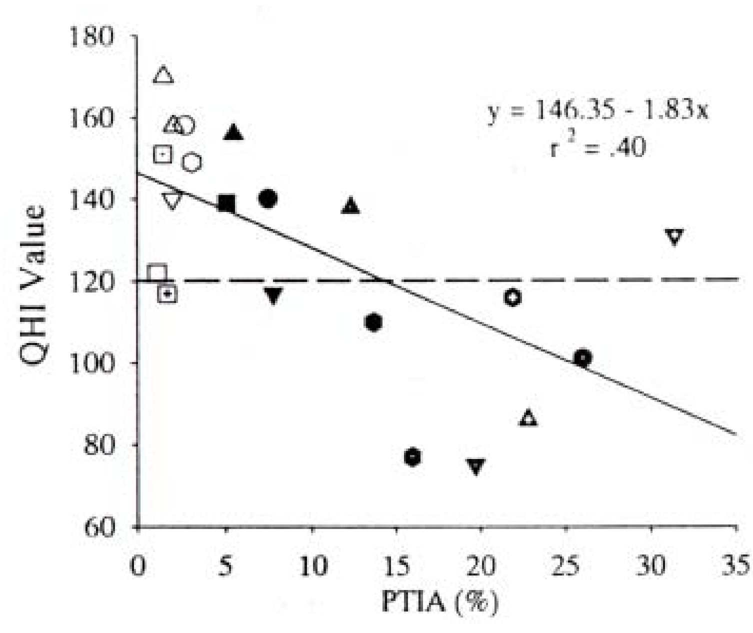


Figure 23: Relationship Between Habitat Quality and IC in Maine Streams (Morse, 2001)

3.4 Effect on Individual Elements of Stream Habitat

Roughly a dozen studies have examined the effect of watershed development on the degradation of individual stream habitat features such as bank stability, embeddedness, riffle/pool quality, and loss of LWD (Table 14). Much of this data has been acquired from the Pacific Northwest, where the importance of such habitat for migrating salmon has been a persistent management concern.

3.4.1 Bank Erosion and Bank Stability

It is somewhat surprising that we could only find one study that related bank stability or bank erosion to watershed IC. Conducted by Booth (1991) in the streams of the Puget Sound lowlands, the study reported that stream banks were consistently rated as stable in watersheds with less than 10% IC, but became progressively more unstable above this threshold. Dozens of stream assessments have found high rates of bank erosion in urban streams, but none, to our knowledge, has systematically related the prevalence or severity of bank erosion to watershed IC. As noted earlier, this may reflect the lack of a universally recognized method to measure comparative bank erosion in the field.

3.4.2 Embeddedness

Embeddedness is a term that describes the extent to which the rock surfaces found on the stream bottom are filled in with sand, silts and clay. In a healthy stream, the interstitial pores between cobbles, rock and gravel generally lack fine sediments, and are an active habitat zone and detrital processing area. The increased sediment transport in urban streams can rapidly fill up these pores in a process known as embedding. Normally, embeddedness is visually measured in riffle zones of streams. Riffles tend to be an important habitat for aquatic insects and fish (such as darters and sculpins). Clean stream substrates are also critical to trout and salmon egg incubation and embryo development. May *et al.* (1997) demonstrated that the percent of fine sediment particles in riffles generally increased with watershed IC (Figure 24). However, Finkenbine *et al.* (2000) reported that embeddedness eventually decreased slightly after watershed land use and sediment transport had stabilized for 20 years.

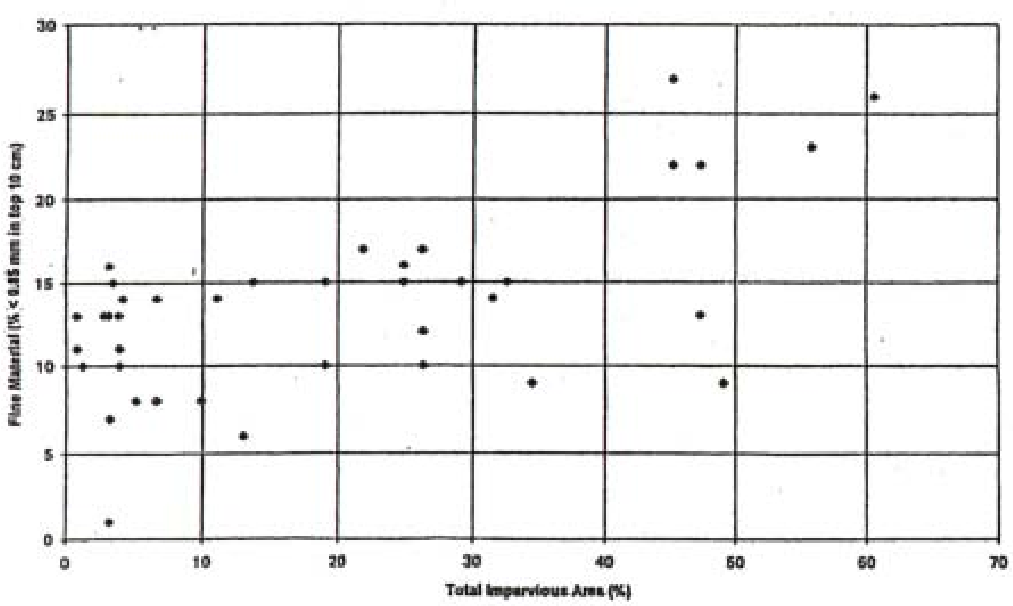


Figure 24: Fine Material Sediment Deposition as a Function of IC in Pacific Northwest Streams (Horner *et al.*, 1997)

Table 14: Research Review of Changes in Urban Stream Habitat

Reference	Key Finding	Location
	% IC Used as Indicator	
Black & Veatch, 1994	Habitat scores were ranked as poor in five subwatersheds that had greater than 30% IC.	MD
Booth and Jackson, 1997	Increase in degraded habitat conditions with increases in watershed IC.	WA
Hicks and Larson, 1997	Reported a reduction in composite stream habitat indices with increasing watershed IC.	MA
May *et al.*, 1997	Composite stream habitat declined most rapidly during the initial phase of the watershed urbanization, when percent IC exceeded the 5-10% range.	WA
Stranko and Rodney, 2001	Composite index of stream habitat declined with increasing watershed IC in coastal plain streams.	MD
Wang *et al.*, 2001	Composite stream habitat scores were not correlated with watershed IC in 47 small watersheds, although channel erosion was. Non-urban watersheds were highly agricultural and often lacked riparian forest buffers.	WI
MNCPPC, 2000	Reported that stream habitat scores were not correlated with IC in suburban watersheds.	MD
Morse, 2001	Composite habitat values tended to decline with increases in watershed IC.	ME
Booth, 1991	Channel stability and fish habitat quality declined rapidly after 10% watershed IC.	WA
Booth *et al.*, 1997	Decreased LWD with increased IC.	PNW
Finkenbine *et al.*, 2000	LWD was scarce in streams with greater than 20% IC in Vancouver.	B.C.
Horner & May, 1999	When IC levels were >5%, average LWD densities fell below 300 pieces/kilometer.	PNW
Horner *et al.*, 1997	Interstitial spaces in streambed sediments begin to fill with increasing watershed IC.	PNW
	Urbanization Used as Indicator	
Dunne and Leopold, 1978	Natural channels replaced by storm drains and pipes; increased erosion rates observed downstream.	MD
May *et al.*, 1997	Forested riparian corridor width declines with increased watershed IC.	PNW
MWCOG, 1992	Fish blockages caused by bridges and culverts noted in urban watersheds.	D.C.
Pizzuto *et al.*, 2000	Urban streams had reduced pool depth, roughness, and sinuosity, compared to rural streams; Pools were 31% shallower in urban streams compared to non-urban ones.	PA
Richey, 1982	Altered pool/riffle sequence observed in urban streams.	WA
Scott *et al.*, 1986	Loss of habitat diversity noted in urban watersheds.	PNW
Spence *et al.*, 1996	Large woody debris is important for habitat diversity and anadromous fish.	PNW

3.4.3 Large Woody Debris (LWD)

LWD is a habitat element that describes the approximate volume of large woody material (< four inches in diameter) found in contact with the stream. The presence and stability of LWD is an important habitat parameter in streams. LWD can form dams and pools, trap sediment and detritus, stabilize stream channels, dissipate flow energy, and promote habitat complexity (Booth *et al.,* 1997). LWD creates a variety of pool features (plunge, lateral, scour and backwater); short riffles; undercut banks; side channels; and a range of water depths (Spence *et al.*, 1996). Urban streams tend to have a low supply of LWD, as increased stormwater flows transport LWD and clears riparian areas. Horner *et al.* (1997) presents evidence from Pacific Northwest streams that LWD decreases in response to increasing watershed IC (Figure 25).

3.4.4 Changes in Other Individual Stream Parameters

One of the notable changes in urban stream habitat is a decrease in pool depth and a general simplification of habitat features such as pools, riffles and runs. For example, Richey (1982) and Scott *et al.* (1986) reported an increase in the prevalence of glides and a corresponding altered riffle/pool sequence due to urbanization. Pizzuto *et al.* (2000) reported a median 31% decrease in pool depth in urban streams when compared to forested streams. Pizzuto *et al.* also reported a modest decrease in channel sinuosity and channel roughness in the same urban streams in Pennsylvania.

Several individual stream habitat parameters appear to have received no attention in urban stream research to date. These parameters include riparian shading, wetted perimeter, various measures of velocity/depth regimes, riffle frequency, and sediment deposition in pools. More systematic monitoring of these individual stream habitat parameters may be warranted.

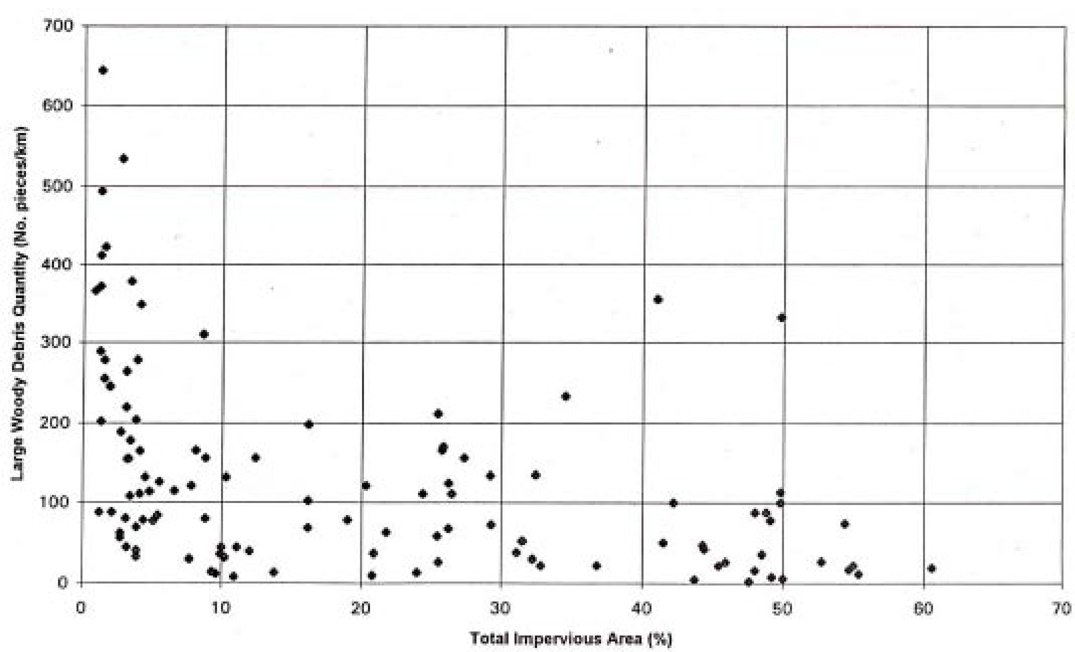


Figure 25: LWD as a Function of IC in Puget Sound Streams (Horner *et al.*, 1997)

3.5 Increased Stream Warming

IC directly influences our local weather in urban areas. This effect is obvious to anyone walking across a parking lot on a hot summer day, when temperatures often reach a scorching 110 to 120 degrees F. Parking lots and other hard surfaces tend to absorb solar energy and release it slowly. Furthermore, they lack the normal cooling properties of trees and vegetation, which act as natural air conditioners. Finally, urban areas release excess heat as a result of the combustion of fossil fuels for heating, cooling and transportation. As a result, highly urban areas tend to be much warmer than their rural counterparts and are known as urban heat islands. Researchers have found that summer temperatures tend to be six to eight degrees F warmer in the summer and two to four degrees F warmer during the winter months.

Water temperature in headwater streams is strongly influenced by local air temperatures. Summer temperatures in urban streams have been shown to increase by as much as five to 12 degrees F in response to watershed development (Table 15). Increased water temperatures can preclude temperature-sensitive species from being able to survive in urban streams.

Figure 26 shows the stream warming phenomenon in small headwater streams in the Maryland Piedmont.

Galli (1990) reported that stream temperatures throughout the summer increased in urban watersheds. He monitored five headwater streams in the Maryland Piedmont with different levels of IC. Each urban stream had mean temperatures that were consistently warmer than a forested reference stream, and stream warming appeared to be a direct function of watershed IC. Other factors, such as lack of riparian cover and the presence of ponds, were also demonstrated to amplify stream warming, but the primary contributing factor appeared to be watershed IC.

Johnson (1995) studied how stormwater influenced an urban trout stream in Minnesota and reported up to a 10 degree F increase in stream water temperatures after summer storm events. Paul *et al.* (2001) evaluated stream temperatures for 30 subwatersheds to the Etowah River in Georgia, which ranged from five to 61% urban land. They found a correlation between summer daily mean water temperatures and the percentage of urban land in a subwatershed.

Table 15: Research Review of Thermal Impacts in Urban Streams

Reference	Key Finding	Location
%IC Used as Indicator		
Galli, 1990	Increase in stream temperatures of five to 12 degrees Fahrenheit in urban watersheds; stream warming linked to IC.	MD
Urbanization Used as Indicator		
Johnson, 1995	Up to 10 degrees Fahrenheit increases in stream temperatures after summer storm events in an urban area	MN
LeBlanc *et al.*, 1997	Calibrated a model predicting stream temperature increase as a result of urbanization	Ontario
MCDEP, 2000	Monitoring effect of urbanization and stormwater ponds on stream temperatures revealed stream warming associated with urbanization and stormwater ponds	MD
Paul *et al.*, 2001	Daily mean stream temperatures in summer increased with urban land use	GA

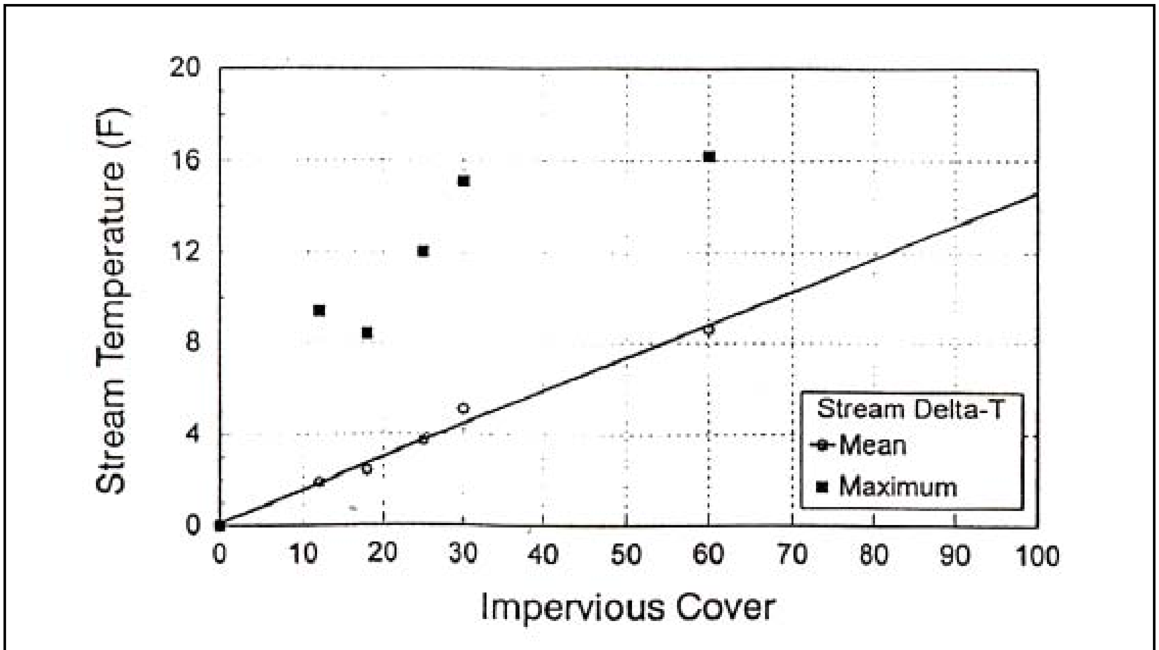


Figure 26: Stream Temperature Increase in Response to IC in Maryland Piedmont Streams (Galli, 1990)

Discharges from stormwater ponds can also contribute to stream warming in urban watersheds. Three studies highlight the temperature increase that can result from stormwater ponds. A study in Ontario found that baseflow temperatures below wet stormwater ponds increased by nine to 18 degrees F in the summer (SWAMP, 2000a, b). Oberts (1997) also measured change in the baseflow temperature as it flowed through a wetland/wet pond system in Minnesota. He concluded that the temperature had increased by an average of nine degrees F during the summer months. Galli (1988) also observed a mean increase of two to 10 degrees F in four stormwater ponds located in Maryland.

3.6 Alteration of Stream Channel Networks

Urban stream channels are often severely altered by man. Channels are lined with rip rap or concrete, natural channels are straightened, and first order and ephemeral streams are enclosed in storm drain pipes. From an engineering standpoint, these modifications rapidly convey flood waters downstream and locally stabilize stream banks. Cumulatively, however, these modifications can have a dramatic effect on the length and habitat quality of headwater stream networks.

3.6.1 Channel Modification

Over time, watershed development can alter or eliminate a significant percentage of the perennial stream network. In general, the loss of stream network becomes quite extensive when watershed IC exceeds 50%. This loss is striking when pre- and post-development stream networks are compared (Figure 27). The first panel illustrates the loss of stream network over time in a highly urban Northern Virginia watershed; the second panel shows how the drainage network of Rock Creek has changed in response to watershed development.

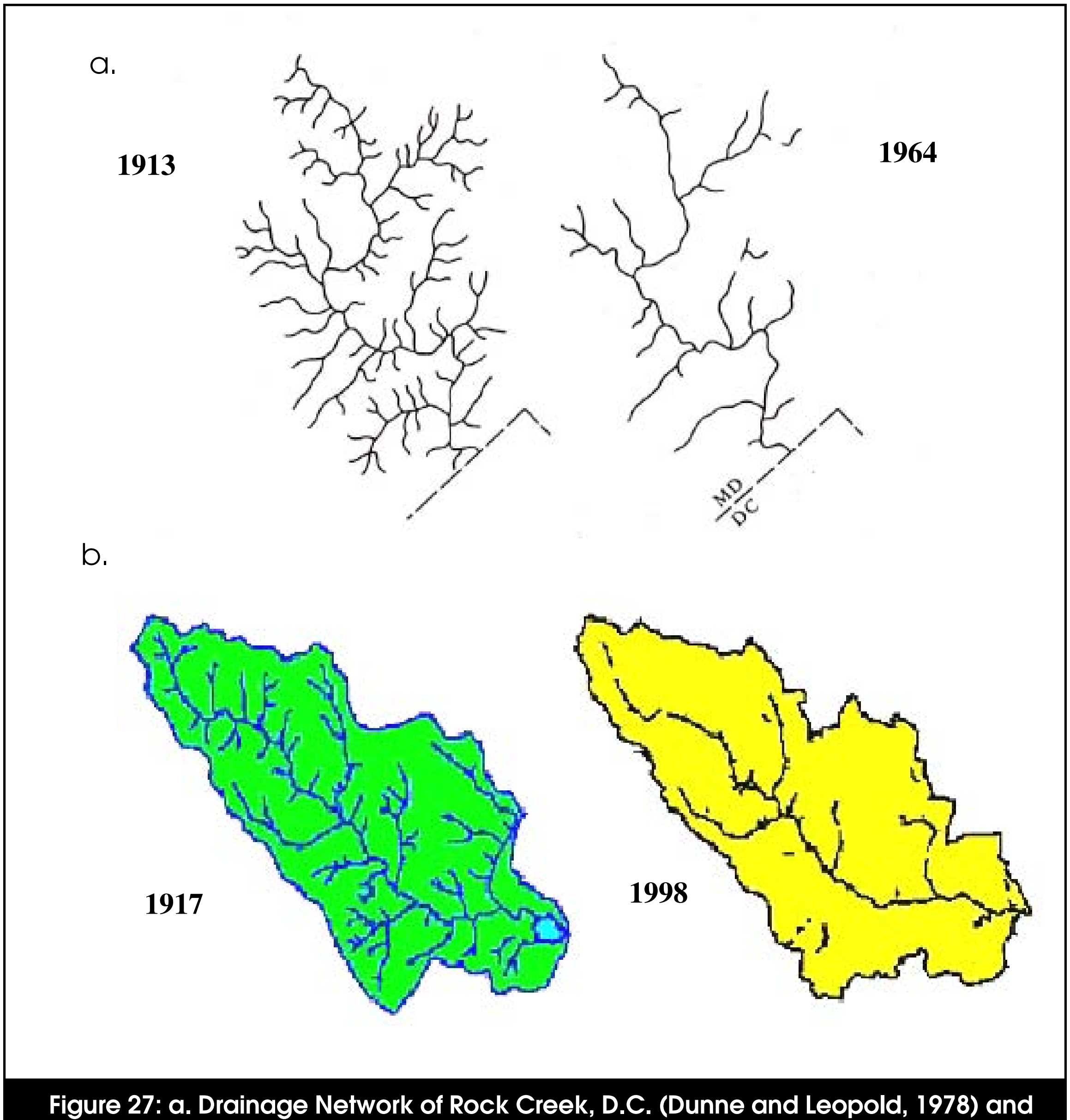


Figure 27: a. Drainage Network of Rock Creek, D.C. (Dunne and Leopold, 1978) and b. Drainage Network of Four Mile Run, VA Before and After Urbanization (NVRC, 2001)

In a national study of 269 gaged urban watersheds, Sauer *et al.* (1983) observed that channelization and channel hardening were important watershed variables that control peak discharge rates. The channel modifications increase the efficiency with which runoff is transported through the stream channel, increasing critical shear stress velocities and causing downstream channel erosion.

3.6.2 Barriers to Fish Migration

Infrastructure such as bridges, dams, pipelines and culverts can create partial or total barriers to fish migration and impair the ability of fish to move freely in a watershed. Blockages can have localized effects on small streams where non-migratory fish species can be prevented from re-colonizing upstream areas after acutely toxic events. The upstream movement of anadromous fish species such as shad, herring, salmon and steelhead can also be blocked by these barriers. Figure 28 depicts the prevalence of fish barriers in the Anacostia Watershed (MWCOG, 1992).

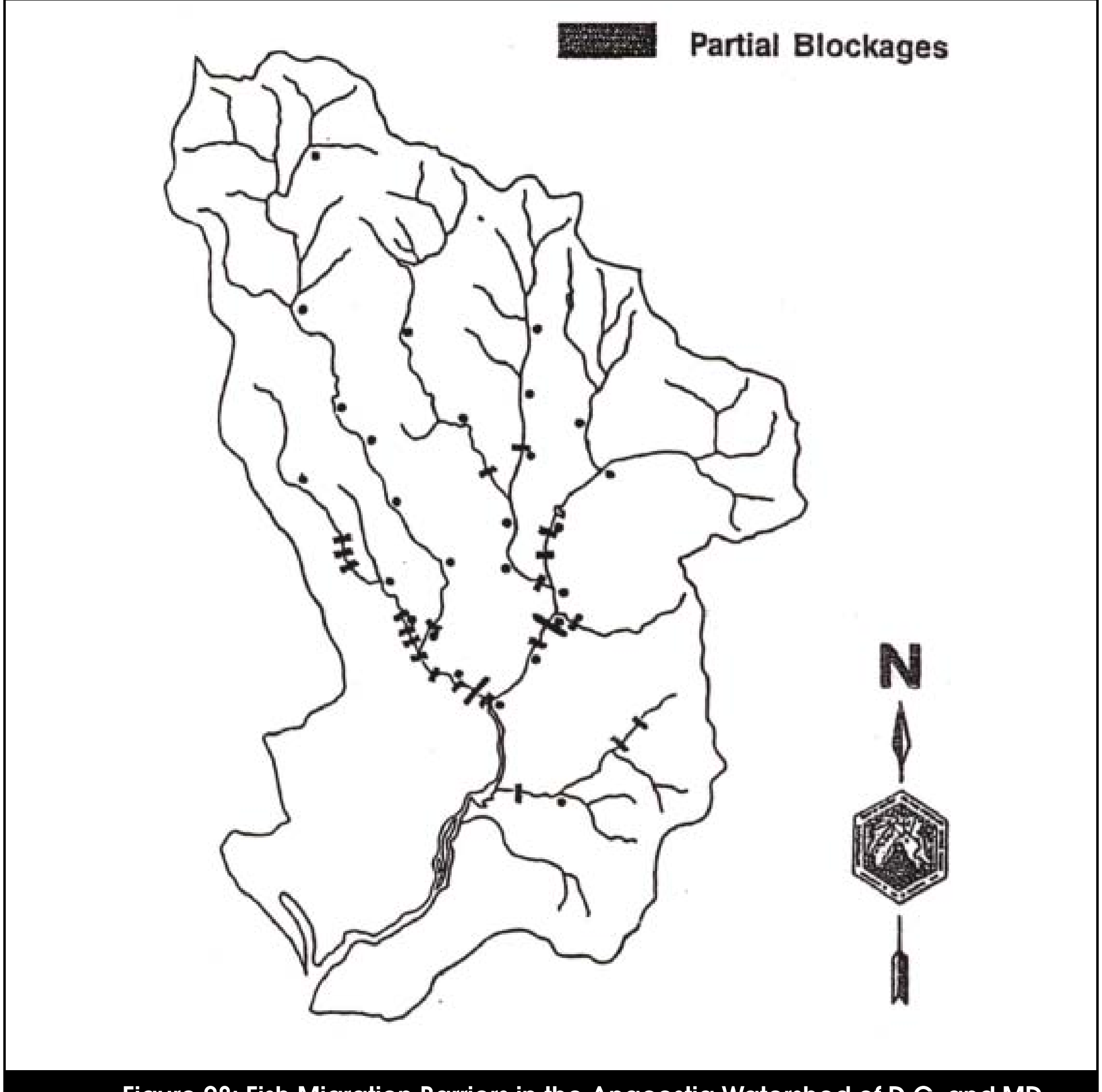


Figure 28: Fish Migration Barriers in the Anacostia Watershed of D.C. and MD (MWCOG, 1992)

3.7 Conclusion

Watershed development and the associated increase in IC have been found to significantly degrade the physical habitat of urban streams. In alluvial streams, the effects of channel enlargement and sediment transport can be severe at relatively low levels of IC (10 to 20%). However, the exact response of any stream is also contingent upon a combination of other physical factors such as geology, vegetation, gradient, the age of development, sediment supply, the use and design of stormwater treatment practices, and the extent of riparian buffers (Bledsoe, 2001).

Despite the uncertainty introduced by these factors, the limited geomorphic research to date suggests that physical habitat quality is almost always degraded by higher levels of watershed IC. Even in bedrock-controlled channels, where sediment transport and channel enlargement may not be as dramatic, researchers have noted changes in stream habitat features, such as embeddedness, loss of LWD, and stream warming.

Overall, the following conclusions can be made about the influence of watershed development on the physical habitat of urban streams:

- The major changes in physical habitat in urban streams are caused by the increased frequency and duration of bankfull and sub-bankfull discharges, and the attendant changes in sediment supply and transport. As a consequence, many urban streams experience significant channel enlargement. Generally, channel enlargement is most evident in alluvial streams.

- Typical habitat changes observed in urban streams include increased embeddedness, reduced supply of LWD, and simplification of stream habitat features such as pools, riffles and runs, as well as reduced channel sinuosity.

- Stream warming is often directly linked to watershed development, although more systematic subwatershed sampling is needed to precisely predict the extent of warming.

- Channel straightening, hardening and enclosure and the creation of fish barriers are all associated with watershed development. More systematic research is needed to establish whether these variables can be predicted based on watershed IC.

- In general, stream habitat diminishes at about 10% watershed IC, and becomes severely degraded beyond 25% watershed IC.

While our understanding of the relationship between stream habitat features and watershed development has improved in recent years, the topic deserves greater research in three areas. First, more systematic monitoring of composite habitat variables needs to be conducted across the full range of watershed IC. In particular, research is needed to define the approximate degree of watershed IC where urban streams are transformed into urban drainage systems.

Second, additional research is needed to explore the relationship between watershed IC and individual and measurable stream habitat parameters, such as bank erosion, channel sinuosity, pool depth and wetted perimeter. Lastly, more research is needed to determine if watershed treatment such as stormwater practices and stream buffers can mitigate the impacts of watershed IC on stream habitat. Together, these three research efforts could provide a technical foundation to develop a more predictive model of how watershed development influences stream habitat.

Chapter 4: Water Quality Impacts of Impervious Cover

This chapter presents information on pollutant concentrations found in urban stormwater runoff based on a national and regional data assessment for nine categories of pollutants. Included is a description of the Simple Method, which can be used to estimate pollutant loads based on the amount of IC found in a catchment or subwatershed. This chapter also addresses specific water quality impacts of stormwater pollutants and explores research on the sources and source areas of stormwater pollutants.

This chapter is organized as follows:

4.1 Introduction

Streams are usually the first aquatic system to receive stormwater runoff, and their water quality can be compromised by the pollutants it contains. Stormwater runoff typically contains dozens of pollutants that are detectable at some concentration, however small. Simply put, any pollutant deposited or derived from an activity on land will likely end up in stormwater runoff, although certain pollutants are consistently more likely to cause water quality problems in receiving waters. Pollutants that are frequently found in stormwater runoff can be grouped into nine broad categories: sediment, nutrients, metals, hydrocarbons, bacteria and pathogens, organic carbon, MTBE, pesticides, and deicers.

The impact that stormwater pollutants exert on water quality depends on many factors, including concentration, annual pollutant load, and category of pollutant. Based on nationally reported concentration data, there is considerable variation in stormwater pollutant concentrations. This variation has been at least partially attributed to regional differences, including rainfall and snowmelt. The volume and regularity of rainfall, the length of snow accumulation, and the rate of snowmelt can all influence stormwater pollutant concentrations.

The annual pollutant load can have long-term effects on stream water quality, and is particularly important information for stormwater managers to have when dealing with non-point source pollution control. The Simple Method is a model developed to estimate the pollutant load for chemical pollutants, assuming that the annual pollutant load is a function of IC. It is an effective method for determining annual sediment, nutrient, and trace metal loads. It cannot always be applied to other stormwater pollutants, since they are not always correlated with IC.

The direct water quality impact of stormwater pollutants also depends on the type of pollutant, as different pollutants impact streams differently. For example, sediments affect stream habitat and aquatic biodiversity; nutrients cause eutrophication; metals, hydrocarbons, deicers, and MTBE can be toxic to aquatic life; and organic carbon can lower dissolved oxygen levels.

The impact stormwater pollutants have on water quality can also directly influence human uses and activities. Perhaps the pollutants of greatest concern are those with associated public health impacts, such as bacteria and pathogens. These pollutants can affect the availability of clean drinking water and limit consumptive recreational activities, such as swimming or fishing. In extreme situations, these pollutants can even limit contact recreational activities such as boating and wading.

It should be noted that although there is much research available on the effects of urbanization on water quality, the majority has not been focused on the impact on streams, but on the response of lakes, reservoirs, rivers and estuaries. It is also important to note that not all pollutants are equally represented in monitoring conducted to date. While we possess excellent monitoring data for sediment, nutrients and trace metals, we have relatively little monitoring data for pesticides, hydrocarbons, organic carbon, deicers, and MTBE.

4.2 Summary of National and Regional Stormwater Pollutant Concentration Data

4.2.1 National Data

National mean concentrations of typical stormwater pollutants are presented in Table 16. National stormwater data are compiled from the Nationwide Urban Runoff Program (NURP), with additional data obtained from the U.S.Geological Survey (USGS), as well as initial stormwater monitoring conducted for EPA's National Pollutant Discharge Elimination System (NPDES) Phase I stormwater program.

In most cases, stormwater pollutant data is reported as an event mean concentration (EMC), which represents the average concentration of the pollutant during an entire stormwater runoff event.

When evaluating stormwater EMC data, it is important to keep in mind that regional EMCs can differ sharply from the reported national pollutant EMCs. Differences in EMCs between regions are often attributed to the variation in the amount and frequency of rainfall and snowmelt.

4.2.2 Regional Differences Due to Rainfall

The frequency of rainfall is important, since it influences the accumulation of pollutants on IC that are subsequently available for wash-off during storm events. The USGS developed a national stormwater database encompassing 1,123 storms in 20 metropolitan areas and used it as the primary data source to define regional differences in stormwater EMCs. Driver (1988) performed regression analysis to determine which factors had the greatest influence on stormwater EMCs and determined that annual rainfall depth was the best overall predictor. Driver grouped together stormwater EMCs based on the depth of average annual rainfall, and Table 17 depicts the regional rainfall groupings and general trends for each region. Table 18 illustrates the distribution of stormwater EMCs for a range of rainfall regions from 13 local studies, based on other monitoring studies. In general, stormwater EMCs for nutrients, suspended sediment and metals tend to be higher in arid and semi-arid

Table 16: National EMCs for Stormwater Pollutants

Pollutant	Source	EMCs		Number of Events
		Mean	Median	
Sediments (mg/l)				
TSS	(1)	78.4	54.5	3047
Nutrients (mg/l)				
Total P	(1)	0.32	0.26	3094
Soluble P	(1)	0.13	0.10	1091
Total N	(1)	2.39	2.00	2016
TKN	(1)	1.73	1.47	2693
Nitrite & Nitrate	(1)	0.66	0.53	2016
Metals (Fg/l)				
Copper	(1)	13.4	11.1	1657
Lead	(1)	67.5	50.7	2713
Zinc	(1)	162	129	2234
Cadmium	(1)	0.7	N/R	150
Chromium	(4)	4	7	164
Hydrocarbons (mg/l)				
PAH	(5)	3.5	N/R	N/R
Oil and Grease	(6)	3	N/R	N/R
Bacteria and Pathogens (colonies/ 100ml)				
Fecal Coliform	(7)	15,038	N/R	34
Fecal Streptococci	(7)	35,351	N/R	17
Organic Carbon (mg/l)				
TOC	(11)	17	15.2	19 studies
BOD	(1)	14.1	11.5	1035
COD	(1)	52.8	44.7	2639
MTBE	(8)	N/R	1.6	592
Pesticides (Fg/l)				
Diazinon	(10)	N/R	0.025	326
	(2)	N/R	0.55	76
Chlorpyrifos	(10)	N/R	N/R	327
Atrazine	(10)	N/R	0.023	327
Prometon	(10)	N/R	0.031	327
Simazine	(10)	N/R	0.039	327
Chloride (mg/l)				
Chloride	(9)	N/R	397	282

Sources: [1] Smullen and Cave, 1998; [2] Brush et al., 1995; [3] Baird et al., 1996; [4] Bannerman et al., 1996; [5] Rabanal and Grizzard, 1995; [6] Crunkilton et al., 1996; [7] Schueler, 1999; [8] Delzer, 1996; [9] Environment Canada, 2001; [10] USEPA, 1998; [11] CWP, 2001a   N/R - Not Reported

Table 17: Regional Groupings by Annual Rainfall Amount (Driver, 1988)

Region	Annual Rainfall	States Monitored	Concentration Data
Region I: Low Rainfall	<20 inches	AK, CA, CO, NM, UT	Highest mean and median values for Total N, Total P, TSS and COD
Region II: Moderate Rainfall	20 40 inches	HA, IL, MI, MN, MI, NY, TX, OR, OH, WA, WI	Higher mean and median values than Region III for TSS, dissolved phosphorus and cadmium
Region III: High Rainfall	>40 inches	FL, MD, MA, NC, NH, NY, TX, TN, AR	Lower values for many parameters likely due to the frequency of storms and the lack of build up in pollutants

regions and tend to decrease slightly when annual rainfall increases (Table 19).

It is also hypothesized that a greater amount of sediment is eroded from pervious surfaces in arid or semi-arid regions than in humid regions due to the sparsity of protective vegetative cover. Table 19 shows that the highest concentrations of total suspended solids were recorded in regions with least rainfall. In addition, the chronic toxicity standards for several metals are most frequently exceeded during low rainfall regions (Table 20).

4.2.3 Cold Region Snowmelt Data

In colder regions, snowmelt can have a significant impact on pollutant concentrations. Snow accumulation in winter coincides with pollutant build-up; therefore, greater concentrations of pollutants are measured during snowmelt events. Sources of snowpack pollution in urban areas include wet and dry atmospheric deposition, traffic emissions, urban litter, deteriorated infrastructure, and deicing chemicals and abrasives (WERF, 1999).

Oberts *et al.* (1989) measured snowmelt pollutants in Minnesota streams and found that as much as 50% of annual sediment, nutrient, hydrocarbon and metal loads could be attributed to snowmelt runoff during late winter and early spring. This trend probably applies to any region where snow cover persists through much of the winter. Pollutants accumulate in the snowpack and then contribute high concentrations during snowmelt runoff. Oberts (1994) described four types of snowmelt runoff events and the resulting pollutant characteristics (Table 21).

A typical hydrograph for winter and early spring snow melts in a northern cold climate is portrayed in Figure 29. The importance of snowpack melt on peak runoff during March 1989 can clearly be seen for an urban watershed located in St. Paul, Minnesota.

Major source areas for snowmelt pollutants include snow dumps and roadside snowpacks. Pollutant concentrations in snow dumps can be as much as five times greater than typical stormwater pollutant concentrations (Environment Canada, 2001). Snow dumps and packs accumulate pollutants over the winter months and can release them during a few rain or snow melt events in the early spring. High levels of chloride, lead, phosphorus, biochemical oxygen demand, and total suspended solids have been reported in snow pack runoff (La Barre *et al*, 1973; Oliver *et al.*, 1974; Pierstorff and Bishop, 1980; Scott and Wylie, 1980; Van Loon, 1972).

Atmospheric deposition can add pollutants to snow piles and snowpacks. Deposited pollutants include trace metals, nutrients and particles that are primarily generated by fossil fuel combustion and industrial emissions (Boom and Marsalek, 1988; Horkeby and Malmqvist, 1977; Malmqvist, 1978; Novotny and Chester, 1981; Schrimpff and Herrman, 1979).

Table 18: Stormwater Pollutant Event Mean Concentration for Different U.S. Regions (Units: mg/l, except for metals which are in Fg/l)

		Region I - Low Rainfall				Region II - Moderate Rainfall			Region III - High Rainfall				Snow
	National	Phoenix, AZ	San Diego, CA	Boise, ID	Denver, CO	Dallas, TX	Marquette, MI	Austin, TX	MD	Louisville, KY	GA	FL	MN
Reference	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(11)	(12)
Annual Rainfall (in.)	N/A	7.1"	10"	11"	15"	28"	32"	32"	41"	43"	51"	52"	N/R
Number of Events	3000	40	36	15	35	32	12	N/R	107	21	81	N/R	49
Pollutant													
TSS	78.4	227	330	116	242	663	159	190	67	98	258	43	112
Total N	2.39	3.26	4.55	4.13	4.06	2.70	1.87	2.35	N/R	2.37	2.52	1.74	4.30
Total P	0.32	0.41	0.7	0.75	0.65	0.78	0.29	0.32	0.33	0.32	0.33	0.38	0.70
Soluble P	0.13	0.17	0.4	0.47	N/R	N/R	0.04	0.24	N/R	0.21	0.14	0.23	0.18
Copper	14	47	25	34	60	40	22	16	18	15	32	1.4	N/R
Lead	68	72	44	46	250	330	49	38	12.5	60	28	8.5	100
Zinc	162	204	180	342	350	540	111	190	143	190	148	55	N/R
BOD	14.1	109	21	89	N/R	112	15.4	14	14.4	88	14	11	N/R
COD	52.8	239	105	261	227	106	66	98	N/R	38	73	64	112

Sources: Adapted from Caraco, 2000a: (1) Smullen and Cave, 1998; (2) Lopes et al.; 1995; (3) Schiff, 1996; (4) Kjelstrom, 1995 (computed); (5) DRCOG, 1983, (6) Brush et al., 1995; (7) Steuer et al., 1997; (8) Barrett et al., 1995; (9) Barr, 1997; (10) Evaldi et al., 1992; (11) Thomas and McClelland, 1995; (12) Oberts, 1994 N/R = Not Reported; N/A = Not Applicable

Table 19: Mean and Median Nutrient and Sediment Stormwater Concentrations for Residential Land Use Based on Rainfall Regions (Driver, 1988)

Region	Total N (median)	Total P (median)	TSS (mean)
Region I: Low Rainfall	4	0.45	320
Region II: Moderate Rainfall	2.3	0.31	250
Region III: High Rainfall	2.15	0.31	120

Table 20: EPA 1986 Water Quality Standards and Percentage of Metal Concentrations Exceeding Water Quality Standards by Rainfall Region (Driver, 1988)

	Cadmium	Copper	Lead	Zinc
EPA Standards	10 Fg/l	12 Fg/l	32 Fg/l	47 Fg/l
	Percent Exceedance of EPA Standards			
Region I: Low Rainfall	1.5%	89%	97%	97%
Region II: Moderate Rainfall	0	78%	89%	85%
Region III: High Rainfall	0	75%	91%	84%

Table 21: Runoff and Pollutant Characteristics of Snowmelt Stages (Oberts, 1994)

Snowmelt Stage	Duration /Frequency	Runoff Volume	Pollutant Characteristics
Pavement	Short, but many times in winter	Low	Acidic, high concentrations of soluble pollutants; Chloride, nitrate, lead; total load is minimal
Roadside	Moderate	Moderate	Moderate concentrations of both soluble and particulate pollutants
Pervious Area	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants; moderate to high concentrations of particulate pollutants depending on flow
Rain-on-Snow	Short	Extreme	High concentrations of particulate pollutants; moderate to high concentrations of soluble pollutants; high total load

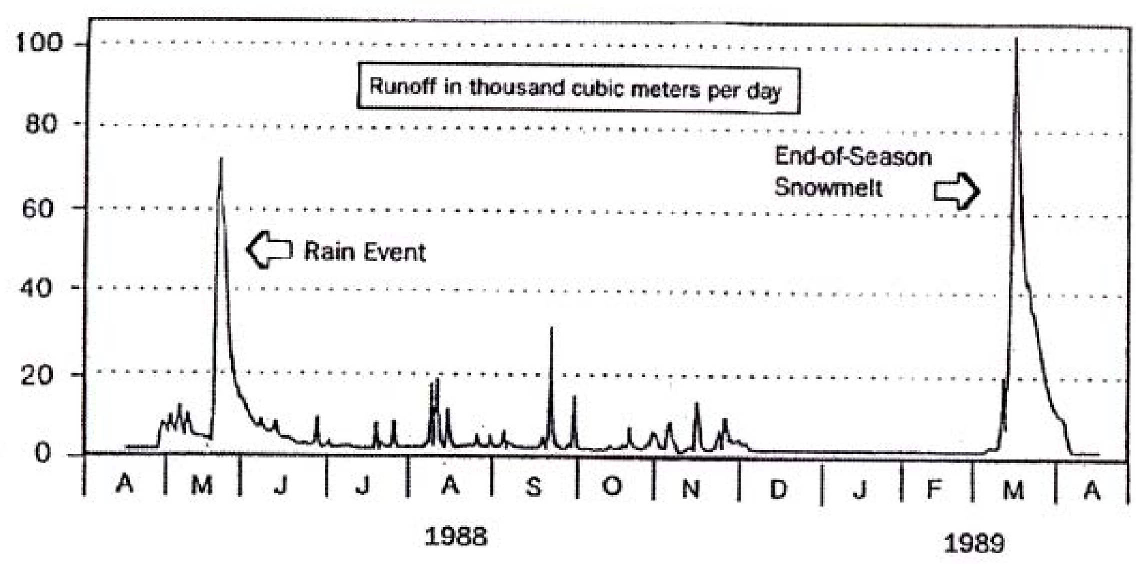


Figure 29: Snowmelt Runoff Hydrograph for Minneapolis Stream (Oberts, 1994)

4.3 Relationship Between Pollutant Loads and IC: The Simple Method

Urban stormwater runoff contains a wide range of pollutants that can degrade downstream water quality. The majority of stormwater monitoring research conducted to date supports several generalizations. First, the unit area pollutant load delivered to receiving waters by stormwater runoff increases in direct proportion to watershed IC. This is not altogether surprising, since pollutant load is the product of the average pollutant concentration and stormwater runoff volume. Given that runoff volume increases in direct proportion to IC, pollutant loads must automatically increase when IC increases, as long the average pollutant concentration stays the same (or increases). This relationship is a central assumption in most simple and complex pollutant loading models (Bicknell *et al.*, 1993; Donigian and Huber, 1991; Haith *et al.*, 1992; Novotny and Chester, 1981; NVPDC, 1987; Pitt and Voorhees, 1989).

Recognizing the relationship between IC and pollutant loads, Schueler (1987) developed the "Simple Method" to quickly and easily estimate stormwater pollutant loads for small urban watersheds (see Figure 30). Estimates of pollutant loads are important to watershed managers as they grapple with costly decisions on non-point source control. The Simple Method is empirical in nature and utilizes the extensive regional and national database (Driscoll, 1983; MWCOG, 1983; USEPA, 1983). Figure 30 provides the basic equations to estimate pollutant loads using the Simple

Figure 30: The Simple Method - Basic Equations

The Simple Method estimates pollutant loads as the product of annual runoff volume and pollutant EMC, as:

$$(1)\ L = 0.226 * R * C * A$$

Where: L = Annual load (lbs), and:
R = Annual runoff (inches)
C = Pollutant concentration in stormwater, EMC (mg/l)
A = Area (acres)
0.226 = Unit conversion factor

For bacteria, the equation is slightly different, to account for the differences in units. The modified equation for bacteria is:

$$(2)\ L = 1.03 * 10^{-3} * R * C * A$$

Where: L = Annual load (Billion Colonies), and:
R = Annual runoff (inches)
C = Bacteria concentration (#/100 ml)
A = Area (acres)
$1.03 * 10^{-3}$ = Unit conversion factor

Annual Runoff

The Simple Method calculates the depth of annual runoff as a product of annual runoff volume and a runoff coefficient (Rv). Runoff volume is calculated as:

$$(3)\ R = P * P_j * Rv$$

Where: R = Annual runoff (inches), and:
P = Annual rainfall (inches)
P_j = Fraction of annual rainfall events that produce runoff (usually 0.9)
Rv = Runoff coefficient

In the Simple Method, the runoff coefficient is calculated based on IC in the subwatershed. The following equation represents the best fit line for the data set (N=47, R^2=0.71).

$$(4)\ Rv = 0.05 + 0.9Ia$$

Where: Rv = runoff coefficient, and:
Ia = Impervious fraction

Method. It assumes that loads of stormwater pollutants are a direct function of watershed IC, as IC is the key independent variable in the equation.

The technique requires a modest amount of information, including the subwatershed drainage area, IC, stormwater runoff pollutant EMCs, and annual precipitation. With the Simple Method, the investigator can either divide up land use into specific areas (i.e. residential, commercial, industrial, and roadway) and calculate annual pollutant loads for each land use, or utilize a generic urban land use. Stormwater pollutant EMC data can be derived from the many summary tables of local, regional, or national monitoring efforts provided in this chapter (e.g., Tables 16, 18, 22, 28, 30, 35, 36, 40, and 44). The model also requires different IC values for separate land uses within a subwatershed. Representative IC data from Cappiella and Brown (2001) were provided in Table 2 (Chapter 1).

Additionally, the Simple Method should not be used to estimate annual pollutant loads of deicers, hydrocarbons and MTBE, because they have not been found to be correlated with IC. These pollutants have been linked to other indicators. Chlorides, hydrocarbons and MTBE are often associated with road density and vehicle miles traveled (VMT). Pesticides are associated with turf area, and traffic patterns and "hotspots" have been noted as potential indicators for hydrocarbons and MTBE.

Limitations of the Simple Method

The Simple Method should provide reasonable estimates of changes in pollutant export resulting from urban development. However, several caveats should be kept in mind when applying this method.

The Simple Method is most appropriate for assessing and comparing the relative stormflow pollutant load changes from different land uses and stormwater treatment scenarios. The Simple Method provides estimates of storm pollutant export that are probably close to the "true" but unknown value for a development site, catchment, or subwatershed. However, it is very important not to overemphasize the precision of the load estimate obtained. For example, it would be inappropriate to use the Simple Method to evaluate relatively similar development scenarios (e.g., 34.3% versus 36.9% IC). The Simple Method provides a general planning estimate of likely storm pollutant export from areas at the scale of a development site, catchment or subwatershed. More sophisticated modeling is needed to analyze larger and more complex watersheds.

In addition, the Simple Method only estimates pollutant loads generated during storm events. It does not consider pollutants associated with baseflow during dry weather. Typically, baseflow is negligible or non-existent at the scale of a single development site and can be safely neglected. However, catchments and subwatersheds do generate significant baseflow volume. Pollutant loads in baseflow are generally low and can seldom be distinguished from natural background levels (NVPDC, 1979).

Consequently, baseflow pollutant loads normally constitute only a small fraction of the total pollutant load delivered from an urban area. Nevertheless, it is important to remember that the load estimates refer only to storm event derived loads and should not be confused with the total pollutant load from an area. This is particularly important when the development density of an area is low. For example, in a low density residential subwatershed (IC < 5%), as much as 75% of the annual runoff volume could occur as baseflow. In such a case, annual baseflow load may be equivalent to the annual stormflow load.

4.4 Sediment

Sediment is an important and ubiquitous pollutant in urban stormwater runoff. Sediment can be measured in three distinct ways: Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and turbidity. TSS is a measure of the total mass suspended sediment particles in water. The measurement of TSS in urban stormwater helps to estimate sediment load transported to local and downstream receiving waters. Table 22 summarizes stormwater EMCs for total suspended solids, as reported by Barrett *et al.* (1995), Smullen and Cave (1998), and USEPA (1983). TDS is a measure of the dissolved solids and minerals present in stormwater runoff and is used as a primary indication of the purity of drinking water. Since few stormwater monitoring efforts have focused on TDS, they are not reported in this document. Turbidity is a measure of how suspended solids present in water reduce the ability of light to penetrate the water column. Turbidity can exert impacts on aquatic biota, such as the ability of submerged aquatic vegetation to receive light and the ability of fish and aquatic insects to use their gills (Table 23).

4.4.1 Concentrations

TSS concentrations in stormwater across the country are well documented. Table 18 reviews mean TSS EMCs from 13 communities across the country and reveals a wide range of recorded concentrations. The lowest concentration of 43 mg/l was reported in Florida, while TSS reached 663 mg/l in Dallas, Texas. Variation in sediment concentrations has been attributed to regional rainfall differences (Driver, 1988); construction site runoff (Leopold, 1968); and bank erosion (Dartiguenave *et al.*, 1997). National values are provided in Table 22.

Turbidity levels are not as frequently reported in national and regional monitoring summaries. Barrett and Malina (1998) monitored turbidity at two sites in Austin, Texas and reported a mean turbidity of 53 NTU over 34 storm events (Table 22).

4.4.2 Impacts of Sediment on Streams

The impacts of sediment on aquatic biota are well documented and can be divided into impacts caused by suspended sediment and those caused by deposited sediments (Tables 23 and 24).

In general, high levels of TSS and/or turbidity can affect stream habitat and cause sedimentation in downstream receiving waters. Deposited sediment can cover benthic organisms such as aquatic insects and freshwater mussels. Other problems associated with high sediments loads include stream warming by reflecting radiant energy due to increased turbidity (Kundell and Rasmussen, 1995), decreased flow capacity (Leopold, 1973), and increasing overbank flows (Barrett and Malina, 1998). Sediments also transport other pollutants which bind to sediment particles. Significant levels of pollutants can be transported by sediment during stormwater runoff events,

Table 22: EMCs for Total Suspended Solids and Turbidity

Pollutant	EMCs		Number of Events	Source
	Mean	Median		
TSS (mg/l)	78.4	54.5	3047	Smullen and Cave, 1998
	174	113	2000	USEPA, 1983
Turbidity (NTU)	53	N/R	423	Barrett and Malina, 1998

N/R = Not Reported

Table 23: Summary of Impacts of Suspended Sediment on the Aquatic Environment (Schueler and Holland, 2000)
Abrades and damages fish gills, increasing risk of infection and disease
Scouring of periphyton from stream (plants attached to rocks)
Loss of sensitive or threatened fish species when turbidity exceeds 25 NTU
Shifts in fish community toward more sediment-tolerant species
Decline in sunfish, bass, chub and catfish when month turbidity exceeds 100 NTU
Reduces sight distance for trout, with reduction in feeding efficiency
Reduces light penetration causing reduction in plankton and aquatic plant growth
Adversely impacts aquatic insects, which are the base of the food chain
Slightly increases the stream temperature in the summer
Suspended sediments can be a major carrier of nutrients and metals
Reduces anglers chances of catching fish

Table 24: Summary of Impacts of Deposited Sediments on the Aquatic Environment (Schueler and Holland, 2000)
1. Physical smothering of benthic aquatic insect community
2. Reduced survival rates for fish eggs
3. Destruction of fish spawning areas and eggs
4. Embeddedness of stream bottom reduced fish and macroinvertebrate habitat value
5. Loss of trout habitat when fine sediments are deposited in spawning or riffle-runs
6. Sensitive or threatened darters and dace may be eliminated from fish community
7. Increase in sediment oxygen demand can deplete dissolved oxygen in streams
8. Significant contributing factor in the alarming decline of freshwater mussels
9. Reduced channel capacity, exacerbating downstream bank erosion and flooding
10. Reduced flood transport capacity under bridges and through culverts
11. Deposits diminish scenic and recreational values of waterways

including trace metals, hydrocarbons and nutrients (Crunkilton *et al.,* 1996; Dartiguenave *et al*., 1997; Gavin and Moore, 1982; Novotny and Chester, 1989; Schueler 1994b).

4.4.3 Sources and Source Areas of Sediment

Sediment sources in urban watersheds include stream bank erosion; erosion from exposed soils, such as from construction sites; and washoff from impervious areas (Table 25).

As noted in this chapter, streambank erosion is generally considered to be the primary source of sediment to urban streams. Recent studies by Dartiguenave *et al.* (1997) and Trimble (1997) determined that streambank erosion contributes the majority of the annual sediment budget of urban streams. Trimble (1997) directly measured stream cross sections, sediment aggradation and suspended sediment loads and determined that two-thirds of the annual sediment budget of a San Diego, California watershed was supplied by streambank erosion. Dartiguenave *et al.* (1997) developed a GIS based model in Austin, Texas to determine the effects of stream bank erosion on the annual sediment budget. They compared modeled sediment loads from the watershed with the actual sediment loads measured at USGS gaging stations and concluded that more than 75% of the sediment load came from streambank erosion. Dartiguenave *et al.* (1997) reported that sediment load per unit area increases with increasing IC (Figure 31).

Sediment loads are also produced by washoff of sediment particles from impervious areas and their subsequent transport in stormwater runoff sediment. Source areas include parking lots, streets, rooftops, driveways and lawns. Streets and parking lots build up dirt and grime from the wearing of the street surface, exhaust particulates, “blown on” soil and organic matter, and atmospheric deposition. Lawn runoff primarily contains soil and organic matter. Urban source areas that produce the highest TSS concentrations include streets, parking lots and lawns (Table 26).

Parking lots and streets are not only responsible for high concentrations of sediment but also high runoff volumes. The SLAMM source loading model (Pitt and Voorhees, 1989) looks at runoff volume and concentrations of pollutants from different urban land uses and predicts stream loading. When used in the Wisconsin and Michigan subwatersheds, it demonstrated that parking lots and streets were responsible for over 70% of the TSS delivered to the stream. (Steuer *et al*., 1997; Waschbusch *et al*., 2000).

Table 25: Sources and Loading of Suspended Solids Sediment in Urban Areas

Sources	Loading	Source
Bank Erosion	75% of stream sediment budget	Dartinguenave *et al*., 1997
	66% of stream sediment budget	Trimble, 1997
Overland Flow- Lawns	397 mg/l (geometric mean)	Bannerman *et al*., 1993
	262 mg/l	Steuer *et al*., 1997
	11.5% (estimated; 2 sites)	Waschbusch *et al*., 2000
Construction Sites	200 to 1200 mg/l	Table 27
Washoff from Impervious Surfaces	78 mg/l (mean)	Table 16

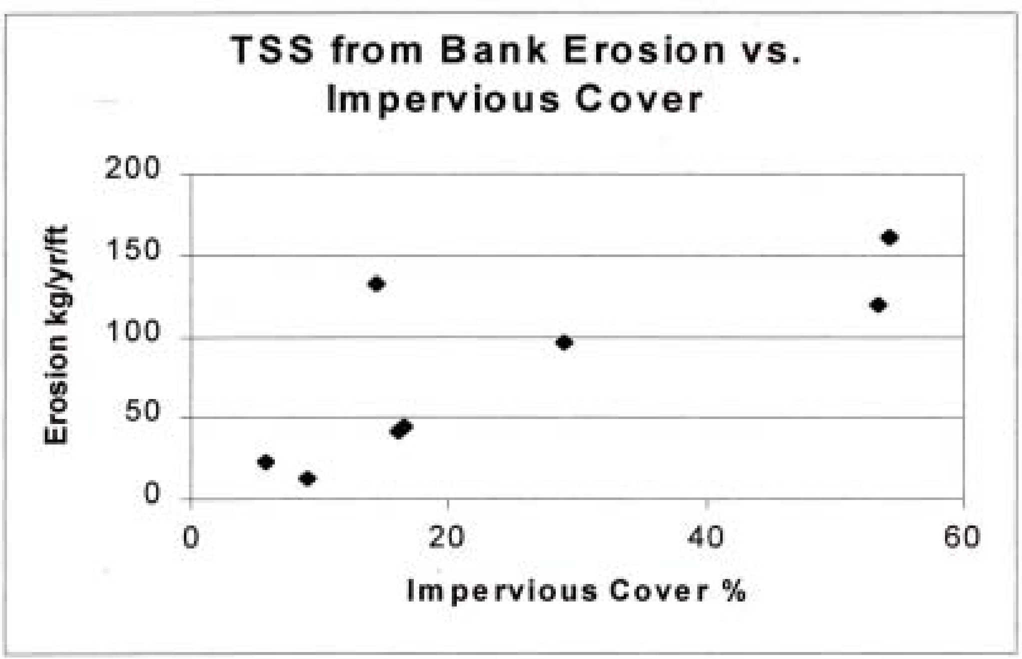


Figure 31: TSS from Bank Erosion vs. IC in Texas Streams (Daringuenave *et al*., 1997)

The third major source of sediment loads is erosion from construction sites. Several studies have reported extremely high TSS concentrations in construction site runoff, and these findings are summarized in Table 27. TSS concentrations from uncontrolled construction sites can be more than 150 times greater than those from undeveloped land (Leopold, 1968) and can be reduced if erosion and sediment control practices are applied to construction sites.

Table 26: Source Area Geometric Mean Concentrations for Suspended Solids in Urban Areas

Source Area	Suspended Solids (mg/l)		
Source	(1)	(2)	(3)
Commercial Parking Lot	110	58	51
High Traffic Street	226	232	65
Medium Traffic Street	305	326	51
Low Traffic Street	175	662	68
Commercial Rooftop	24	15	18
Residential Rooftop	36	27	15
Residential Driveway	157	173	N/R
Residential Lawn	262	397	59

Sources: (1) Steuer et al., 1997; (2) Bannerman et al., 1993; (3) Waschbusch et al., 2000; N/R = Not Reported

Table 27: Mean TSS Inflow and Outflow at Uncontrolled, Controlled and Simulated Construction Sites

Source	Mean Inflow TSS Concentration (mg/l)	Mean Outflow TSS Concentration (mg/l)	Location
Uncontrolled Sites			
Horner *et al.*, 1990	7,363	281	PNW
Schueler and Lugbill,1990	3,646	501	MD
York and Herb, 1978	4,200	N/R	MD
Islam *et al.*, 1988	2,950	N/R	OH
Controlled Sites			
Schueler and Lugbill, 1990	466	212	MD
Simulated Sediment Concentrations			
Jarrett, 1996	9,700	800	PA
Sturm and Kirby, 1991	1,500-4,500	200-1,000	GA
Barfield and Clar, 1985	1,000-5,000	200-1,200	MD
Dartiguenave *et al.*, 1997	N/R	600	TX

N/R = Not Reported

4.5 Nutrients

Nitrogen and phosphorus are essential nutrients for aquatic systems. However, when they appear in excess concentrations, they can exert a negative impact on receiving waters. Nutrient concentrations are reported in several ways. Nitrogen is often reported as nitrate (NO_3) and nitrite (NO_2), which are inorganic forms of nitrogen; total nitrogen (Total N), which is the sum of nitrate, nitrite, organic nitrogen and ammonia; and total Kjeldhal nitrogen (TKN), which is organic nitrogen plus ammonia.

Phosphates are frequently reported as soluble phosphorus, which is the dissolved and reactive form of phosphorus that is available for uptake by plants and animals. Total phosphorus (Total P) is also measured, which includes both organic and inorganic forms of phosphorus. Organic phosphorus is derived from living plants and animals, while inorganic phosphate is comprised of phosphate ions that are often bound to sediments.

4.5.1 Concentrations

Many studies have indicated that nutrient concentrations are linked to land use type, with urban and agricultural watersheds producing the highest nutrient loads (Chessman *et al.* 1992; Paul *et al.*, 2001; USGS, 2001b and Wernick *et al.*,1998). Typical nitrogen and phosphorus EMC data in urban stormwater runoff are summarized in Table 28.

Some indication of the typical concentrations of nitrate and phosphorus in stormwater runoff are evident in Figures 32 and 33. These graphs profile average EMCs in stormwater runoff recorded at 37 residential catchments across the U.S. The average nitrate EMC is remarkably consistent among residential neighborhoods, with most clustered around the mean of 0.6 mg/l and a range of 0.25 to 1.4 mg/l. The concentration of phosphorus during storms is also very consistent with a mean of 0.30 mg/l and a rather tight range of 0.1 to 0.66 mg/l (Schueler, 1995).

The amount of annual rainfall can also influence the magnitude of nutrient concentrations in stormwater runoff. For example, both Caraco (2000a) and Driver (1988) reported that the highest nutrient EMCs were found in stormwater from arid or semi-arid regions.

Table 28: EMCs of Phosphorus and Nitrogen Urban Stormwater Pollutants

Pollutant	EMCs (mg/l)		Number of Events	Source
	Mean	Median		
Total P	0.315	0.259	3094	Smullen and Cave, 1998
	0.337	0.266	1902	USEPA, 1983
Soluble P	0.129	0.103	1091	Smullen and Cave, 1998
	0.1	0.078	767	USEPA, 1983
Total N	2.39	2.00	2016	Smullen and Cave, 1998
	2.51	2.08	1234	USEPA, 1983
TKN	1.73	1.47	2693	Smullen and Cave, 1998
	1.67	1.41	1601	USEPA, 1983
Nitrite & Nitrate	0.658	0.533	2016	Smullen and Cave, 1998
	0.837	0.666	1234	USEPA, 1983

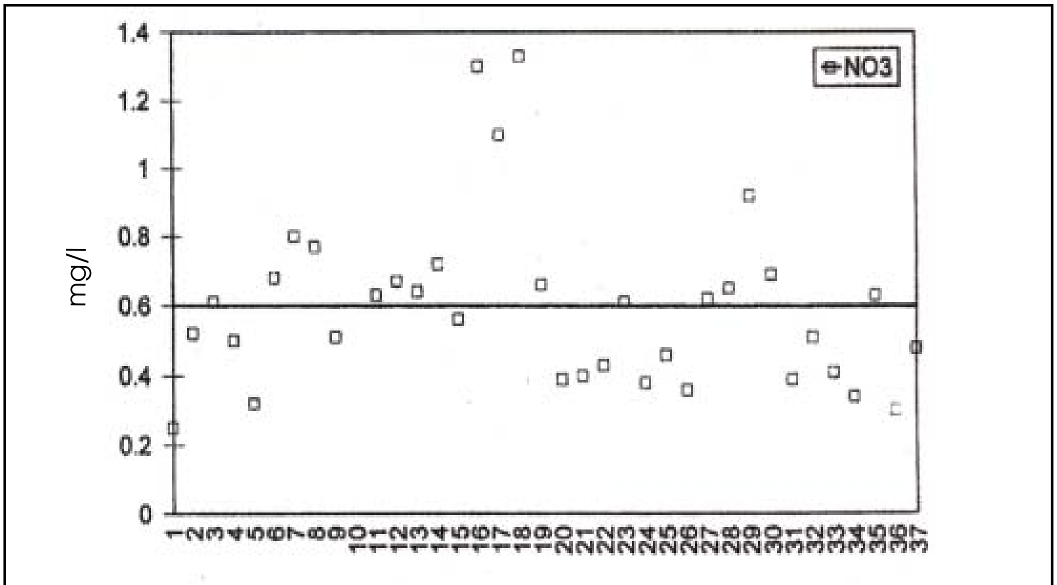


Figure 32: Nitrate-Nitrogen Concentration in Stormwater Runoff at 37 Sites Nationally (Schueler, 1999)

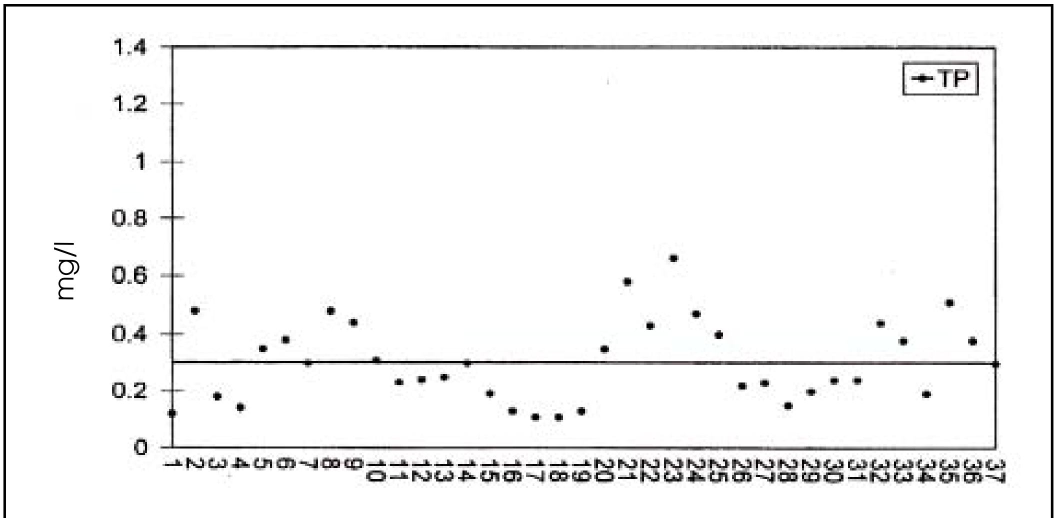


Figure 33: Total Phosphorus Concentration in Stormwater at 37 Sites Nationally (Schueler, 1999)

4.5.2 Impacts of Nutrients on Streams

Much research on the impact of nutrient loads has been focused on lakes, reservoirs and estuaries, which can experience eutrophication. Nitrogen and phosphorus can contribute to algae growth and eutrophic conditions, depending on which nutrient limits growth (USEPA, 1998). Dissolved oxygen is also affected by eutrophication. When algae or aquatic plants that are stimulated by excess nutrients die off, they are broken down by bacteria, which depletes the oxygen in the water. Relatively few studies have specifically explored the impact of nutrient enrichment on urban streams. Chessman *et al*. (1992) studied the limiting nutrients for periphyton growth in a variety of streams and noted that the severity of eutrophication was related to low flow conditions. Higher flow rates in streams may cycle nutrients faster than in slow flow rates, thus diminishing the extent of stream eutrophication.

4.5.3 Sources and Source Areas of Nutrients

Phosphorus is normally transported in surface water attached to sediment particles or in soluble forms. Nitrogen is normally transported by surface water runoff in urban watersheds. Sources for nitrogen and phosphorus in urban stormwater include fertilizer, pet waste, organic matter (such as leaves and detritus), and stream bank erosion. Another significant source of nutrients is atmospheric deposition. Fossil fuel combustion by automobiles, power plants and industry can supply nutrients in both wet fall and dry fall. The Metropolitan Washington Council of Governments (MWCOG, 1983) estimated total annual atmospheric deposition rates of 17 lbs/ac for nitrogen and 0.7 lbs/ac for phosphorus in the Washington, D.C. metro area.

Research from the upper Midwest suggests "hot spot" sources can exist for both nitrogen and phosphorus in urban watersheds. Lawns, in particular, contribute greater concentrations of Total N, Total P and dissolved phosphorus than other urban source areas. Indeed, source research suggests that nutrient concentrations in lawn runoff can be as much as four times greater than other urban sources such as streets, rooftops or driveways (Bannerman *et al.*, 1993; Steuer *et al.*, 1997 and Waschbusch *et al.*, 2000) (Table 29). This finding is significant, since lawns can comprise more than 50% of the total area in suburban watersheds. Lawn care, however, has seldom been directly linked to elevated nutrient concentrations during storms. A very recent lakeshore study noted that phosphorus concentrations were higher in fertilized lawns compared to unfertilized lawns, but no significant difference was noted for nitrogen (Garn, 2002).

Wash-off of deposited nutrients from IC is thought to be a major source of nitrogen and phosphorus during storms (MWCOG, 1983). While the concentration of nitrogen and phosphorus from parking lots and streets is lower than lawns, the volume of runoff is significantly higher. In two studies using the SLAMM source loading model (Pitt and Voorhees, 1989), parking lots and streets were responsible for over 30% of the nitrogen and were second behind lawns in their contributions to the phosphorus load (Steuer *et al.*, 1997; Waschbusch *et al.*, 2000).

Table 29: Source Area Monitoring Data for Total Nitrogen and Total Phosphorous in Urban Areas

Source Area	Total N (mg/l)	Total P (mg/l)		
Source	(1)	(1)	(2)	(3)
Commercial Parking Lot	1.94	0.20	N/R	0.10
High Traffic Street	2.95	0.31	0.47	0.18
Med. Traffic Street	1.62	0.23	1.07	0.22
Low Traffic Street	1.17	0.14	1.31	0.40
Commercial Rooftop	2.09	0.09	0.20	0.13
Residential Rooftop	1.46	0.06	0.15	0.07
Residential Driveway	2.10	0.35	1.16	N/R
Residential Lawn	9.70	2.33	2.67	0.79
Basin Outlet	1.87	0.29	0.66	N/R

(1) Steuer et al., 1997; (2) Bannerman et al., 1993; (3) Waschbusch et al., 2000; N/R= Not Reported

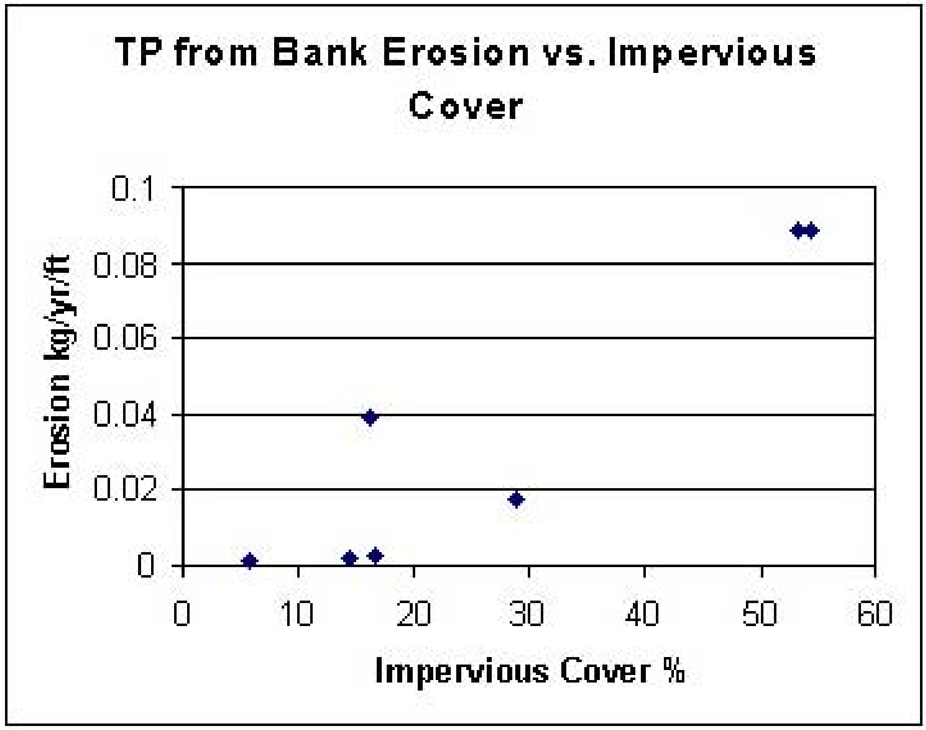


Figure 34: Total Phosphorus from Bank Erosion as a Function of IC in Texas Streams (Dartiguenave *et al.*, 1997)

Streambank erosion also appears to be a major source of nitrogen and phosphorus in urban streams. Both nitrogen and phosphorus are often attached to eroded bank sediment, as indicated in a recent study by Dartiguenave *et al.* (1997) in Austin, Texas. They showed that channel erosion contributed nearly 50% of the Total P load shown for subwatersheds with IC levels between 10 and 60 % (Figure 34). These findings suggest that prevention or reduction of downstream channel erosion may be an important nutrient reduction strategy for urban watersheds.

Snowmelt runoff generally has higher nutrient EMCs, compared to stormwater runoff. Oberts (1994) found that TKN and nitrate EMCs were much higher in snowmelt at all sites. The same pattern has also been observed for phosphorus EMCs during snowmelt and stormwater runoff. Zapf-Gilje *et al*. (1986) found that the first 20% of snowmelt events contained 65% of the phosphorus and 90% of the nitrogen load. Ayers *et al.* (1985) reported that a higher percentage of the annual nitrate, TKN and phosphorus load was derived from snowmelt runoff compared to stormwater runoff in an urban Minnesota watershed, which presumably reflects the accumulation of nutrients in the snowpack during the winter.

4.6 Trace Metals

Many trace metals can be found at potentially harmful concentrations in urban stormwater. Certain metals, such as zinc, copper, lead, cadmium and chromium, are consistently present at concentrations that may be of concern. These metals primarily result from the use of motor vehicles, weathering of metals and paints, burning of fossil fuels and atmospheric deposition.

Metals are routinely reported as the total recoverable form or the dissolved form. The dissolved form refers to the amount of metal dissolved in the water, which excludes metals attached to suspended particles that cannot pass through a 0.45 micron filter. Total recoverable refers to the concentration of an unfiltered sample that is treated with hot dilute mineral acid. In general, the toxicity of metals is related more to the dissolved form than the recoverable form.

4.6.1 Concentrations

Stormwater EMCs for zinc, copper, lead, cadmium and chromium vary regionally and are reviewed in Table 30. Regional differences in trace metal concentrations and water quality standard exceedence appears to be related to climate. In general, drier regions often have a

Table 30: EMCs and Detection Frequency for Metals in Urban Stormwater

Metal	Detection Frequency(1)	EMCs (Fg/l)		Number of Events	Source
		Mean	Median		
Zinc	94%	162	129	2234	Smullen and Cave, 1998
		176	140	1281	USEPA, 1983
Copper	91%	13.5	11.1	1657	Smullen and Cave, 1998
		66.6	54.8	849	USEPA, 1983
Lead	94%	67.5	50.7	2713	Smullen and Cave, 1998
		175(2)	131 (2)	1579	USEPA, 1983
Cadmium	48%	0.7	N/R	150	USEPA, 1983
		0.5	N/R	100	USEPA, 1993
		N/R	0.75 **R** 0.96 **C** 2.1 **I**	30	Baird *et al.*, 1996
		3 **I** 1**U**	N/R	9	Doerfer and Urbonas, 1993
Chromium	58%	4	N/R	32	Baird *et al.*, 1996
		N/R	2.1 **R** 10 **C** 7 **I**	30	Baird *et al.*, 1996
		N/R	7	164	Bannerman *et al.*, 1993

N/R = Not Reported; R- Residential, C- Commercial, I- Industrial; (1) as reprinted in USEPA, 1983; (2) Lead levels have declined over time with the introduction of unleaded gasoline

Table 31: Average Total Recoverable and Dissolved Metals for 13 Stormwater Flows and Nine Baseflow Samples from Lincoln Creek in 1994 (Crunkilton *et al.*, 1996)

	Total Recoverable		Dissolved	
Metal (Fg/l)	**Storm Flow**	**Baseflow**	**Storm Flow**	**Baseflow**
Lead	35	3	1.7	1.2
Zinc	133	22	13	8
Copper	23	7	5	4
Cadmium	0.6	0.1	0.1	0.1

higher risk of exceeding trace metal concentration standards.

Crunkilton *et al.* (1996) measured recoverable and dissolved metals concentrations in Lincoln Creek, Wisconsin and found higher EMCs during storm events compared to baseflow periods (Table 31). They also found that total recoverable metal concentrations were almost always higher than the dissolved concentration (which is the more available form).

4.6.2 Impacts of Trace Metals on Streams

Although a great deal is known about the concentration of metals in urban stormwater, much less is known about their possible toxicity on aquatic biota. The primary concern related to the presence of trace metals in streams is their potential toxicity to aquatic organisms. High concentrations can lead to bioaccumulation of metals in plants and animals, possible chronic or acute toxicity, and contamination of sediments, which can affect bottom dwelling organisms (Masterson and Bannerman, 1994). Generally, trace metal concentrations found in urban stormwater are not high enough to cause acute toxicity (Field and Pitt, 1990). The cumulative accumulation of trace metal concentrations in bottom sediments and animal tissues are of greater concern. Some evidence exists for trace metal accumulation in bottom sediments of receiving waters and for bioaccumulation in aquatic species (Bay and Brown, 2000 and Livingston, 1996).

Relatively few studies have examined the chronic toxicity issue. Crunkilton *et al.* (1996) found that concentrations of lead, zinc and copper exceeded EPA's Chronic Toxicity Criteria more than 75% of the time in stormflow in stormwater samples for Lincoln Creek in Wisconsin. When exposed to storm and base flows in Lincoln Creek, *Ceriodaphnia dubia*, a common invertebrate test species, demonstrated significant mortality in extended flow-through tests. Around 30% mortality was recorded after seven days of exposure and 70% mortality was recorded after 14 days.

Crunkilton *et al.* (1996) also found that significant mortality in bullhead minnows occurred in only 14% of the tests by the end of 14 days, but mortality increased to 100% during exposures of 17 to 61 days (see Table 32). In a related study in the same watershed, Masterson and Bannerman (1994) determined that crayfish in Lincoln Creek had elevated levels of lead, cadmium, chromium and copper when compared to crayfish from a reference stream. The Lincoln Creek research provides limited evidence that prolonged exposure to trace metals in urban streams may result in significant toxicity.

Most toxicity research conducted on urban stormwater has tested for acute toxicity over a short period of time (two to seven days). Shorter term whole effluent toxicity protocols are generally limited to seven days (Crunkilton *et al.*, 1996). Research by Ellis (1986) reported delayed toxicity in urban streams. Field and Pitt (1990) demonstrated that pollutants deposited to the stream during storm events may take upwards of 10 to 14 days to exert influence. The research suggests that longer term in-situ and flow-through monitoring are needed to definitively answer the question whether metal levels in stormwater can be chronically toxic.

An additional concern is that trace metals co-occur with other pollutants found in urban stormwater, and it is not clear whether they interact to increase or decrease potential toxicity. Hall and Anderson (1988) investigated the toxicity and chemical composition of urban stormwater runoff in British Columbia and found that the interaction of pollutants changed the toxicity of some metals. In laboratory analysis with *Daphnia pulex*, an aquatic invertebrate, they found that the toxicity of iron was low and that its presence reduced the toxicity of other metals. On the other hand, the presence of lead increased the toxicity of copper and zinc.

Interaction with sediment also influences the impact of metals. Often, over half of the trace metals are attached to sediment (MWCOG, 1983). This effectively removes the metals from the water column and reduces the availability for biological uptake and subsequent bioaccumulation (Gavin and Moore, 1982 and OWML, 1983). However, metals accumulated in bottom sediment can then be resuspended during storms (Heaney and Huber, 1978). It is important to note that the toxic effect of metals can be altered when found in conjunction with other substances. For instance, the presence of chlorides can increase the toxicity of some metals. Both metals and chlorides are common pollutants in snowpacks (see section 4.2 for more snow melt information).

4.6.3 Sources and Source Areas of Trace Metals

Research conducted in the Santa Clara Valley of California suggests that cars can be the dominant loading source for many metals of concern, such as cadmium, chromium, copper, lead, mercury and zinc (EOA, Inc., 2001). Other sources are also important and include atmospheric deposition, rooftops and runoff from industrial and residential sites.

The sources and source areas for zinc, copper, lead, chromium and cadmium are listed in Table 33. Source areas for trace metals in the urban environment include streets, parking lots, snowpacks and rooftops. Copper is often found in higher concentrations on urban streets, because some vehicles have brake pads that contain copper. For example, the Santa Clara study estimated that 50% of the total copper load was due to brake pad wear (Woodward-Clyde, 1992). Sources of lead include atmospheric deposition and diesel fuel emissions, which frequently occur along rooftops

Table 32: Percentage of In-situ Flow-through Toxicity Tests Using Daphnia *magna* and Pimephales *promelas* with Significant Toxic Effects from Lincoln Creek (Crunkilton *et al.*, 1996)

Species	Effect	Percent of Tests with Significant (p<0.05) Toxic Effects as Compared to Controls According to Exposure				
		48 hours	96 hours	7 days	14 days	17-61 days
D. *magna*	Mortality	0	N/R	36%	93%	N/R
	Reduced Reproduction	0	N/R	36%	93%	N/R
P. *promelas*	Mortality	N/R	0	0	14%	100%
	Reduced Biomass	N/R	N/R	60%	75%	N/R

N/R = Not Reported

and streets. Zinc in urban environments is a result of the wear of automobile tires (estimated 60% in the Santa Clara study), paints, and weathering of galvanized gutters and downspouts. Source area concentrations of trace metals are presented in Table 34. In general, trace metal concentrations vary considerably, but the relative rank among source areas remains relatively constant. For example, a source loading model developed for an urban watershed in Michigan estimated that parking lots, driveways and residential streets were the primary source areas for zinc, copper and cadmium loads (Steuer *et al.*, 1997).

Table 33: Metal Sources and Source Area "Hotspots" in Urban Areas

Metal	Sources	Source Area Hotspots
Zinc	tires, fuel combustion, galvanized pipes, roofs and gutters, road salts **estimate of 60% from tires*	parking lots, commercial and industrial rooftops, and streets
Copper	auto brake linings, pipes and fittings, algacides, and electroplating **estimate of 50% from brake pad wear*	parking lots, commercial roofs and streets
Lead	diesel fuel, paints and stains	parking lots, rooftops, and streets
Cadmium	component of motor oil and corrodes from alloys and plated surfaces	parking lots, rooftops, and streets
Chromium	found in exterior paints and corrodes from alloys and plated surfaces	most frequently found in industrial and commercial runoff
Sources: Bannerman et al., 1993; Barr, 1997; Steuer et al., 1997; Good, 1993; Woodward - Clyde, 1992		

Table 34: Metal Source Area Concentrations in the Urban Landscape (*F*g/l)

Source Area	Dissolved Zinc	Total Zinc	Dissolved Copper		Total Copper	Dissolved Lead		Total Lead		
Source	(1)	(2)	(1)	(2)	(2)	(1)	(3)	(1)	(3)	(2)
Commercial Parking Lot	64	178	10.7	9	15	N/R	N/R	40	N/R	22
High Traffic Street	73	508	11.2	18	46	2.1	1.7	37	25	50
Medium Traffic Street	44	339	7.3	24	56	1.5	1.9	29	46	55
Low Traffic Street	24	220	7.5	9	24	1.5	.5	21	10	33
Commercial Rooftop	263	330	17.8	6	9	20	N/R	48	N/R	9
Residential Rooftop	188	149	6.6	10	15	4.4	N/R	25	N/R	21
Residential Driveway	27	107	11.8	9	17	2.3	N/R	52	N/R	17
Residential Lawn	N/R	59	N/R	13	13	N/R	N/R	N/R	N/R	N/R
Basin Outlet	23	203	7.0	5	16	2.4	N/R	49	N/R	32
Sources: (1) Steuer et al., 1997; (2) Bannerman et al., 1993; (3) Waschbusch, 2000; N/R = Not Reported										

4.7 Hydrocarbons: PAH, Oil and Grease

Hydrocarbons are petroleum-based substances and are found frequently in urban stormwater. The term “hydrocarbons” is used to refer to measurements of oil and grease and polycy-clic-aromatic hydrocarbons (PAH). Certain components of hydrocarbons, such as pyrene and benzo[b]fluoranthene, are carcinogens and may be toxic to biota (Menzie-Cura , 1995). Hydrocarbons normally travel attached to sediment or organic carbon. Like many pollutants, hydrocarbons accumulate in bottom sediments of receiving waters, such as urban lakes and estuaries. Relatively few studies have directly researched the impact of hydrocarbons on streams.

4.7.1 Concentrations

Table 35 summarizes reported EMCs of PAH and oil and grease derived from storm event monitoring at three different areas of the U.S. The limited research on oil and grease concentrations in urban runoff indicated that the highest concentrations were consistently found in commercial areas, while the lowest were found in residential areas.

4.7.2 Impacts of Hydrocarbons on Streams

The primary concern of PAH and oil and grease on streams is their potential bioaccumulation and toxicity in aquatic organisms. Bioaccumulation in crayfish, clams and fish has been reported by Masterson and Bannerman (1994); Moring and Rose (1997); and Velinsky and Cummins (1994).

Table 35: Hydrocarbon EMCs in Urban Areas

Hydrocarbon Indicator	EMC	Number of Events	Source	Location
	Mean			
PAH (Fg/l)	3.2*	12	Menzie-Cura, 1995	MA
	7.1	19	Menzie-Cura, 1995	MA
	13.4	N/R	Crunkilton *et al.*, 1996	WI
Oil and Grease (mg/l)	1.7 **R**** 9 **C** 3 **I**	30	Baird *et al.*, 1996	TX
	3	N/R	USEPA, 1983	U.S.
	5.4*	8	Menzie-Cura, 1995	MA
	3.5	10	Menzie-Cura, 1995	MA
	3.89 **R** 13.13 **C** 7.10 **I**	N/R	Silverman *et al.*, 1988	CA
	2.35 **R** 5.63 **C** 4.86 **I**	107	Barr, 1997	MD

*N/R = Not Reported; R = Residential, C = Commercial, I = Industrial; * = geometric mean, ** = median*

Moring and Rose (1997) also showed that not all PAH compounds accumulate equally in urban streams. They detected 24 different PAH compounds in semi-permeable membrane devices (SPMDs), but only three PAH compounds were detected in freshwater clam tissue. In addition, PAH levels in the SPMDs were significantly higher than those reported in the clams.

While acute PAH toxicity has been reported at extremely high concentrations (Ireland *et al.*, 1996), delayed toxicity has also been found (Ellis, 1986). Crayfish from Lincoln Creek had a PAH concentration of 360 Fg/kg, much higher than the concentration thought to be carcinogenic (Masterson and Bannerman, 1994). By comparison, crayfish in a non-urban stream had undetectable PAH levels. Toxic effects from PAH compounds may be limited since many are attached to sediment and may be less available, with further reduction occurring through photodegradation (Ireland *et al.,* 1996).

The metabolic effect of PAH compounds on aquatic life is unclear. Crunkilton *et al.* (1996) found potential metabolic costs to organisms, but Masterson and Bannerman (1994) and MacCoy and Black (1998) did not. The long-term effect of PAH compounds in sediments of receiving waters remains a question for further study.

4.7.3 Sources and Source Areas of Hydrocarbons

In most residential stormwater runoff, hydrocarbon concentrations are generally less than 5mg/l, but the concentrations can increase to five to 10 mg/l within some commercial, industrial and highway areas (See Table 35). Specific "hotspots" for hydrocarbons include gas stations, commuter parking lots, convenience stores, residential parking areas and streets (Schueler and Shepp, 1993). These authors evaluated hydrocarbon concentrations within oil and grease separators in the Washington Metropolitan area and determined that gas stations had significantly higher concentrations of hydrocarbons and trace metals, as compared to other urban source areas. Source area research in an urban catchment in Michigan showed that commercial parking lots contributed 64% of the total hydrocarbon load (Steuer *et al.*, 1997). In addition, highways were found to be a significant contributor of hydrocarbons by Lopes and Dionne (1998).

4.8 Bacteria and Pathogens

Bacteria are single celled organisms that are too small to see with the naked eye. Of particular interest are coliform bacteria, typically found within the digestive system of warm-blooded animals. The coliform family of bacteria includes fecal coliform, fecal streptococci and Escherichia coli, which are consistently found in urban stormwater runoff. Their presence confirms the existence of sewage or animal wastes in the water and indicates that other harmful bacteria, viruses or protozoans may be present, as well. Coliform bacteria are indicators of potential public health risks and not actual causes of disease.

A pathogen is a microbe that is actually known to cause disease under the right conditions. Two of the most common waterborne pathogens in the U.S. are the protozoans *Cryptosporidium parvum* and *Giardia lambia*. *Cryptosporidium* is a waterborne intestinal parasite that infects cattle and domestic animals and can be transmitted to humans, causing life-threatening problems in people with impaired immune systems (Xiao *et al.*, 2001). *Giardia* can cause intestinal problems in humans and animals when ingested (Bagley *et al.*, 1998). To infect new hosts, protozoans create hard casings known as oocysts (*Cryptosporidium*) or cysts (*Giardia*) that are shed in feces and travel through surface waters in search of a new host.

4.8.1 Concentrations

Concentrations of fecal coliform bacteria in urban stormwater typically exceed the 200 MPN/100 ml threshold set for human contact recreation (USGS, 2001b). Bacteria concentrations also tend to be highly variable from storm to storm. For example, a national summary of fecal coliform bacteria in stormwater runoff is shown in Figure 35 and Table 36. The variability in fecal coliform ranges from 10 to 500,000 MPN/100ml with a mean of 15,038 MPN/100ml (Schueler, 1999). Another national database of more than 1,600 stormwater events computed a mean concentration of 20,000

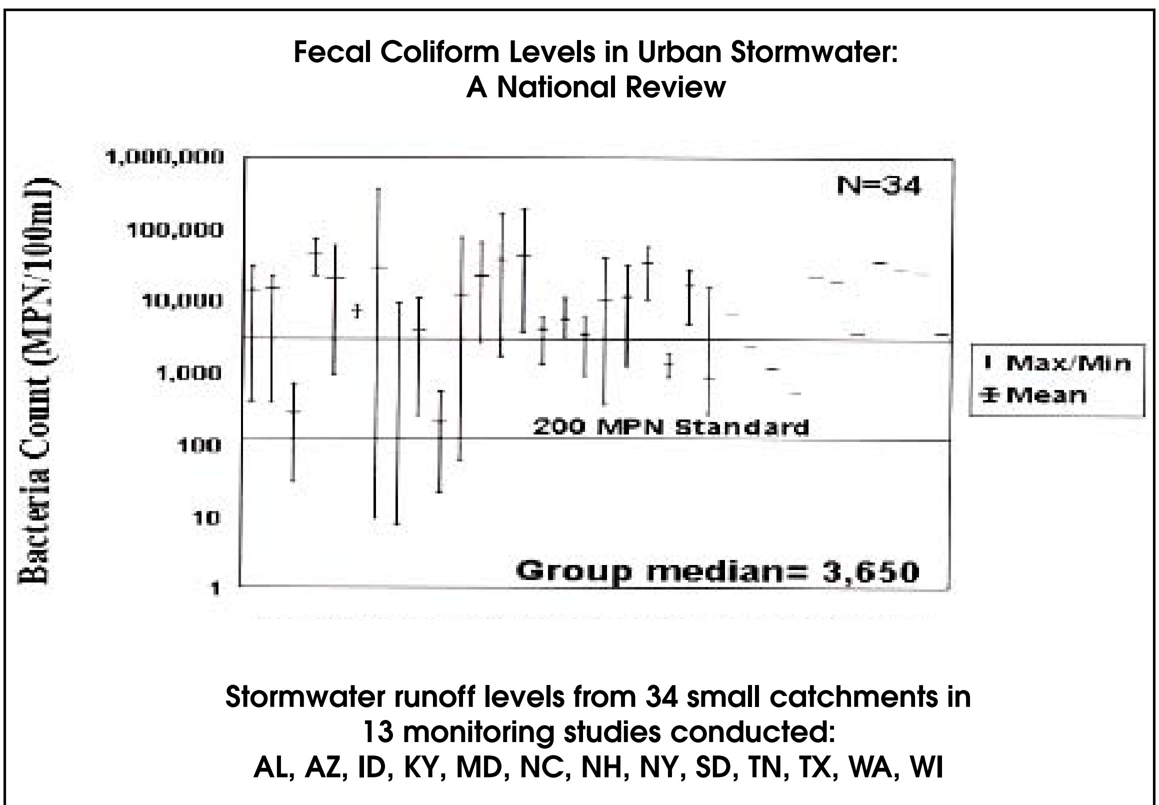


Figure 35: Fecal Coliform Levels in Urban Stormwater (Schueler, 1999)

Table 36: Bacteria EMCs in Urban Areas				
Bacteria Type	EMCs (MPN/100ml) Mean	Number of Events	Source	Location
Fecal Coliform	15,038	34	Schueler, 1999	U.S.
	20,000	1600	Pitt, 1998	U.S.
	7,653	27	Thomas and McClelland, 1995	GA
	20,000 **R*** 6900 **C** 9700 **I**	30*	Baird *et al.*, 1996	TX
	77,970	21 watersheds	Chang *et al.*, 1990	TX
	4,500	189	Varner, 1995	WA
	23,500	3	Young and Thackston, 1999	TN
Fecal Strep	35,351	17	Schueler, 1999	U.S.
	28,864 **R**	27	Thomas and McClelland, 1995	GA
	56,000 **R** * 18,000 **C** 6,100 **I**	30*	Baird *et al.*, 1996	TX

*N/R = Not Reported, R = Residential Area, C = Commercial Area, I = Industrial Area, * = Median*

MPN/100ml for fecal coliform (Pitt, 1998). Fecal streptococci concentrations for 17 urban sites across the country had a mean of 35,351 MPN/100ml (Schueler, 1999).

Young and Thackston (1999) showed that bacteria concentrations at four sites in metro Nashville were directly related to watershed IC. Increasing IC reflects the cumulative increase in potential bacteria sources in the urban landscape, such as failing septic systems, sewage overflows, dogs, and inappropriate discharges. Other studies show that concentrations of bacteria are typically higher in urban areas than rural areas (USGS, 1999a), but they are not always directly related to IC. For example, Hydroqual (1996) found that concentrations of fecal coliform in seven subwatersheds of the Kensico watershed in New York were generally higher for more developed basins, but fecal coliform concentrations did not directly increase with IC in the developed basins (Figure 36).

There is some evidence that higher concentrations of coliform are found in arid or semi-arid watersheds. Monitoring data from semi-arid regions in Austin, San Antonio, and Corpus Christi, Texas averaged 61,000, 37,500 and 40,500 MPN/100ml, respectively (Baird *et al.*,1996 and Chang *et al.* 1990). Schiff (1996), in a report of Southern California NPDES monitoring, found that median concentrations of fecal coliform in San Diego were 50,000 MPN/100ml and averaged 130,000 MPN/100ml in Los Angeles. In all of these arid and semi-arid regions, concentrations were significantly higher than the national average of 15,000 to 20,000 MPN/100ml.

Concentrations of *Cryptosporidium* and *Giardia* in urban stormwater are shown in Table 37. States *et al.* (1997) found high concentrations of *Cryptosporidium* and *Giardia* in storm samples from a combined sewer in Pittsburgh (geometric mean 2,013 oocysts/100ml and 28,881 cysts/100ml). There is evidence that urban stormwater runoff may have higher concentrations of *Cryptosporidium* and *Giardia* than other surface waters, as reported in Table 38 (Stern, 1996). Both pathogens were detected in about 50% of urban stormwater samples, suggesting some concern for drinking water supplies.

4.8.2 Impacts of Bacteria and Pathogens on Streams

Fecal coliform bacteria indicate the potential for harmful bacteria, viruses, or protozoans and are used by health authorities to determine public health risks. These standards were established to protect human health based on exposures to water during recreation and drinking. Bacteria standards for various water uses are presented in Table 39 and are all easily exceeded by typical urban stormwater concentrations. In fact, over 80,000 miles of streams and rivers are currently in non-attain-

Table 37: *Cryptosporidium* and *Giardia* EMCs

Pathogens	Units	EMCs		Number of Events	Source
		Mean	Median		
Cryptosporidium	oocysts	37.2	3.9	78	Stern, 1996
	oocysts/100ml	2013	N/R	N/R	States *et al.*, 1997
Giardia	cysts	41.0	6.4	78	Stern, 1996
	cysts/100ml	28,881	N/R	N/R	States *et al.*, 1997

N/R= Not reported

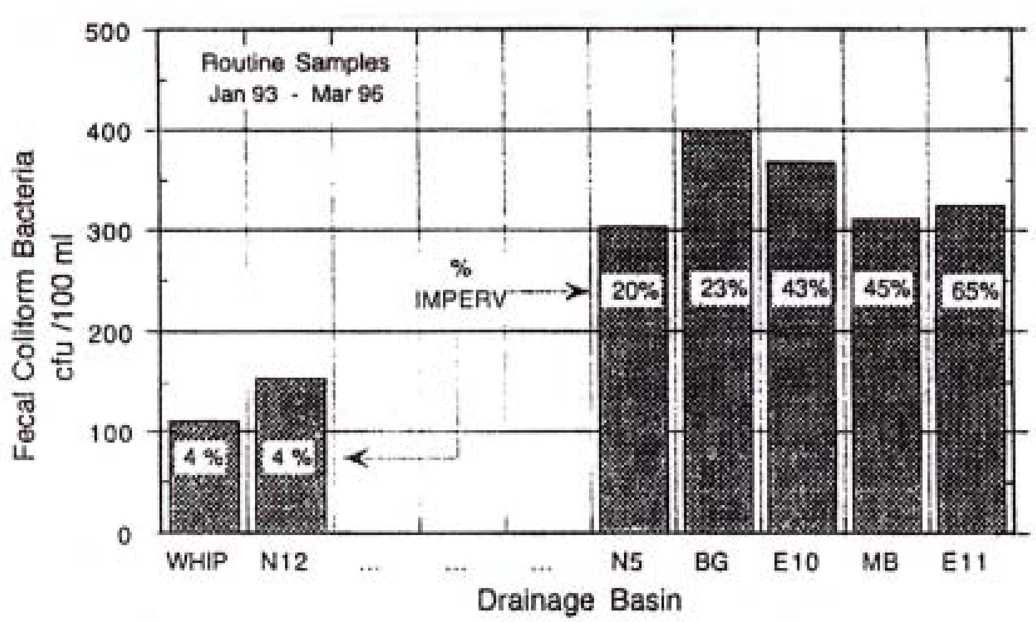


Figure 36: Relationship Between IC and Fecal Coliform Concentrations in New York Streams (Hydroqual, 1996)

Table 38: Percent Detection of *Giardia* cysts and *Cryptosporidium* oocysts in Subwatersheds and Wastewater Treatment Plant Effluent in the New York City Water Supply Watersheds (Stern, 1996)

Source Water Sampled	Number of Sources/ Number of Samples	Percent Detection			
		Total *Giardia*	Confirmed *Giardia*	Total *Cryptosporidium*	Confirmed *Cryptosporidium*
Wastewater Effluent	8/147	41.5%	12.9%	15.7%	5.4%
Urban Subwatershed	5/78	41.0%	6.4%	37.2%	3.9%
Agricultural Subwatershed	5/56	30.4%	3.6%	32.1%	3.6%
Undisturbed Subwatershed	5/73	26.0%	0.0%	9.6%	1.4%

Table 39: Typical Coliform Standards for Different Water Uses (USEPA, 1998)

Water Use	Microbial Indicator	Typical Water Standard
Water Contact Recreation	Fecal Coliform	<200 MPN per 100ml
Drinking Water Supply	Fecal Coliform	<20 MPN per 100ml
Shellfish Harvesting	Fecal Coliform	<14 MPN/ 100ml
Treated Drinking Water	Total Coliform	No more than 1% coliform positive samples per month
Freshwater Swimming	E.Coli	<126 MPN per 100ml

Important Note: Individual state standards may employ different sampling methods, indicators, averaging periods, averaging methods, instantaneous maximums and seasonal limits. MPN = most probable number. Higher or lower limits may be prescribed for different water use classes.

ment status because of high fecal coliform levels (USEPA, 1998).

4.8.3 Sources and Source Areas of Bacteria and Pathogens

Sources of coliform bacteria include waste from humans and wildlife, including livestock and pets. Essentially, any warm-blooded species that is present in significant numbers in a watershed is a potential culprit. Source identification studies, using methods such as DNA fingerprinting, have put the blame on species such as rats in urban areas, ducks and geese in stormwater ponds, livestock from hobby farms, dogs and even raccoons (Blankenship, 1996; Lim and Olivieri, 1982; Pitt, 1998; Samadpour and Checkowitz, 1998).

Transport of bacteria takes place through direct surface runoff, direct inputs to receiving waters, or indirect secondary sources. Source areas in the urban environment for direct runoff include lawns and turf, driveways, parking lots and streets. For example, dogs have high concentrations of fecal coliform in their feces and have a tendency to defecate in close proximity to IC (Schueler, 1999). Weiskel *et al. (*1996) found that direct inputs of fecal coliform from waterfowl can be very important; these inputs accounted for as much as 67% of the annual coliform load to Buttermilk Bay, Massachusetts.

Indirect sources of bacteria include leaking septic systems, illicit discharges, sanitary sewer overflows (SSOs), and combined sewer overflows (CSOs). These sources have the potential to deliver high coliform concentrations to urban streams. In fact, extremely high bacteria concentrations are usually associated with wastewater discharges. CSOs and SSOs occur when the flow into the sewer exceeds the capacity of the sewer lines to drain them. CSOs result from stormwater flow in the lines, and SSOs are a result of infiltration problems or blockages in the lines.

Illicit connections from businesses and homes to the storm drainage system can discharge sewage or washwater into receiving waters. Illicit discharges can often be identified by baseflow sampling of storm sewer systems. Leaking septic systems are estimated to comprise between 10 and 40% of the systems, and individual inspections are the best way to determine failing systems (Schueler, 1999).

There is also evidence that coliform bacteria can survive and reproduce in stream sediments and storm sewers (Schueler, 1999). During a storm event, they often become resuspended and add to the in-stream bacteria load. Source area studies reported that end of pipe concentrations were an order of magnitude higher than any source area on the land surface; therefore, it is likely that the storm sewer system itself acts as a source of fecal coliform (Bannerman *et al.*, 1993 and Steuer *et al.*, 1997). Resuspension of fecal coliform from fine stream sediments during storm events has been reported in New Mexico (NMSWQB, 1999). The sediments in-stream and in the storm sewer system may be significant contributors to the fecal coliform load.

Sources of *Cryptosporidium* and *Giardia* include human sewage and animal feces. *Cryptosporidium* is commonly found in cattle, dogs and geese. Graczyk *et al.* (1998) found that migrating Canada geese were a vector for *Cryptosporidium* and *Giardia*, which has implications for water quality in urban ponds that support large populations of geese.

4.9 Organic Carbon

Total organic carbon (TOC) is often used as an indicator of the amount of organic matter in a water sample. Typically, the more organic matter present in water, the more oxygen consumed, since oxygen is used by bacteria in the decomposition process. Adequate levels of dissolved oxygen in streams and receiving waters are important because they are critical to maintain aquatic life. Organic carbon is routinely found in urban stormwater, and high concentrations can result in an increase in Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD and COD are measures of the oxygen demand caused by the decay of organic matter.

4.9.1 Concentrations

Urban stormwater has a significant ability to exert a high oxygen demand on a stream or receiving water, even two to three weeks after an individual storm event (Field and Pitt, 1990). Average concentrations of TOC, BOD and COD in urban stormwater are presented in Table 40. Mean concentrations of TOC, BOD and COD during storm events in nationwide studies were 17 mg/l, 14.1 mg/l and 52.8 mg/l, respectively (Kitchell, 2001 and Smullen and Cave,1998).

4.9.2 Impacts of Organic Carbon on Streams

TOC is primarily a concern for aquatic life because of its link to oxygen demand in streams, rivers, lakes and estuaries. The initial effect of increased concentrations of TOC, BOD or COD in stormwater runoff may be a depression in oxygen levels, which may persist for many days after a storm, as deposited organic matter gradually decomposes (Field and Pitt, 1990).

TOC is also a concern for drinking water quality. Organic carbon reacts with chlorine during the drinking water disinfection process and forms trihalomethanes and other disinfection by-products, which can be a serious drinking water quality problem (Water, 1999). TOC concentrations greater than 2 mg/l in treated water and 4 mg/l in source water can result in unacceptably high levels of disinfection byproducts and must be treated to reduce TOC or remove the disinfection byproducts (USEPA, 1998). TOC can also be a carrier for other pollutants, such as trace metals, hydrocarbons and nutrients.

4.9.3 Sources and Source Areas of Total Organic Carbon

The primary sources of TOC in urban areas appear to be decaying leaves and other organic matter, sediment and combustion by-products. Source areas include curbs, storm drains, streets and stream channels. Dartiguenave *et al.* (1997) determined that about half of the annual TOC load in urban watersheds of Austin, TX was derived from the eroding streambanks.

Table 40: EMCs for Organic Carbon in Urban Areas

Organic Carbon Source	EMCs (mg/l)		Number of Events	Source
	Mean	Median		
Total Organic Carbon (TOC)	32.0	N/R	423	Barrett and Malina, 1998
	17	15.2	19 studies	Kitchell, 2001
Biological Oxygen Demand (BOD)	14.1	11.5	1035	Smullen and Cave, 1998
	10.4	8.4	474	USEPA, 1983
Chemical Oxygen Demand (COD)	52.8	44.7	2639	Smullen and Cave, 1998
	66.1	55	1538	USEPA, 1983

N/R = Not Reported

4.10 MTBE

Methyl tertiary butyl-ether (MTBE) is a volatile organic compound (VOC) that is added to gasoline to increase oxygen levels, which helps gas burn cleaner (called an oxygenate). MTBE has been used as a performance fuel additive since the 1970s. In 1990, the use of oxygenates was mandated by federal law and concentrations of MTBE in gasoline increased. Today, MTBE is primarily used in large metropolitan areas that experience air pollution problems. Since 1990, MTBE has been detected at increasing levels in both surface water and groundwater and is one of the most frequently detected VOCs in urban watersheds (USGS, 2001a). EPA has declared MTBE to be a potential human carcinogen at high doses. In March 2000, a decision was made by EPA to follow California's lead to significantly reduce or eliminate the use of MTBE in gasoline.

4.10.1 Concentrations

MTBE is highly soluble in water and therefore not easily removed once it enters surface or ground water. Delzer (1999) detected the presence of MTBE in 27% of the shallow wells monitored in eight urban areas across the country (Figure 37). Detection frequency was significantly higher in New England and Denver, as shown in Table 41. In a second study conducted in 16 metropolitan areas, Delzer (1999) found that 83% of MTBE detections occurred between October and March, the time when MTBE is primarily used as a fuel additive. The median MTBE concentration was 1.5 ppb, well below EPA's draft advisory level of 20 ppb (Delzer, 1996).

4.10.2 Impacts of MTBE on Streams

The primary concerns regarding MTBE are that it is a known carcinogen to small mammals, a suspected human carcinogen at higher

Table 41: MTBE Detection Frequency

Location	Detection Frequency	Source	Year
211 shallow wells in eight urban areas	27%	Delzer	1999
Surface water samples in 16 metro areas	7%	Delzer	1996

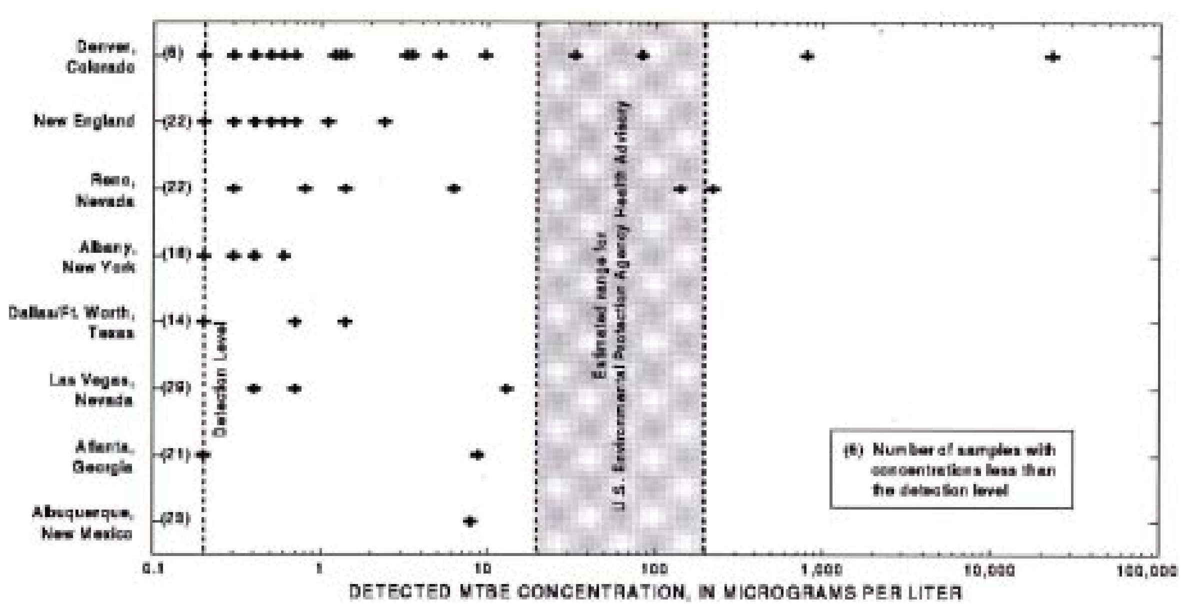


Figure 37: MTBE Concentrations in Surface Water from Eight Cities (Delzer, 1996)

doses and may possibly be toxic to aquatic life in small streams (Delzer, 1996). MTBE can also cause taste and odor problems in drinking water at fairly low concentrations. EPA issued a Drinking Water Advisory in 1997 that indicated that MTBE concentrations less than 20 ppb should not cause taste and odor problems for drinking water. However, the Association of California Water Agencies reports that some consumers can detect MTBE at levels as low as 2.5 ppb (ACWA, 2000). Because MTBE is frequently found in groundwater wells, it is thought to be a potential threat to drinking water (Delzer, 1999). For example, Santa Monica, California reportedly lost half of its groundwater drinking water supply due to MTBE contamination (Bay and Brown, 2000). MTBE has also been detected in human blood, especially in people frequently exposed to gasoline, such as gas station attendants (Squillace *et al.*, 1995).

4.10.3 Sources and Source Areas of MTBE

Since MTBE is a gasoline additive, its potential sources include any area that produces, transports, stores, or dispenses gasoline, particularly areas that are vulnerable to leaks and spills. Leaking underground storage tanks are usually associated with the highest MTBE concentrations in groundwater wells (Delzer, 1999). Vehicle emissions are also an important source of MTBE. Elevated levels are frequently observed along road corridors and drainage ditches. Once emitted, MTBE can travel in stormwater runoff or groundwater. Main source areas include heavily used multi-lane highways. Gas stations may also be a hotspot source area for MTBE contamination.

Another potential source of MTBE is watercraft, since two cycle engines can discharge as much as 20 to 30% of their fuel through the exhaust (Boughton and Lico, 1998). MTBE concentrations are clearly associated with increased use of gas engines, and there is concern that MTBE is an increasing component of atmospheric deposition (Boughton and Lico, 1998 and UC Davis, 1998).

4.11 Pesticides

Pesticides are used in the urban environment to control weeds, insects and other organisms that are considered pests. EPA estimates that nearly 70 million pounds of active pesticide ingredients are applied to urban lawns each year as herbicides or insecticides. Herbicides are used on urban lawns to target annual and perennial broadleaf weeds, while insecticides are used to control insects. Many types of pesticides are available for use in urban areas. Immerman and Drummond (1985) report that 338 different active ingredients are applied to lawns and gardens nationally. Each pesticide varies in mobility, persistence and potential aquatic impact. At high levels, many pesticides have been found to have adverse effects on ecological and human health. Several recent research studies by the USGS have shown that insecticides are detected with the greatest frequency in urban streams, and that pesticide detection frequency increases in proportion to the percentage of urban land in a watershed (Ferrari *et al.*, 1997; USGS, 1998, 1999a-b, 2001b). A national assessment by the USGS

Table 42: Median Concentrations and Detection Frequency of Herbicides and Insecticides in Urban Streams

Pollutant	Detection Frequency	Median Concentration (Fg/l)	Number of Samples	Source
Insecticides				
Diazinon	75%	0.025	326	USGS, 1998b
	92%	0.55	76	Brush *et al.*, 1995
	17%	0.002	1795	Ferrari *et al.*, 1997
Chlorpyrifos	41%	Non Detect	327	USGS, 1998b
	14%	0.004	1218	Brush *et al.*, 1995
Carbaryl	46%	Non Detect	327	USGS, 1998b
	22%	0.003	1128	Ferrari *et al.*, 1997
Herbicides				
Atrazine	86%	0.023	327	USGS, 1998b
	72%	0.099	2076	Ferrari *et al.*, 1997
Prometon	84%	0.031	327	USGS, 1998b
	56%	0.029	1531	Ferrari *et al.*, 1997
Simazine	88%	0.039	327	USGS, 1998b
	17%	0.046	1995	Ferrari *et al.*, 1997
2,4 -D	67%	1.1	11	Dindorf, 1992
	17%	0.035	786	Ferrari *et al.*, 1997
Dicamba	22%	1.8	4	Dindorf, 1992
MCPP	56%	1.8	10	Dindorf, 1992
MCPA	28%	1.0	5	Dindorf, 1992

(2001a) also indicates that insecticides are usually detected at higher concentrations in urban streams than in agricultural streams.

4.11.1 Concentrations

Median concentrations and detection frequency for common pesticides are shown in Table 42. Herbicides that are frequently detected in urban streams include atrazine; simazine; prometon; 2,4-D; dicamba; MCPP; and MCPA. Insecticides are also frequently encountered in urban streams, including diazinon, chlorpyrifos, malathion, and carbaryl. A USGS (1996) study monitored 16 sites in Gills Creek in Columbia, South Carolina over four days. This study reported that pesticide detection frequency increased as percent urban land increased.

Wotzka *et al.* (1994) monitored herbicide levels in an urban stream in Minneapolis, Minnesota during more than 40 storms. They found herbicides, such as 2,4-D; dicamba; MCPP; and MCPA in 85% of storm runoff events sampled. Total herbicide EMCs ranged from less than one to 70 µg/l. Ferrari *et al.* (1997) analyzed 463 streams in the mid-Atlantic region for the presence of 127 pesticide compounds. At least one pesticide was detected at more than 90% of the streams sampled.

Diazinon is one of the most commonly detected insecticides in urban stormwater runoff and dry weather flow. Diazinon was detected in 75% of National Water Quality Assessment (NAWQA) samples, 92% of stormflow samples from Texas, and 100% of urban stormflow samples in King County, Washington (Brush *et al.*, 1995 and USGS, 1999b). Diazinon is most frequently measured at concentrations greater than freshwater aquatic life criteria in urban stormwater (USGS, 1999a). USGS reports that diazinon concentrations were generally higher during urban stormflow (Ferrari *et al.,* 1997).

4.11.2 Impacts of Pesticides on Streams

Many pesticides are known or suspected carcinogens and can be toxic to humans and aquatic species. However, many of the known health effects require exposure to higher concentrations than typically found in the environment, while the health effects of chronic exposure to low levels are generally unknown (Ferrari *et al.*, 1997).

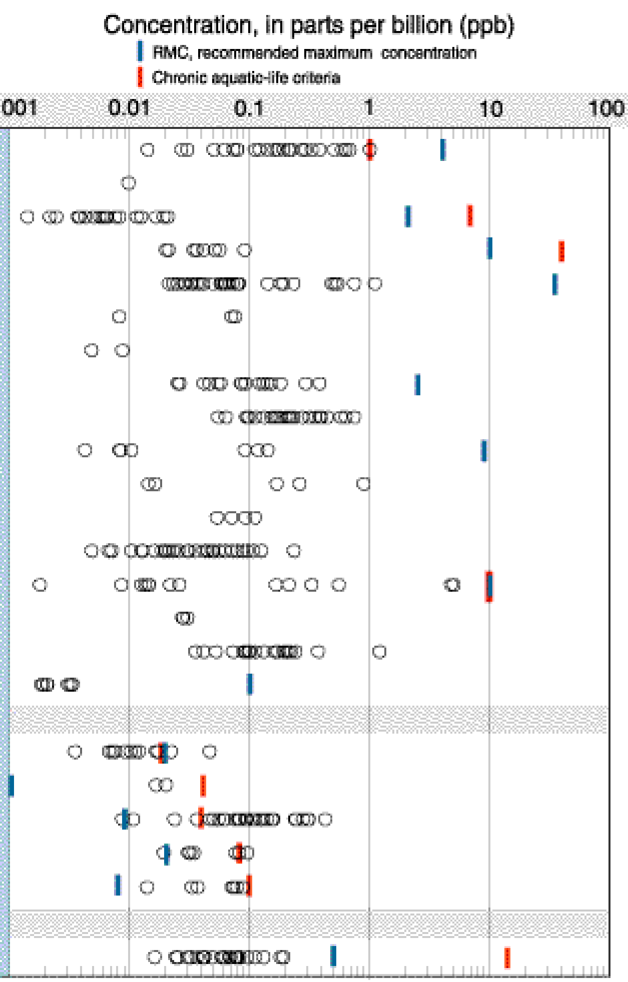
Studies that document the toxicity of insecticides and herbicides in urban stormwater have been focused largely on diazinon. Diazinon is responsible for the majority of acute toxicity in stormwater in Alameda County, California and King County, Washington (S.R. Hansen & Associates, 1995). Concentrations of diazinon in King County stormwater frequently exceed the freshwater aquatic life criteria (Figure 38). Similarly, research on Sacramento, California streams revealed acute toxicity for diazinon in 100% of stormwater samples using *Ceriodaphnia* as the test organism (Connor, 1995). Diazinon has a half-life of 42 days and is very soluble in water, which may explain its detection frequency and persistence in urban stormwater. Diazinon is also reported to attach fairly readily to organic carbon; consequently, it is likely re-suspended during storm events.

Insecticide concentrations exceeding acute and chronic toxicity thresholds for test organisms such as *Ceriodaphnia* have frequently been found in urban stormwater in New York, Texas, California, and Washington (Scanlin and Feng, 1997; Brush *et al.*, 1995; USGS, 1999b). The possibility exists that pesticides could have impacts on larger bodies of water, but there is a paucity of data on the subject at this time.

4.11.3 Sources and Source Areas of Pesticides

Sources for pesticides in urban areas include applications by homeowners, landscaping contractors and road maintenance crews. Source areas for pesticides in urban areas include lawns in residential areas; managed turf, such as golf courses, parks, and ball fields; and rights-of-way in nonresidential areas. Storage areas, which are subject to spills and leaks, can also be a source area. A study in San Francisco was able to trace high diazinon concentrations in some streams back to just a few households which had applied the pesticide at high levels (Scanlin and Feng, 1997). Two herbicides, simazine and atrazine, were detected in over 60% of samples in King County, WA stormwater but were not identified as being sold in retail stores. It is likely these herbicides are applied to nonresidential areas such as rights-of-way, parks and recreational areas (USGS, 1999b). Because pesticides are typically applied to turf, IC is not a direct indicator for pesticide concentrations, although they can drift onto paved surfaces and end up in stormwater runoff.

Active ingredient and trade name[1] example in parentheses	Freshwater aquatic-life criteria, in parts per billion (-- no aquatic-life criteria exist)		
Herbicide	**Acute**	**Chronic**	**RMC**
2,4-D (Weedone)	[4]10	[4]1	[5,2]4
Acetochlor (Guardian)	--	--	--
Atrazine (AAtrex)	[4]70	[4]7	[5]2
Dicamba (Banvel)	[4]390	[4]39	[5]10
Dichlobenil (Casoron)	--	--	[2]37
Dichlorprop (2,4-DP)	--	--	--
EPTC (Eptam)	--	--	--
MCPA (Kilsem)	--	--	[5]2.6
MCPP (Mecoprop)	--	--	--
Metolachlor (Dual)	--	--	[5]8
Napropamide (Devrinol)	--	--	--
Oxadiazon (Ronstar)	--	--	--
Prometon (Pramitol)	--	--	--
Simazine (Princep)	[4]100	[4]10	[2,5]10
Tebuthiuron (Spike)	--	--	--
Triclopyr (Garlon)	[4]5,600	[4]560	--
Trifluralin (Treflan)	--	--	[5]0.1
Insecticide			
Carbaryl (Sevin)	[4]0.17	[4]0.017	[2]0.02
Chlorpyrifos (Dursban)	[3,7]0.083	[3,7]0.041	[2]0.001
Diazinon (Diazinon)	[6]0.16	[6]0.04	[2]0.009
gamma-HCH (Lindane)	[3]0.95	[7]0.08	[2]0.02
Malathion (Malathion)	--	[3]0.1	[2]0.008
Fungicide			
Pentachlorophenol (Penta)	[3,8]19	[3,8]15	[5]0.5



[1] Use of trade names is for descriptive purposes and does not imply endorsement by the U.S. Geological Survey, the Department of Ecology, or King County
[2] National Academy of Sciences and National Academy of Engineering, 1973
[3] U.S. Environmental Protection Agency, 1998
[4] Norris and Dost, 1991, Table 3
[5] Ministers of Health Canada and Environment Canada, 1995
[6] Menconi and Cox, 1994
[7] State of Washington, 1992
[8] Criteria are pH dependent; values shown calculated at pH of 7.8

Figure 38: Concentrations of Pesticides in Stormwater in King County, WA (S.R. Hansen & Associates, 1995 and USGS, 1999b)

4.12 Deicers

Deicers are substances used to melt snow and ice to keep roads and walking areas safe. The most commonly used deicer is sodium chloride, although it may also be blended with calcium chloride or magnesium chloride. Other less frequently used deicers include urea and glycol, which are primarily used at airports to deice planes. Table 43 summarizes the composition, use and water quality effects of common deicers.

Chlorides are frequently found in snowmelt and stormwater runoff in most regions that experience snow and ice in the winter months (Oberts, 1994 and Sherman, 1998). Figure 39 shows that the application of deicer salts has increased since 1940 from 200,000 tons to 10 to 20 million tons per year in recent years (Salt Institute, 2001). Several U.S. and Canadian studies indicate severe inputs of road salts on water quality and aquatic life (Environment Canada, 2001 and Novotny *et al.*, 1999).

Table 43: Use and Water Quality Effect of Snowmelt Deicers (Ohrel, 1995; Sills and Blakeslee, 1992)

Deicer	Description	Use	Water Quality Effect
Chlorides	Chloride based deicer usually combined with Na, Ca or Mg	Road Deicer and Residential Use	Cl complexes can release heavy metals, affect soil permeability, impacts to drinking water, potential toxic effects to small streams
Urea	Nitrogen-based fertilizer product	Used as alternative to glycol	Increased nitrogen in water and potential toxicity to organisms
Ethylene Glycol	Petroleum based organic compounds, similar to antifreeze	Used at airports for deicing planes	Toxicity effects, high BOD and COD, hazardous air pollutant

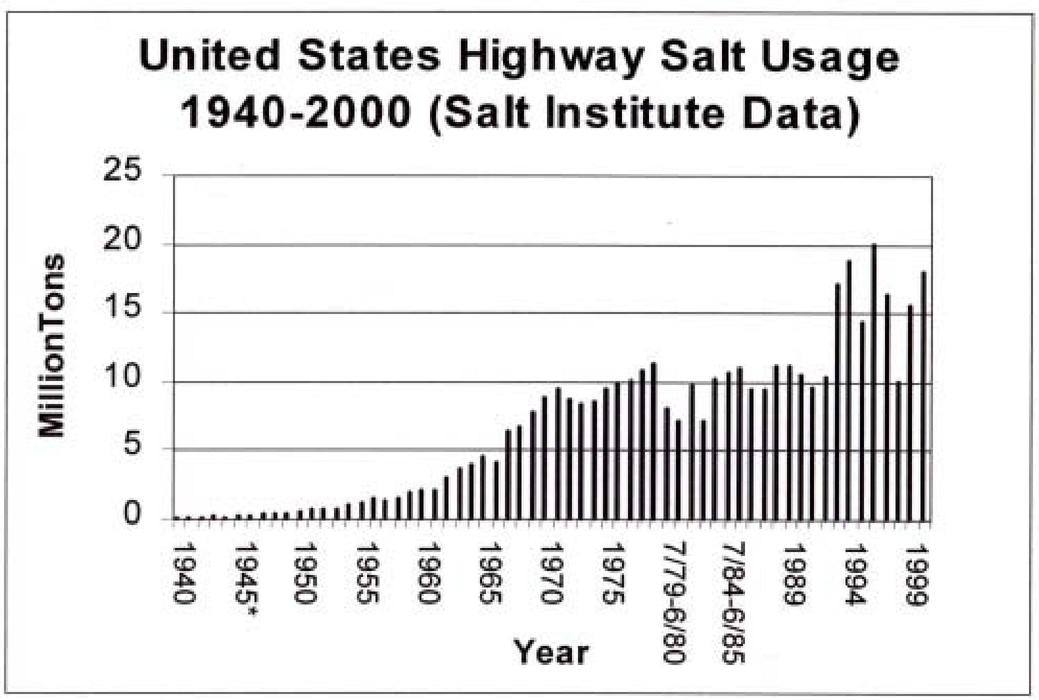


Figure 39: U.S. Highway Salt Usage Data (Salt Institute, 2001)

4.12.1 Concentrations

Chloride concentrations in snowmelt runoff depend on the amount applied and the dilution in the receiving waters. Data for snowmelt and stormwater runoff from several studies are presented in Table 44. For example, chloride concentrations in Lincoln Creek in Wisconsin were 1,612 mg/l in winter snowmelt runoff, as compared to 40 mg/l in non-winter runoff (Novotny *et al.*, 1999 and Masterson and Bannerman, 1994). Chloride concentrations in the range of 2,000 to 5,000 mg/l have been reported for Canadian streams (Environment Canada, 2001). Novotny *et al.* (1999) monitored chloride concentrations in snowmelt near Syracuse, New York and found that residential watersheds had higher chloride concentrations than rural watersheds.

Concentrations of glycol in stormwater runoff are also highly variable and depend on the amount of deicer used, the presence of a recovery system, and the nature of the precipitation event. Corsi *et al*. (2001) monitored streams receiving stormwater runoff from a Wisconsin airport. They found concentrations of propylene glycol as high as 39,000 mg/l at airport outfall sites during deicing operations and concentrations of up to 960 mg/l during low-flow sampling at an airport outfall site.

4.12.2 Impacts of Deicers on Streams

Chloride levels can harm aquatic and terrestrial life and contaminate groundwater and drinking water supplies (Ohrel, 1995). Generally, chloride becomes toxic to many organisms when it reaches concentrations of 500 to1,000 mg/l (Environment Canada, 2001). These concentrations are common in small streams in snow regions, at least for short periods of time. Many plant species are relatively intolerant to high salt levels in wetland swales and roadside corridors. Fish are also negatively affected by high chloride concentrations, with sensitivity as low as 600 mg/l for some species (Scott and Wylie, 1980).

Table 45 compares the maximum chloride concentrations for various water uses in eight states (USEPA, 1988). Snowmelt chloride concentrations typically exceed these levels.

Table 44: EMCs for Chloride in Snowmelt and Stormwater Runoff in Urban Areas

Form of Runoff	EMCs (mg/l) Mean	Number of Events	Sources	Location
Snowmelt	116*	49	Oberts, 1994	MN
	2119	N/R	Sherman, 1998	Ontario
	1267 **R** 474 **U**	N/R	Novotny *et al.*, 1999	NY
	1612	N/R	Masterson and Bannerman, 1994	WI
	397	282	Environment Canada, 2001	Ontario, Canada
Non-winter Storm Event	42	61	Brush *et al.*, 1995	TX
	45	N/R	Sherman, 1998	Ontario
	40.5	N/R	Masterson and Bannerman, 1994	WI

*N/R = Not Reported, R = residential, U = urban, * = Median*

Chloride is a concern in surface drinking water systems because it can interfere with some of the treatment processes and can cause taste problems at concentrations as low as 250 mg/l. Chloride is also extremely difficult to remove once it enters the water.

Glycol-based deicers have been shown to be highly toxic at relatively low concentrations in streams receiving airport runoff. These deicers contain many proprietary agents, which may increase their toxicity and also make it very difficult to set standards for their use (Hartwell *et al.*, 1995). Corsi *et al.* (2001) observed acute toxicity of *Ceriodaphnia dubia*, *Pimephelas promelax*, *Hyalela azteca*, and *Chironimus tentans* in Wisconsin streams that experienced propylene glycol concentrations of 5,000 mg/l or more. Chronic toxicity was observed for *Ceriodaphnia dubia* and *Pimephelas promelax* at propylene glycol concentrations of 1,500 mg/l in the same study. In addition, glycol exerts an extremely high BOD on receiving waters, which can quickly reduce or eliminate dissolved oxygen. Glycol can also be toxic to small animals that are attracted by its sweet taste (Novotny *et al.*, 1999).

As with many urban pollutants, the effects of chloride can be diluted in larger waterbodies. In general, small streams are more likely to experience chloride effects, compared to rivers, which have a greater dilution ability.

4.12.3 Sources and Source Areas of Deicers

The main sources for deicers in urban watersheds include highway maintenance crews, airport deicing operations, and homeowner applications. Direct road application is the largest source of chloride, by far. Source areas include roads, parking lots, sidewalks, storm drains, airport runways, and snow collection areas. Because deicers are applied to paved surfaces, the primary means of transport to streams is through stormwater and meltwater runoff. Therefore, concentrations of deicer compounds are typically associated with factors such as road density or traffic patterns.

Table 45: Summary of State Standards for Salinity of Receiving Waters (USEPA, 1988)

State	Limiting Concentration (mg/l)	Beneficial Use
CO	250*	Drinking water
IL	500	General water supply
	250	Drinking water
IN	500	Drinking water
MA	250	Class A waters
MN	250	Drinking water
	500	Class A fishing and recreation
OH	250	Drinking water
SD	250	Drinking water
	100	Fish propagation
VA	250	Drinking water

** Monthly average*

4.13 Conclusion

IC collects and accumulates pollutants deposited from the atmosphere, leaked from vehicles, or derived from other sources. The pollutants build up over time but are washed off quickly during storms and are often efficiently delivered to downstream waters. This can create water quality problems for downstream rivers, lakes and estuaries.

As a result of local and national monitoring efforts, we now have a much better understanding of the nature and impacts of stormwater pollution. The typical sample of urban stormwater is characterized by high levels of many common pollutants such as sediment, nutrients, metals, organic carbon, hydrocarbons, pesticides, and fecal coliform bacteria. Other pollutants that have more recently become a concern in urban areas include MTBE, deicers, and the pathogens *Cryptosporidium* and *Giardia*. Concentrations of most stormwater pollutants can be characterized, over the long run, by event mean storm concentrations. Monitoring techniques have also allowed researchers to identify source areas for pollutants in the urban environment, including stormwater hotspots, which generate higher pollutant loads than normal development.

In general, most monitoring data shows that mean pollutant storm concentrations are higher in urban watersheds than in non-urban ones. For many urban pollutants, EMCs can be used to predict stormwater pollutant loads for urban watersheds, using IC as the key predictive variable. While a direct relationship between IC and pollutant concentrations does not usually exist, IC directly influences the volume of stormwater and hence, the total load. A few exceptions are worth noting. MTBE, deicers, and PAH appear to be related more to traffic or road density than IC. Additionally, MTBE and PAH concentrations may be greater at hotspot source areas, which are not always widely or uniformly distributed across a watershed. Pesticides, bacteria and pathogens are often associated with turf areas rather than IC. Bacteria and pathogen sources also include direct inputs from wildlife and inappropriate sewage discharges that are not uniformly distributed across a watershed and are not directly related to IC.

Further research into the relationship between stormwater pollutant loads and other watershed indicators may be helpful. For example, it would be interesting to see if turf cover is a good indicator of stream quality for impacted streams. Other important watershed indicators worth studying are the influence of watershed treatment practices, such as stormwater practices and stream buffers.

The direct effects of stormwater pollutants on aquatic systems appears to be a function of the size of the receiving water and the initial health of the aquatic community. For example, a small urban stream receiving high stormwater pollutant concentrations would be more likely to experience impacts than a large river, which is diluted by other land uses. Likewise, organisms in sensitive streams should be more susceptible to stormwater pollutants than pollution-tolerant organisms found in non-supporting streams.

Overall, the following conclusions can be made:

- Sediment, nutrient and trace metal loads in stormwater runoff can be predicted as a function of IC, although concentrations are not tightly correlated with watershed IC.
- Violations of bacteria standards are indirectly associated with watershed IC.
- It is not clear whether loads of hydrocarbons, pesticides or chlorides can be predicted on the basis of IC at the small watershed level.
- More research needs to be conducted to evaluate the usefulness of other watershed indicators to predict stormwater pollutant loads. For example, traffic, road density or hotspots may be useful in predicting MTBE, deicer and hydrocarbon loads. Also, watershed turf cover may be useful in predicting pesticide and bacterial loads.

- Most research on pollutants in stormwater runoff has been conducted at the small watershed level. Additional research is needed to evaluate the impact of watershed treatment, such as stormwater and buffer practices to determine the degree to which these may change stormwater concentrations or loads.
- Regional differences are evident for many stormwater pollutants, and these appear to be caused by either differences in rainfall frequency or snowmelt.

Chapter 5: Biological Impacts of Impervious Cover

This chapter reviews research on the impact of urbanization on the aquatic community, focusing on aquatic insects, fish, amphibians, freshwater mussels, and freshwater wetlands. Specifically, the relationship between the health of the aquatic community and the amount of watershed IC is analyzed within the context of the Impervious Cover Model (ICM).

The chapter is organized as follows:

5.1 Introduction
5.2 Indicators and General Trends
5.3 Effects on Aquatic Insect[1] Diversity
5.4 Effects on Fish Diversity
5.5 Effects on Amphibian Diversity
5.6 Effects on Wetland Diversity
5.7 Effects on Freshwater Mussel Diversity
5.8 Conclusion

5.1 Introduction

A number of studies, crossing different ecoregions and utilizing various techniques, have examined the link between watershed urbanization and its impact on stream and wetland biodiversity. These studies reveal that a relatively small amount of urbanization has a negative effect on aquatic diversity, and that as watersheds become highly urban, aquatic diversity becomes extremely degraded. As documented in prior chapters, hydrologic, physical, and water quality changes caused by watershed urbanization all stress the aquatic community and collectively diminish the quality and quantity of available habitat. As a result, these stressors generally cause a decline in biological diversity, a change in trophic structure, and a shift towards more pollution-tolerant organisms.

Many different habitat conditions are critical for supporting diverse aquatic ecosystems. For example, streambed substrates are vulnerable to deposition of fine sediments, which affects spawning, egg incubation and fry-rearing. Many aquatic insect species shelter in the large pore spaces among cobbles and boulders, particularly within riffles. When fine sediment fills these pore spaces, it reduces the quality and quantity of available habitat. The aquatic insect community is typically the base of the food chain in streams, helps break down organic matter and serves as a food source for juvenile fish.

Large woody debris (LWD) plays a critical role in the habitat of many aquatic insects and fish. For example, Bisson *et al.* (1988) contend that no other structural component is more important to salmon habitat than LWD, especially in the case of juvenile coho salmon. Loss of LWD due to the removal of stream side vegetation can significantly hinder the survival of more sensitive aquatic species. Since LWD creates different habitat types, its quality and quantity have been linked to salmonid rearing habitat and the ability of multiple fish species to coexist in streams.

The number of stream crossings (e.g., roads, sewers and pipelines) has been reported to increase directly in proportion to IC (May *et al.*, 1997). Such crossings can become partial or total barriers to upstream fish migration, particularly if the stream bed downcuts below the fixed elevation of a culvert or pipeline. Fish barriers can prevent migration and recolonization of aquatic life in many urban streams.

Urbanization can also increase pollutant levels and stream temperatures. In particular, trace metals and pesticides often bind to sediment particles and may enter the food chain, particularly by aquatic insects that collect and filter particles. While in-stream data is rare, some data are available for ponds. A study of trace

[1]*Throughout this chapter, the term "aquatic insects" is used rather than the more cumbersome but technically correct "benthic macroinvertebrates."*

metal bioaccumulation of three fish species found in central Florida stormwater ponds discovered that trace metal levels were significantly higher in urban ponds than in non-urban control ponds, often by a factor of five to 10 (Campbell, 1995; see also Karouna-Renier, 1995). Although typical stormwater pollutants are rarely acutely toxic to fish, the cumulative effects of sublethal pollutant exposure may influence the stream community (Chapter 4).

Table 46 summarizes some of the numerous changes to streams caused by urbanization that have the potential to alter aquatic biodiversity. For a comprehensive review of the impacts of urbanization on stream habitat and biodiversity, the reader should consult Wood and Armitage (1997) and Hart and Finelli (1999).

Table 46: Review of Stressors to Urban Streams and Effects on Aquatic Life

Stream Change	Effects on Organisms
Increased flow volumes/ Channel forming storms	Alterations in habitat complexity Changes in availability of food organisms, related to timing of emergence and recovery after disturbance Reduced prey diversity Scour-related mortality Long-term depletion of LWD Accelerated streambank erosion
Decreased base flows	Crowding and increased competition for foraging sites Increased vulnerability to predation Increased fine sediment deposition
Increase in sediment transport	Reduced survival of eggs and alevins, loss of habitat due to deposition Siltation of pool areas, reduced macroinvertebrate reproduction
Loss of pools and riffles	Shift in the balance of species due to habitat change Loss of deep water cover and feeding areas
Changes in substrate composition	Reduced survival of eggs Loss of inter-gravel fry refugial spaces Reduced aquatic insect production
Loss of LWD	Loss of cover from predators and high flows Reduced sediment and organic matter storage Reduced pool formation and organic substrate for aquatic insects
Increase in temperature	Changes in migration patterns Increased metabolic activity, increased disease and parasite susceptibility Increased mortality of sensitive fish
Creation of fish blockages	Loss of spawning habitat for adults Inability to reach overwintering sites Loss of summer rearing habitat, Increased vulnerability to predation
Loss of vegetative rooting systems	Decreased channel stability Loss of undercut banks Reduced streambank integrity
Channel straightening or hardening	Increased stream scour Loss of habitat complexity
Reduction in water quality	Reduced survival of eggs and alevins Acute and chronic toxicity to juveniles and adult fish Increased physiological stress
Increase in turbidity	Reduced survival of eggs Reduced plant productivity Physiological stress on aquatic organisms
Algae blooms	Oxygen depletion due to algal blooms, increased eutrophication rate of standing waters

5.2 Indicators and General Trends

Stream indicators are used to gauge aquatic health in particular watersheds. The two main categories of stream indicators are **biotic** and **development** indices. **Biotic** indices use stream diversity as the benchmark for aquatic health and use measures, such as species abundance, taxa richness, EPT Index, native species, presence of pollution-tolerant species, dominance, functional feeding group comparisons, or proportion with disease or anomalies. **Development** indices evaluate the relationship between the degree of watershed urbanization and scores for the biotic indices. Common development indices include watershed IC, housing density, population density, and percent urban land use.

5.2.1 Biological Indicators

Biotic indices are frequently used to measure the health of the aquatic insect or fish community in urban streams. Because many aquatic insects have limited migration patterns or a sessile mode of life, they are particularly well-suited to assess stream impacts over time. Aquatic insects integrate the effects of short-term environmental variations, as most species have a complex but short life cycle of a year or less. Sensitive life stages respond quickly to environmental stressors, but the overall community responds more slowly. Aquatic insect communities are comprised of a broad range of species, trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects. Unlike fish, aquatic insects are abundant in most small, first and second order streams. Individuals are relatively easy to identify to family level, and many "intolerant" taxa can be identified to lower taxonomic levels with ease.

Fish are good stream indicators over longer time periods and broad habitat conditions because they are relatively long-lived and mobile. Fish communities generally include a range of species that represents a variety of trophic levels (omnivores, herbivores, insectivores, planktivores, and piscivores). Fish tend to integrate the effects of lower trophic levels; thus, their community structure reflects the prevailing food sources and habitat conditions. Fish are relatively easy to collect and identify to the species level. Most specimens can be sorted and identified in the field by experienced fisheries scientists and subsequently released unharmed.

A review of the literature indicates that a wide variety of metrics are used to measure the aquatic insect and fish community. Community indices, such as the Index of Biotic Integrity (IBI) for fish and the Benthic Index of Biotic Integrity (B-IBI) for the aquatic insect community are a weighted combination of various metrics that typically characterize the community from "excellent" to "poor." Common metrics of aquatic community are often based on a composite of measures, such as species richness, abundance, tolerance, trophic status, and native status. Combined indices (C-IBI) measure both fish and aquatic insect metrics and a variety of physical habitat conditions to classify streams. Table 47 lists several common metrics used in stream assessments. It should be clearly noted that community and combined indices rely on different measurements and cannot be directly compared. For a comprehensive review of aquatic community indicators, see Barbour *et al.*(1999).

5.2.2 Watershed Development Indices

Watershed IC, housing density, population density, and percent urban land have all been used as indices of the degree of watershed development. In addition, reverse indicators such as percent forest cover and riparian continuity have also been used. The majority of studies so far have used IC to explore the relationship between urbanization and aquatic diversity. Percent urban land has been the second most frequently used indicator to describe the impact of watershed development. Table 48 compares the four watershed development indices and the thresholds where significant impacts to aquatic life are typically observed.

Table 47: Examples of Biodiversity Metrics Used to Assess Aquatic Communities		
Measurement	**Applied to:**	**Definition of Measurement**
Abundance	Fish, Aquatic Insects	Total number of individuals in a sample; sometimes modified to exclude tolerant species.
Taxa Richness	Fish, Aquatic Insects	Total number of unique taxa identified in a sample. Typically, an increase in taxa diversity indicates better water and habitat quality.
EPT Index	Aquatic Insects	Taxa belonging to the following three groups: *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies). Typically, species in these orders are considered to be pollution-intolerant taxa and are generally the first to disappear with stream quality degradation.
Native Status	Fish	Native vs. non-native taxa in the community.
Specific Habitat	Fish	Riffle benthic insectivorous individuals. Total number of benthic insectivores. Often these types of individuals, such as darters, sculpins, and dace are found in high velocity riffles and runs and are sensitive to physical habitat degradation.
		Minnow species Total number of minnow species present. Often used as an indicator of pool habitat quality. Includes all species present in the family Cyprinidae, such as daces, minnows, shiners, stonerollers, and chubs.
Tolerant Species	Fish, Aquatic Insects	The total number of species sensitive to and the number tolerant of degraded conditions. Typically, intolerant species decline with decreasing water quality and stream habitat. A common high pollution-tolerant species that is frequently used is Chironomids.
Dominance	Fish, Aquatic Insects	The proportion of individuals at each station from the single most abundant taxa at that particular station. Typically, a community dominated by a single taxa may be indicative of stream degradation.
Functional Feeding Group Comparisons	Fish	Omnivores/ Generalists: The proportion of individuals characterized as omnivores or generalists to the total number of individuals. Typically, there is a shift away from specialized feeding towards more opportunistic feeders under degraded conditions as food sources become unreliable.
		Insectivores: The proportion of individuals characterized as insectivores to the total number of individuals. Typically, the abundance of insectivores decreases relative to increasing stream degradation.
	Aquatic Insects	Others: The proportion of individuals characterized as shredders, scrapers, or filter feeders to the total number of individuals. Typically, changes in the proportion of functional feeders characterized as shredders can be reflective of contaminated leaf matter. In addition, an overabundance of scrapers over filterers can be indicative of increased benthic algae.
Disease/ Anomalies	Fish	Proportion of individuals with signs of disease or abnormalities. This is ascertained through gross external examination for abnormalities during the field identification process. Typically, this metric assumes that incidence of disease and deformities increases with increasing stream degradation.

** This table is not meant to provide a comprehensive listing of metrics used for diversity indices; it is intended to provide examples of types of measures used in biological stream assessments (see Barbour et al., 1999).*

5.2.3 General Trends

Most research suggests that a decline in both species abundance and diversity begins at or around 10% watershed IC (Schueler, 1994a). However, considerable variations in aquatic diversity are frequently observed from five to 20% IC, due to historical alterations, the effectiveness of watershed management, prevailing riparian conditions, co-occurrence of stressors, and natural biological variation (see Chapter 1).

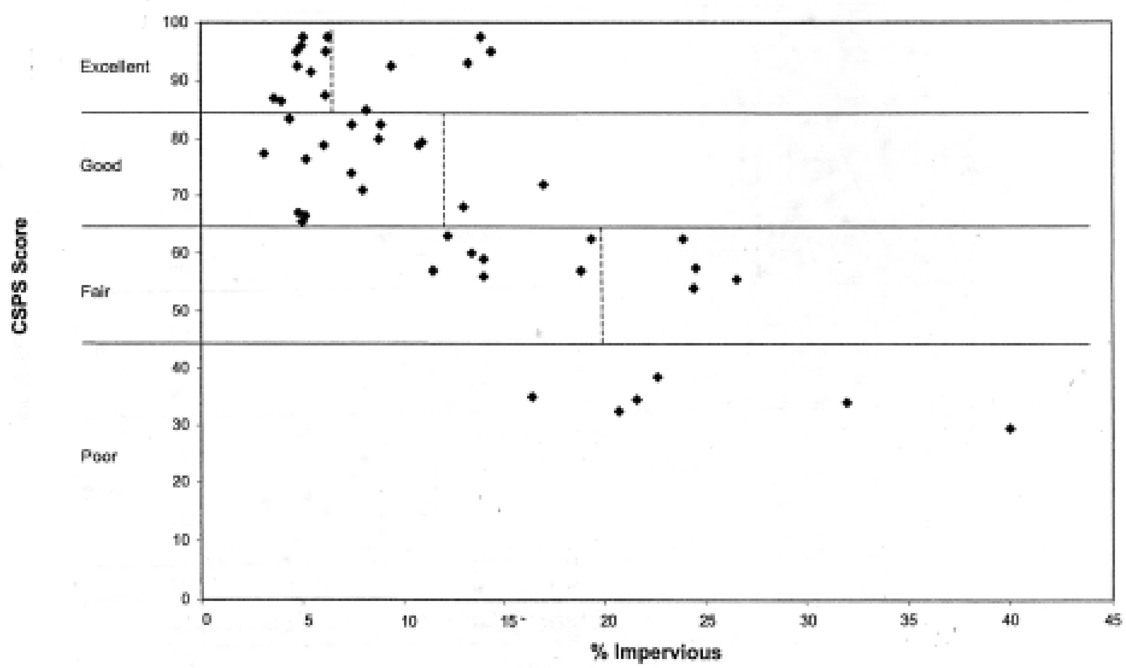
Figures 40 through 42 display the negative relationship commonly seen between biotic indices and various measures of watershed development. For example, stream research in the Maryland Piedmont indicated that IC was the best predictor of stream condition, based on a combined fish and aquatic insect IBI (MNCPPC, 2000). In general, streams with less than 6% watershed IC were in “excellent” condition, whereas streams in “good” condition had less than 12% IC, and streams in “fair” condition had less than 20%. Figure 40 shows the general boundaries and typical variation seen in MNCPPC stream research.

Figure 41 illustrates that B-IBI scores and Coho Salmon/Cutthroat Trout Ratio are a function of IC for 31 streams in Puget Sound, Washington. The interesting finding was that “good” to “excellent” B-IBI scores (greater than 25) were reported in watersheds that had less than 10% IC, with eight notable outliers. These outliers had greater IC (25 to 35%) but similar B-IBI scores. These outliers are unique in that they had a large upstream wetland and/ or a large, intact riparian corridor upstream (i.e. >70% of stream corridor had buffer width >100 feet).

Figure 42 depicts the same negative relationship between watershed urbanization and fish-IBI scores but uses population density as the primary metric of development (Dreher, 1997). The six-county study area included the Chicago metro area and outlying rural watersheds. Significant declines in fish-IBI scores were noted when population density exceeded 1.5 persons per acre.

The actual level of watershed development at which an individual aquatic species begins to decline depends on several variables, but may be lower than that indicated by the ICM. Some researchers have detected impacts for individual aquatic species at watershed IC levels as low as 5%. Other research has suggested that the presence of certain stressors, such as sewage treatment plant discharges (Yoder and Miltner, 2000) or construction sites (Reice, 2000) may alter the ICM and lower the level of IC at which biodiversity impacts become evident.

Table 48: Alternate Land Use Indicators and Significant Impact Levels (Brown, 2000; Konrad and Booth, 2002)			
Land Use Indicator	**Level at which Significant Impact Observed**	**Typical Value for Low Density Residential Use**	**Comments**
% IC	10-20%	10%	Most accurate; highest level of effort and cost
Housing Density	>1 unit/acre	1 unit/acre	Low accuracy in areas of substantial commercial or industrial development; less accurate at small scales
Population Density	1.5 to 8+ people/acre	2.5 people/acre	Low accuracy in areas of substantial commercial or industrial development; less accurate at small scales
% Urban Land Use	33% (variable)	10-100%	Does not measure intensity of development; moderately accurate at larger watershed scales
Road Density	5 miles/square mile	2 miles/square mile	Appears to be a potentially useful indicator



1. Outliers are located to the right of the vertical lines for each CSPS Stream rating.

Figure 40: Combined Fish and Benthic IBI vs. IC in Maryland Piedmont Streams (MNCPPC, 2000)

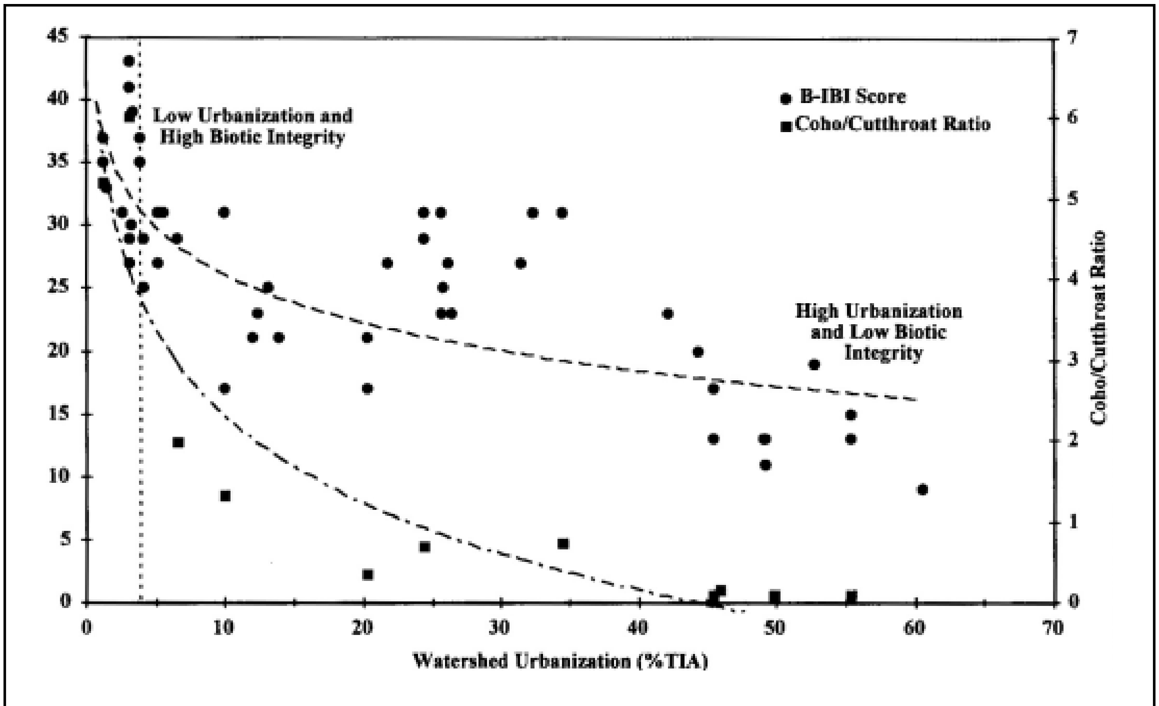


Figure 41: Relationship Between B-IBI, Coho/Cutthroat Ratios, and Watershed IC in Puget Sound Streams (Horner *et al.*, 1997)

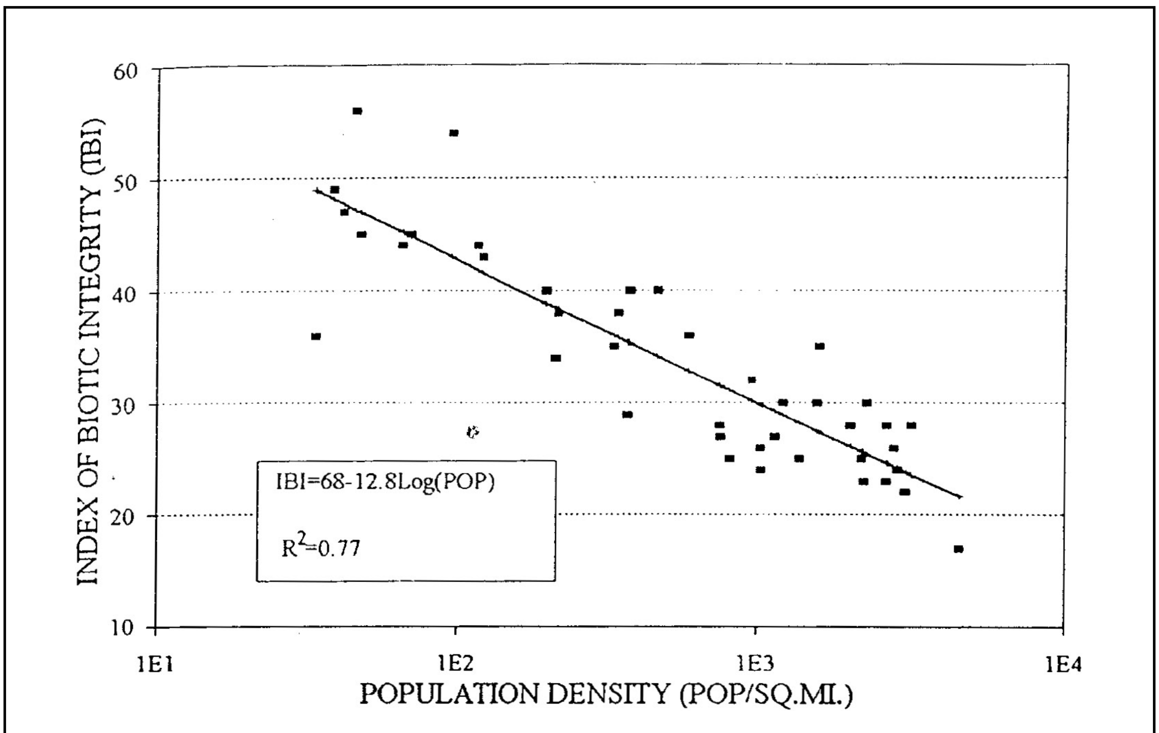


Figure 42: Index for Biological Integrity as a Function of Population Density in Illinois (Dreher, 1997)

5.3 Effects on Aquatic Insect Diversity

The diversity, richness and abundance of the aquatic insect community is frequently used to indicate urban stream quality. Aquatic insects are a useful indicator because they form the base of the stream food chain in most regions of the country. For this reason, declines or changes in aquatic insect diversity are often an early signal of biological impact due to watershed development. The aquatic insect community typically responds to increasing development by losing species diversity and richness and shifting to more pollution-tolerant species. More than 30 studies illustrate how IC and urbanization affect the aquatic insect community. These are summarized in Tables 49 and 50.

5.3.1 Findings Based on IC Indicators

Klein (1979) was one of the first researchers to note that aquatic insect diversity drops sharply in streams where watershed IC exceeded 10 to 15%. While "good" to "fair" diversity was noted in all headwater streams with less than 10% IC, nearly all streams with 12% or more watershed IC recorded "poor" diversity. Other studies have confirmed this general relationship between IC and the decline of aquatic insect species diversity. Their relationships have been an integral part in the development of the ICM. The sharp drop in aquatic insect diversity at or around 12 to 15% IC was also observed in streams in the coastal plain and Piedmont of Delaware (Maxted and Shaver, 1997).

Impacts at development thresholds lower than 10% IC have also been observed by Booth (2000), Davis (2001), Horner *et al.* (1997) and Morse (2001). There seems to be a general recognition that the high levels of variability observed below 10% IC indicate that other factors, such as riparian condition, effluent discharges, and pollution legacy may be better indicators of aquatic insect diversity (Horner and May, 1999; Kennen, 1999; Steedman, 1988; Yoder *et al.*, 1999).

The exact point at which aquatic insect diversity shifts from fair to poor is not known with absolute precision, but it is clear that few, if any, urban streams can support diverse aquatic insect communities with more than 25% IC. Indeed, several researchers failed to find aquatic insect communities with good or excellent diversity in any highly urban stream (Table 52). Indeed, MNCPPC (2000) reported that all streams with more than 20% watershed IC were rated as "poor."

Several good examples of the relationship between IC and B-IBI scores are shown in Figures 43 through 45. Figure 43 depicts the general trend line in aquatic insect diversity as IC increased at 138 stream sites in Northern Virginia (Fairfax County, 2001). The survey study concluded that stream degradation occurred at low levels of IC, and that older developments lacking more efficient site design and stormwater controls tended to have particularly degraded streams. Figures 44 and 45 show similar trends in the relationship between IC and aquatic insect B-IBI scores in Maryland and Washington streams. In particular, note the variability in B-IBI scores observed below 10% IC in both research studies.

Often, shift in the aquatic insect community from pollution-sensitive species to pollution-tolerant species occurs at relatively low IC levels (<10%). This shift is often tracked using the EPT metric, which evaluates sensitive species found in the urban stream community in the orders of *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), and *Trichoptera* (caddisflies). EPT species frequently disappear in urban streams and are replaced by more pollution-tolerant organisms, such as chironomids, tubificid worms, amphipods and snails.

In undisturbed streams, aquatic insects employ specialized feeding strategies, such as shredding leaf litter, filtering or collecting organic matter that flows by, or preying on other insects. These feeding guilds are greatly reduced in urban streams and are replaced by grazers, collectors and deposit feeders. Maxted and Shaver (1997) found that 90% of sensitive

Table 49: Recent Research Examining the Relationship Between IC and Aquatic Insect Diversity in Streams

Index	Key Finding (s)	Source	Location
Community Index	Three years stream sampling across the state at 1000 sites found that when IC was >15%, stream health was never rated good based on a C-IBI.	Boward *et al.*, 1999	MD
Community Index	Insect community and habitat scores were all ranked as poor in five subwatersheds that were greater than 30% IC.	Black and Veatch, 1994	MD
Community Index	Puget sound study finds that some degradation of aquatic invertebrate diversity can occur at any level of human disturbance (at least as measured by IC). 65% of watershed forest cover usually indicates a healthy aquatic insect community.	Booth, 2000	WA
Community Index	In a Puget Sound study, the steepest decline of B-IBI was observed after 6% IC. There was a steady decline, with approximately 50% reduction in B-IBI at 45% IC.	Horner *et al.*, 1997	WA
Community Index	B-IBI decreases with increasing urbanization in study involving 209 sites, with a sharp decline at 10% IC. Riparian condition helps mitigate effects.	Steedman, 1988	Ontario
Community Index	Wetlands, forest cover and riparian integrity act to mitigate the impact of IC on aquatic insect communities.	Horner *et al.*, 2001	WA, MD, TX
Community Index	B-IBI declines for aquatic insect with increasing IC at more than 200 streams.	Fairfax Co., 2001	VA
Community Index	Two-year stream study of eight Piedmont watersheds reported B-IBI scores declined sharply at an IC threshold of 15-30%.	Meyer and Couch,2000	GA
Community Index	Montgomery County study; subwatersheds with <12% IC generally had streams in good to excellent condition based on a combined fish and aquatic insect IBI. Watersheds with >20% IC had streams in poor condition.	MNCPPC, 2000	MD
Community Index	Study of 1st, 2nd, and 3rd order streams in the Patapsco River Basin showed negative relationship between B-IBI and IC.	Dail *et al.*, 1998	MD
Community Index	While no specific threshold was observed, impacts were seen at even low levels of IC. B-IBI values declined with increasing IC, with high scores observed only in reaches with <5% IC or intact riparian zones or upstream wetlands.	Horner and May, 1999	WA
Community Index	The C-IBI also decreased by 50% at 10-15% IC. These trends were particularly strong at low-density urban sites (0-30% IC).	Maxted and Shaver, 1997	DE
Diversity	In both coastal plain and Piedmont streams, a sharp decline in aquatic insect diversity was found around 10-15% IC.	Shaver *et al.*, 1995	DE
Diversity	In a comparison of Anacostia subwatersheds, there was significant decline in the diversity of aquatic insects at 10% IC.	MWCOG, 1992	DC
Diversity	In several dozen Piedmont headwater streams, aquatic diversity declined significantly beyond 10-12% IC.	Klein, 1979	MD
EPT Value	In a 10 stream study with watershed IC ranging from three to 30%, a significant decline in EPT values was reported as IC increased (r2 = 0.76).	Davis, 2001	MO
Sensitive Species	In a study of 38 wadeable, non-tidal streams in the urban Piedmont, 90% of sensitive organisms were eliminated from the benthic community after watershed IC reaches 10-15%.	Maxted and Shaver, 1997	DE
Species Abundance EPT values	For streams draining 20 catchments across the state, an abrupt decline in species abundance and EPT taxa was observed at approximately 6% IC.	Morse, 2001	ME

Table 50: Recent Research Examining the Relationship of Other Indices of Watershed Development on Aquatic Insect Diversity in Streams

Biotic	Key Finding (s)	Source	Location
Percent Urban Land use			
Community Index	Study of 700 streams in 5 major drainage basins found that the amount of urban land and total flow of municipal effluent were the most significant factors in predicting severe impairment of the aquatic insect community. Amount of forested land in drainage area was inversely related to impairment severity.	Kennen, 1999	NJ
Community Index	All 40 urban sites sampled had fair to very poor B-IBI scores, compared to undeveloped reference sites.	Yoder, 1991	OH
Community Index	A negative correlation between B-IBI and urban land use was noted. Community characteristics show similar patterns between agricultural and forested areas the most severe degradation being in urban and suburban areas.	Meyer and Couch, 2000	GA
EPT Value, Diversity, Community Index	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had substantially lower EPT scores (22% vs 5% as number of all taxa, 65% vs 10% as percent abundance) and IBI scores in the poor range.	Crawford and Lenat, 1989	NC
Sensitive Species	Urbanization associated with decline in sensitive taxa, such as mayflies, caddisflies and amphipods while showing increases in oligochaetes.	Pitt and Bozeman, 1982	CA
Sensitive Species	Dramatic changes in aquatic insect community were observed in most urbanizing stream sections. Changes include an abundance of pollution-tolerant aquatic insect species in urban streams.	Kemp and Spotila, 1997	PA
Diversity	As watershed development levels increased, the aquatic insect diversity declined.	Richards *et al.*, 1993	MN
Diversity	Significant negative relationship between number of aquatic insect species and degree of urbanization in 21 Atlanta streams.	Benke *et al.*, 1981	GA
Diversity	Drop in insect taxa from 13 to 4 was noted in urban streams.	Garie and McIntosh, 1986	NJ
Diversity	Aquatic insect taxa were found to be more abundant in non-urban reaches than in urban reaches of the watershed.	Pitt and Bozeman, 1982	CA
Diversity	A study of five urban streams found that as watershed land use shifted from rural to urban, aquatic insect diversity decreased.	Masterson and Bannerman, 1994	WI
Other Land Use Indicators			
Community Index	Most degraded streams were found in developed areas, particularly older developments lacking newer and more efficient stormwater controls.	Fairfax Co., 2001	VA
Diversity	Urban streams had sharply lower aquatic insect diversity with human population above four persons/acre in northern VA.	Jones and Clark, 1987	VA
EPT Value	Monitoring of four construction sites in three varying regulatory settings found that EPT richness was related to enforcement of erosion and sediment controls. The pattern demonstrated that EPT richness was negatively affected as one moved from upstream to at the site, except for one site.	Reice, 2000	NC
Sensitive Species	In a Seattle study, aquatic insect community shifted to chironomid, oligochaetes and amphipod species that are pollution-tolerant and have simple feeding guild.	Pedersen and Perkins,1986	WA

species (based on EPT richness, % EPT abundance, and Hilsenhoff Biotic Index) were eliminated from the aquatic insect community when IC exceeded 10 to 15% in contributing watersheds of Delaware streams (Figure 46). In a recent study of 30 Maine watersheds, Morse (2001) found that reference streams with less than 5% watershed IC had significantly more EPT taxa than more urban streams. He also observed no significant differences in EPT Index values among streams with six to 27% watershed IC (Figure 47).

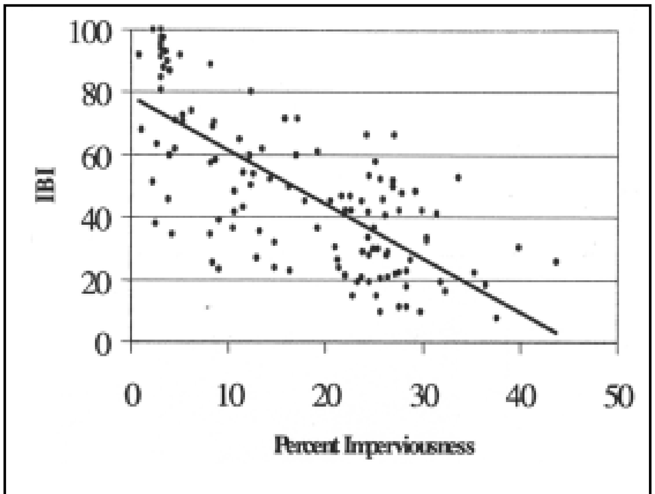


Figure 43: Trend Line Indicating Decline in Benthic IBI as IC Increases in Northern VA Streams (Fairfax County, 2001)

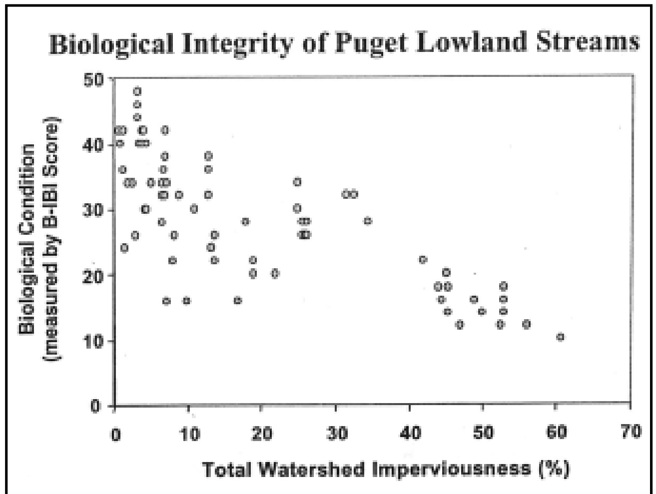


Figure 44: Relationship Between IC and B-IBI Scores in Aquatic Insects in Streams of the Puget Sound Lowlands (Booth, 2000)

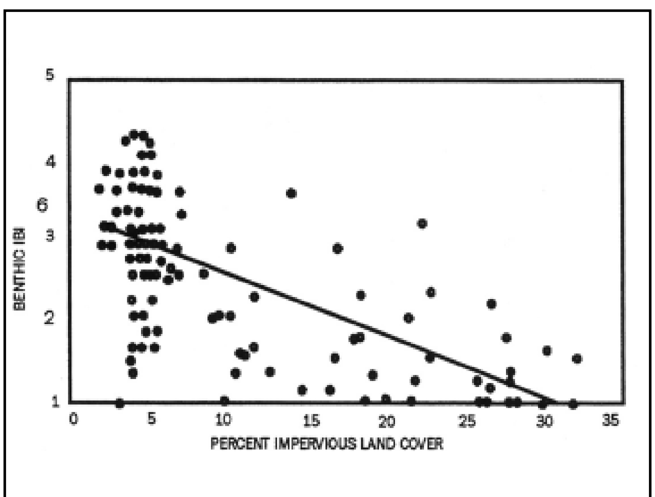


Figure 45: IC and B-IBI at Stream Sites in the Patapsco River Basin, MD (Dail *et al.*, 1998)

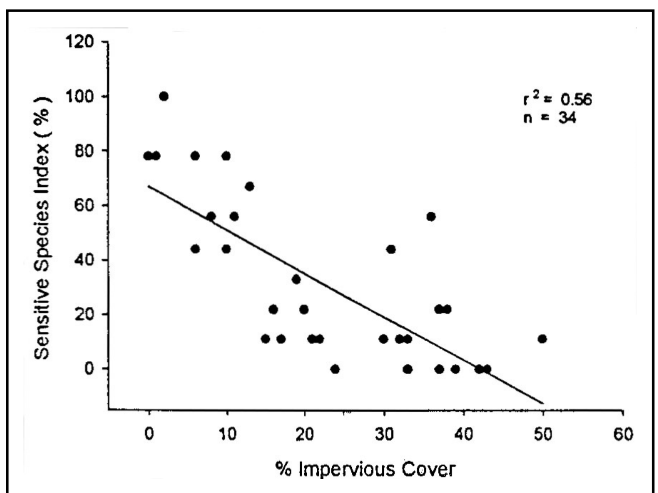


Figure 46: IC vs. Aquatic Insect Sensitivity - EPT Scores in Delaware Streams (Maxted and Shaver, 1997)

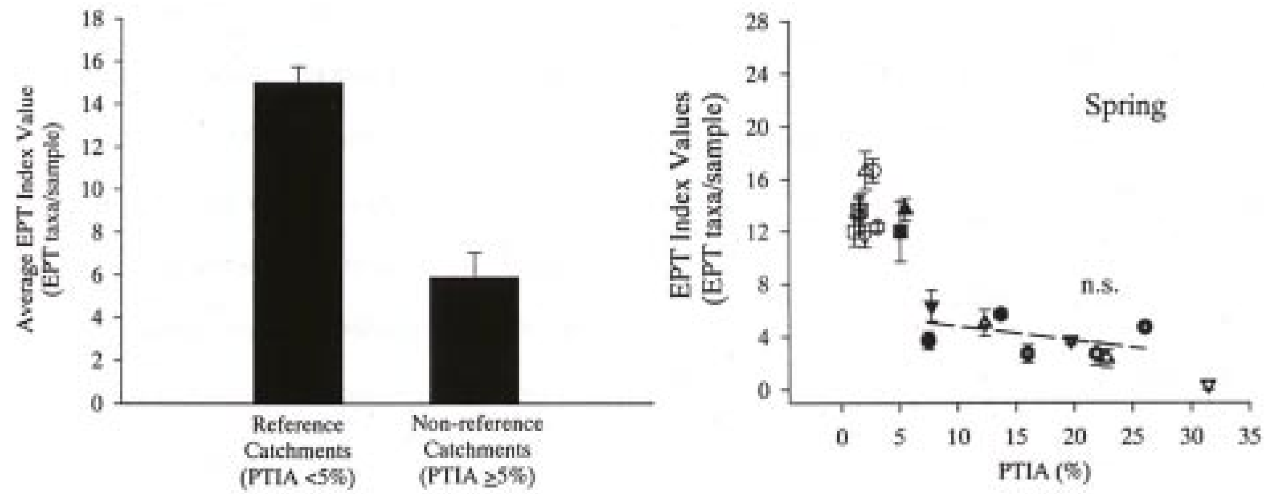


Figure 47: Average and Spring EPT Index Values vs.% IC in 20 Small Watersheds in Maine (Morse, 2001)

5.3.2 Findings Based on Other Development Indicators

Development indices, such as percent urban land use, population density, and forest and riparian cover have also been correlated with changes in aquatic insect communities in urban streams. Declines in benthic IBI scores have frequently been observed in proportion to the percent urban land use in small watersheds (Garie and McIntosh, 1986; Kemp and Spotila, 1997; Kennen, 1999; Masterson and Bannerman, 1994; Richards *et al.*, 1993; USEPA, 1982).

A study in Washington state compared a heavily urbanized stream to a stream with limited watershed development and found that the diversity of the aquatic insect community declined from 13 taxa in reference streams to five taxa in more urbanized streams (Pedersen and Perkins, 1986). The aquatic insect taxa that were lost were poorly suited to handle the variable erosional and depositional conditions found in urban streams. Similarly, a comparison of three North Carolina streams with different watershed land uses concluded the urban watershed had the least taxa and lowest EPT scores and greatest proportion of pollution-tolerant species (Crawford and Lenat, 1989).

Jones and Clark (1987) monitored 22 streams in Northern Virginia and concluded that aquatic insect diversity diminished markedly once watershed population density exceeded four or more people per acre. The population density roughly translates to ½ - 1 acre lot residential use, or about 10 to 20 % IC. Kennen (1999) evaluated 700 New Jersey streams and concluded that the percentage of watershed forest was positively correlated with aquatic insect density. Meyer and Couch (2000) reported a similar cover relationship between aquatic insect diversity and watershed and riparian forest cover for streams in the Atlanta, GA region. A study in the Puget Sound region found that aquatic insect diversity declined in streams once forest cover fell below 65% (Booth, 2000).

5.4 Effects on Fish Diversity

Fish communities are also excellent environmental indicators of stream health. In general, an increase in watershed IC produces the same kind of impact on fish diversity as it does for aquatic insects. The reduction in fish diversity is typified by a reduction in total species, loss of sensitive species, a shift toward more pollution-tolerant species, and decreased survival of eggs and larvae. More than 30 studies have examined the relationship between watershed development and fish diversity; they are summarized in Tables 51 and 52. About half of the research studies used IC as the major index of watershed development, while the remainder used other indices, such as percent urban land use, population density, housing density, and forest cover.

5.4.1 Findings Based on IC Indicators

Recent stream research shows a consistent, negative relationship between watershed development and various measures of fish diversity, such as diversity metrics, species loss and structural changes.

Typically, a notable decline in fish diversity occurs around 10 to 15% watershed IC (Boward *et al.*, 1999; Galli, 1994; Klein, 1979; Limburg and Schmidt, 1990; MNCPPC, 2000; MWCOG, 1992; Steward, 1983). A somewhat higher threshold was observed by Meyer and Couch (2000) for Atlanta streams with 15 to 30% IC; lower thresholds have also been observed (Horner *et al.*, 1997 and May *et al.*, 1997). A typical relationship between watershed IC and fish diversity is portrayed in Figure 48, which shows data from streams in the Patapsco River Basin in Maryland (Dail *et al.*, 1998). Once again, note the variability in fish-IBI scores observed below 10% IC.

Wang *et al.* (1997) evaluated 47 Wisconsin streams and found an apparent threshold around 10% IC. Fish-IBI scores were "good" to "excellent" below this threshold, but were consistently rated as "fair" to "poor." Additionally, Wang documented that the total number of fish species drops sharply when IC increases (Figure 49). Often, researchers also reported that increases in IC were strongly correlated with several fish metrics, such as increases in non-native and pollution-tolerant species in streams in Santa Clara, California (EOA, Inc., 2001).

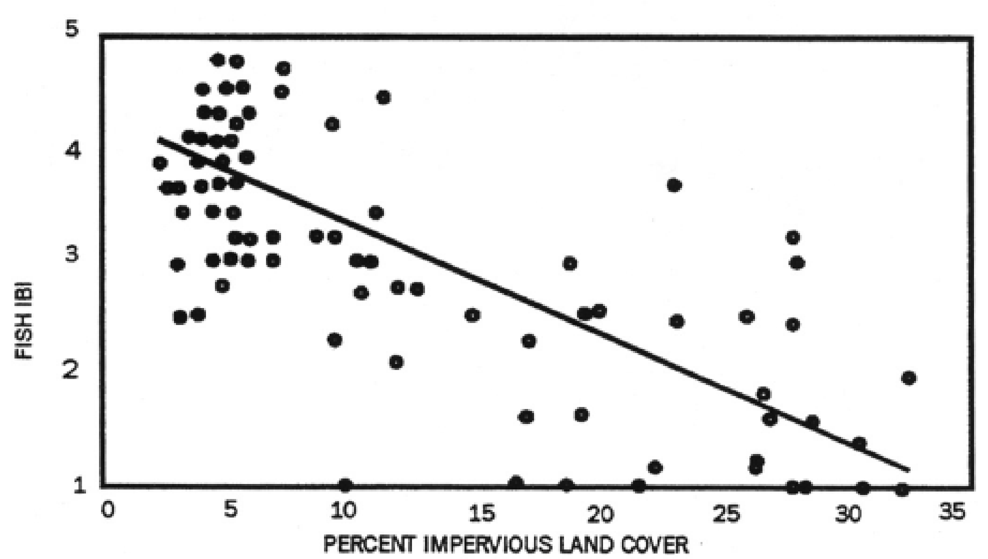


Figure 48: Fish-IBI vs. Watershed IC for Streams in the Patapsco River Basin, MD (Dail *et al.*, 1998)

Table 51: Recent Research Examining the Relationship Between Watershed IC and the Fish Community			
Biotic	**Key Finding (s)**	**Source**	**Location**
Abundance	Brown trout abundance and recruitment declined sharply at 10-15% IC.	Galli, 1994	MD
Salmonids	Seattle study showed marked reduction in coho salmon populations noted at 10-15% IC at nine streams.	Steward, 1983	WA
Anadromous Fish Eggs	Resident and anadromous fish eggs and larvae declined in 16 subwatersheds draining to the Hudson River with >10% IC area.	Limburg and Schmidt, 1990	NY
Community Index	1st, 2nd, and 3rd order streams in the Patapsco River Basin showed negative relationship between IBI and IC.	Dail *et al.*, 1998	MD
Community Index	Fish IBI and habitat scores were all ranked as poor in five subwatersheds that were greater than 30% IC.	Black and Veatch, 1994	MD
Community Index	In the Potomac subregion, subwatersheds with < 12% IC generally had streams in good to excellent condition based on a combined fish and aquatic insect IBI. Watersheds with >20% IC had streams in poor condition.	MNCPPC, 2000	MD
Community Index	In a two-year study of Piedmont streams draining eight watersheds representing various land uses in Chattahochee River Basin, fish community quality dropped sharply at an IC threshold of 15-30%.	Meyer and Couch, 2000	GA
Diversity	Of 23 headwater stream stations, all draining <10% IC areas, rated as good to fair; all with >12% were rated as poor. Fish diversity declined sharply with increasing IC between 10-12%.	Schueler and Galli, 1992	MD
Diversity, Sensitive Species	Comparison of 4 similar subwatersheds in Piedmont streams, there was significant decline in the diversity of fish at 10% IC. Sensitive species (trout and sculpin) were lost at 10-12%.	MWCOG, 1992	MD
Diversity, Community Index	In a comparison of watershed land use and fish community data for 47 streams between the 1970s and 1990s, a strong negative correlation was found between number species and IBI scores with effective connected IC. A threshold of 10% IC was observed with community quality highly variable below 10% but consistently low above 10% IC.	Wang *et al.*, 1997	WI
Diversity	In several dozen Piedmont headwater streams fish diversity declined significantly in areas beyond 10-12% IC.	Klein, 1979	MD
Diversity , Abundance, Non-native Species	IC strongly associated with several fisheries species and individual-level metrics, including number of pollution-tolerant species, diseased individuals, native and non-native species and total species present	EOA, Inc., 2001	CA
Juvenile Salmon Ratios	In Puget Sound study, the steepest decline of biological functioning was observed after six percent IC. There was a steady decline, with approximately 50% reduction in initial biotic integrity at 45% IC area.	Horner *et al.*, 1997	WA
Juvenile Salmon Ratio	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as total IC area exceeded the five to 10% range.	May *et al.*, 1997	WA
Salmonoid	Negative effects of urbanization (IC) with the defacto loss of non-structural BMPs (wetland forest cover and riparian integrity) on salmon ratios	Horner *et al.*, 2001	WA, MD, TX
Salmonoid, Sensitive Species	While no specific threshold was observed (impacts seen at even low levels of IC), Coho/cutthroat salmon ratios >2:1 were found when IC was < 5%. Ratios fell below one at IC levels below 20 %.	Horner and May, 1999	WA
Sensitive species, Salmonid	Three years stream sampling across the state (approximately 1000 sites), MBSS found that when IC was >15%, stream health was never rated good based on CBI, and pollution sensitive brook trout were never found in streams with >2% IC.	Boward *et al.*, 1999	MD
Sensitive Species, Salmonids	Seattle study observed shift from less tolerant coho salmon to more tolerant cutthroat trout population between 10 and 15% IC at nine sites.	Luchetti and Feurstenburg 1993	WA

Sensitive fish are defined as species that strongly depend on clean and stable bottom substrates for feeding and/or spawning. Sensitive fish often show a precipitous decline in urban streams. The loss of sensitive fish species and a shift in community structure towards more pollution-tolerant species is confirmed by multiple studies. Figure 50 shows the results of a comparison of four similar subwatersheds in the Maryland Piedmont that were sampled for the number of fish species present (MWCOG, 1992). As the level of watershed IC increased, the number of fish species collected dropped. Two sensitive species, including sculpin, were lost when IC increased from 10 to 12%, and four more species were lost when IC reached 25%. Significantly, only two species remained in the fish community at 55% watershed IC.

Salmonid fish species (trout and salmon) and anadromous fish species appear to be particularly impacted by watershed IC. In a study in the Pacific Northwest, sensitive coho salmon were seldom found in watersheds above 10 or 15% IC (Luchetti and Feurstenburg, 1993 and Steward, 1983). Key stressors in urban streams, such as higher peak flows, lower dry weather flows, and reduction in habitat complexity (e.g. fewer pools, LWD, and hiding places) are believed to change salmon species composition, favoring cutthroat trout populations over the natural coho populations (WDFW, 1997).

A series of studies from the Puget Sound reported changes in the coho/cutthroat ratios of juvenile salmon as watershed IC increased (Figure 51). Horner *et al.* (1999) found Coho/Cutthroat ratios greater than 2:1 in watersheds with less than 5 % IC. Ratios fell below 1:1 when IC exceeded 20%. Similar results were reported by May *et al.* (1997). In the mid-Atlantic region, native trout have stringent temperature and habitat requirements and are seldom present in watersheds where IC exceeds 15% (Schueler, 1994a). Declines in trout spawning success are evident above 10% IC. In a study of over 1,000 Maryland streams, Boward *et al.* (1999) found that sensitive brook trout were never found in streams that had more than 4% IC in their contributing watersheds.

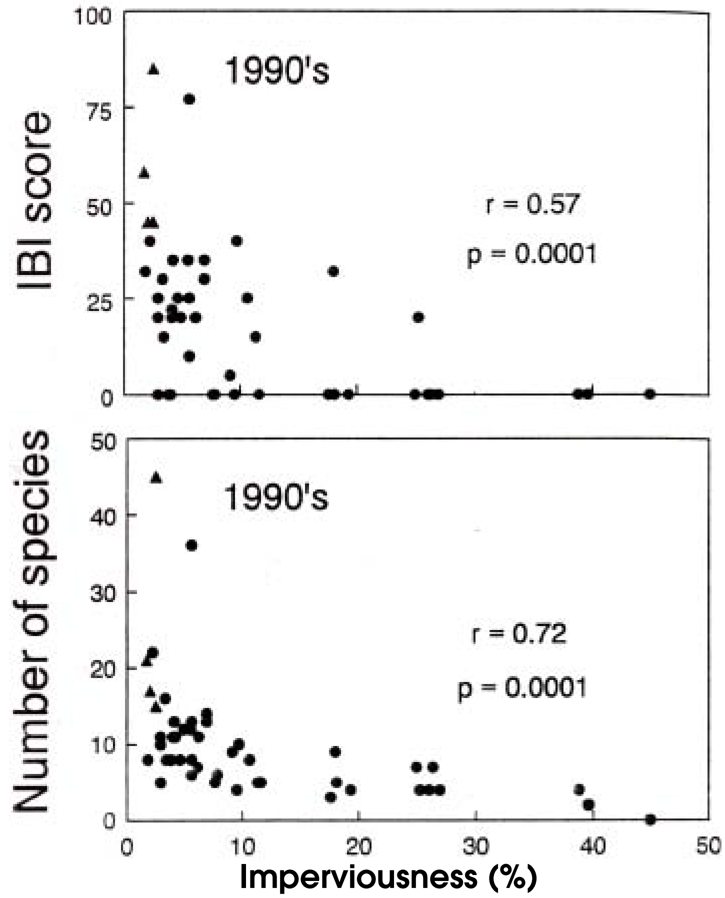


Figure 49: Fish-IBI and Number of Species vs. % IC in Wisconsin Streams (Wang *et al.*, 1997)

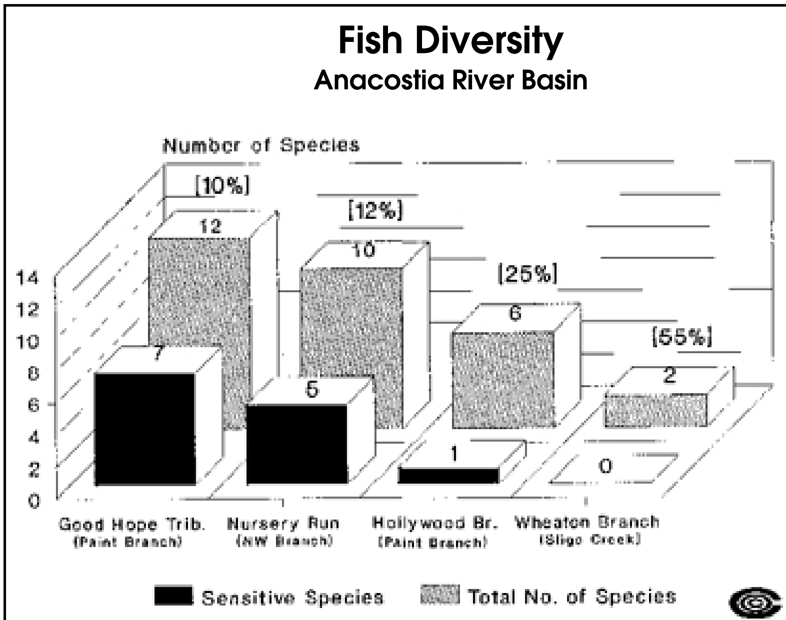


Figure 50: IC and Effects on Fish Species Diversity in Four Maryland Subwatersheds (MWCOG, 1992)

Table 52: Recent Research Examining Urbanization and Freshwater Fish Community Indicators			
Biotic	**Key Finding (s)**	**Source**	**Location**
Urbanization			
Community Index	All 40 urban sites sampled had fair to very poor IBI scores, compared to undeveloped reference sites.	Yoder, 1991	OH
Community Index	Negative correlations between biotic community and riparian conditions and forested areas were found. Similar levels of fish degradation were found between suburban and agricultural; urban areas were the most severe.	Meyer and Couch, 2000	GA
Community Index	Residential urban land use caused significant decrease in fish-IBI scores at 33%. In more urbanized Cuyahoga, a significant drop in IBI scores occurred around 8% urban land use in the watershed. When watersheds smaller than 100mi^2 were analyzed separately, the level of urban land associated with a significant drop in IBI scores occurred at around 15%. Above one du/ac, most sites failed to attain biocriteria regardless of degree of urbanization.	Yoder *et al.*, 1999	OH
Community Index, Abundance	As watershed development increased to about 10%, fish communities simplified to more habitat and trophic generalists and fish abundance and species richness declined. IBI scores for the urbanized stream fell from the good to fair category.	Weaver, 1991	VA
Diversity	A study of five urban streams found that as land use shifted from rural to urban, fish diversity decreased.	Masterson and Bannerman, 1994	WI
Diversity, Community Index	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had IBI scores in the poor range.	Crawford and Lenat, 1989	NC
Salmon Spawning, Flooding Frequency	In comparing three streams over a 25-year period (two urbanizing and one remaining forested), increases in flooding frequencies and decreased trends in salmon spawning were observed in the two urbanizing streams, while no changes in flooding or spawning were seen in the forested system.	Moscript and Montgomery, 1997	WA
Sensitive Species	Observed dramatic changes in fish communities in most urbanizing stream sections, such as absence of brown trout and abundance of pollution-tolerant species in urban reaches.	Kemp and Spotila, 1997	PA
Sensitive Species, Diversity	Decline in sensitive species diversity and composition and changes in trophic structure from specialized feeders to generalists was seen in an urbanizing watershed from 1958 to 1990. Low intensity development was found to affect warm water stream fish communities similarly as more intense development.	Weaver and Garman, 1994	VA
Warm Water Habitat Biocriteria	25-30% urban land use defined as the upper threshold where attainment of warm water habitat biocriterion is effectively lost. Non-attainment also may occur at lower thresholds given the co-occurrence of stressors, such as pollution legacy, WTPs and CSOs.	Yoder and Miltner, 2000	OH
Community Index, Habitat	The amount of urban land use upstream of sample sites had a strong negative relationship with biotic integrity, and there appeared to be a threshold between 10 and 20% urban land use where IBI scores declined dramatically. Watersheds above 20% urban land invariably had scores less than 30 (poor to very poor). Habitat scores were not tightly correlated with degraded fish community attributes.	Wang *et al.*, 1997	WI
Community Index	A study in the Patapsco Basin found significant correlation of fish IBI scores with percent urbanized land over all scales (catchment, riparian area, and local area).	Roth *et al.*, 1998	MD

Table 52 (continued): Recent Research Examining Urbanization and Freshwater Fish Community Indicators			
Biotic	**Key Finding (s)**	**Source**	**Location**
Urbanization			
Sensitive Species	Evaluated effects of runoff in both urban and non-urban streams; found that native species dominated the non-urban portion of the watershed but accounted for only seven percent of species found in the urban portions of the watershed.	Pitt, 1982	CA
Other Land Use Indicators			
Community Index, Habitat	Atlanta study found that as watershed population density increased, there was a negative impact on urban fish and habitat. Urban stream IBI scores were inversely related to watershed population density, and once density exceeded four persons/acre, urban streams were consistently rated as very poor.	Couch *et al.*, 1997	GA
Community Index	In an Atlanta stream study, modified IBI scores declined once watershed population density exceeds four persons/acre in 21 urban watersheds	DeVivo *et al.*, 1997	GA
Community Index	In a six-county study (including Chicago, its suburbs and outlying rural/agricultural areas), streams showed a strong correlation between population density and fish community assessments such that as population density increased, community assessment scores went from the better - good range to fair - poor. Significant impacts seen at 1.5 people/acre.	Dreher, 1997	IL
Community Index	Similarly, negative correlations between biotic community and riparian conditions and forested areas were also found. Similar levels of fish degradation were found between suburban and agricultural; urban areas were the most severe.	Meyer and Couch, 2000	GA
Community Index	Amount of_forested land in basin directly related to IBI scores for fish community condition.	Roth *et al.*, 1996	MD
Salmonid, Sensitive Species	Species community changes from natural coho salmon to cutthroat trout population with increases in peak flow, lower low flow, and reductions in stream complexity.	WDFW, 1997	WA

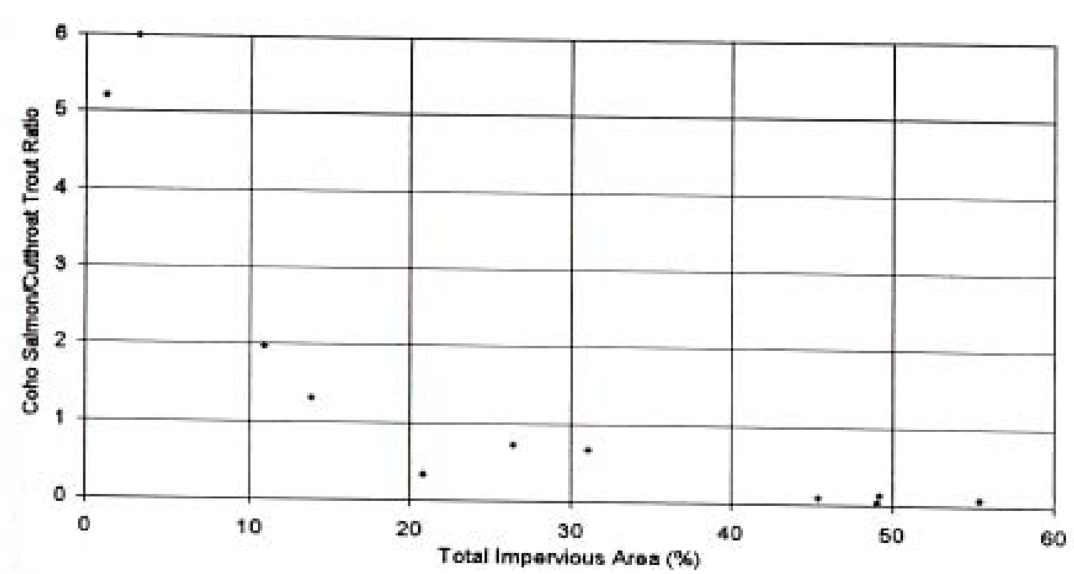


Figure 51: Coho Salmon/Cutthroat Trout Ratio for Puget Sound Streams (Horner *et al.*, 1997)

Many fish species have poor spawning success in urban streams and poor survival of fish eggs and fry. Fish barriers, low intragravel dissolved oxygen, sediment deposition and scour are all factors that can diminish the ability of fish species to successfully reproduce. For example, Limburg and Schmidt (1990) discovered that the density of anadromous fish eggs and larvae declined sharply in subwatersheds with more than 10% IC.

5.4.2 Findings Based on Other Development Indicators

Urban land use has frequently been used as a development indicator to evaluate the impact on fish diversity. Streams in urban watersheds typically had lower fish species diversity and richness than streams located in less developed watersheds. Declines in fish diversity as a function of urban land cover have been documented in numerous studies (Crawford and Lenat, 1989; Masterson and Bannerman, 1994; Roth *et al., 1998;* Yoder, 1991, and Yoder *et al.*, 1999). USEPA (1982) found that native fish species dominated the fish community of non-urban streams, but accounted for only 7% of the fish community found in urban streams. Kemp and Spotila (1997) evaluated streams in Pennsylvania and noted the loss of sensitive species (e.g. brown trout) and the increase of pollution-tolerant species, such as sunfish and creek chub (Figure 52).

Wang *et al.* (1997) cited percentage of urban land in Wisconsin watersheds as a strong negative factor influencing fish-IBI scores in streams and observed strong declines in IBI scores with 10 to 20% urban land use. Weaver and Garman (1994) compared the historical changes in the warm-water fish community of a Virginia stream that had undergone significant urbanization and found that many of the sensitive species present in 1958 were either absent or had dropped sharply in abundance when the watershed was sampled in 1990. Overall abundance had dropped from 2,056 fish collected in 1958 to 417 in 1990. In addition, the 1990 study showed that 67% of the catch was bluegill and common shiner, two species that are habitat and trophic "generalists." This shift in community to more habitat and trophic generalists was observed at 10% urban land use (Weaver, 1991).

Yoder *et al.* (1999) evaluated a series of streams in Ohio and reported a strong decrease in warm-water fish community scores around 33% residential urban land use. In the more urbanized Cuyahoga streams, sharp drops in

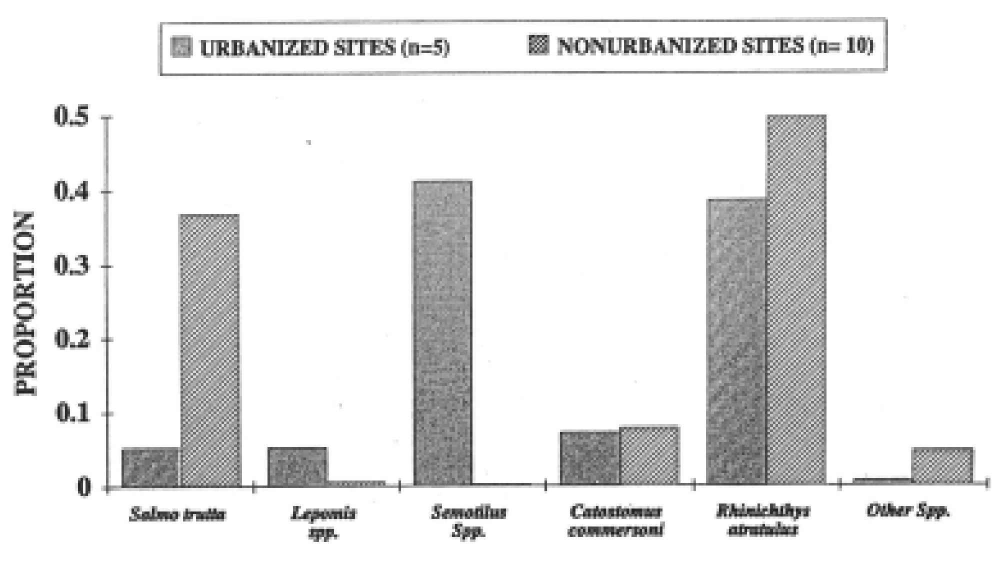


Figure 52: Mean Proportion of Fish Taxa in Urban and Non-Urban Streams, Valley Forge Watershed, PA (Kemp and Spotila, 1997)

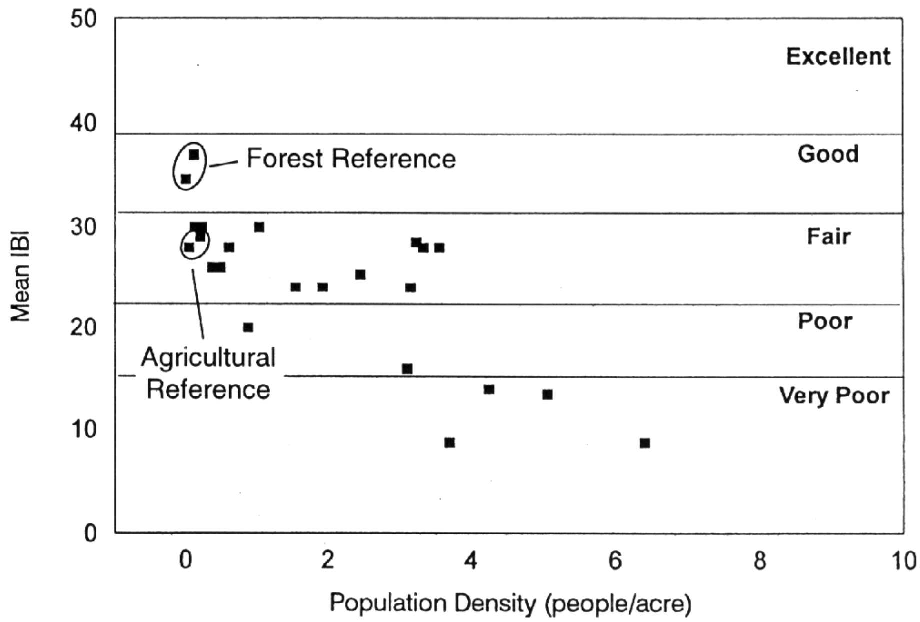


Figure 53: Relationship Between Watershed Population Density and Stream IBI Scores in Georgia Streams (DeVivo *et al.*, 1997)

fish-IBI scores occurred around 8% urban land use, primarily due to certain stressors which functioned to lower the non-attainment threshold. When watersheds smaller than $100mi^2$ were analyzed separately, the percentage of urban land use associated with a sharp drop in fish-IBI scores was around 15%. In a later study, Yoder and Miltner (2000) described an upper threshold for quality warm-water fish habitat at 25 to 30% urban land use.

Watershed population and housing density have also been used as indicators of the health of the fish community. In a study of 21 urban watersheds in Atlanta, DeVivo *et al.* (1997) observed a shift in mean fish-IBI scores from "good to fair" to "very poor" when watershed population density exceeded four people/acre (Figure 53). A study of Midwest streams in metropolitan Illinois also found a negative relationship between increase in population density and fish communities, with significant impacts detected at population densities of 1.5 people or greater per acre (Dreher, 1997). In the Columbus and Cuyahoga watersheds in Ohio, Yoder *et al.* (1999) concluded that most streams failed to attain fish biocriteria above one dwelling unit/acre.

5.5 Effects on Amphibian Diversity

Amphibians spend portions of their life cycle in aquatic systems and are frequently found within riparian, wetland or littoral areas. Relatively little research has been conducted to directly quantify the effects of watershed development on amphibian diversity. Intuitively, it would appear that the same stressors that affect fish and aquatic insects would also affect amphibian species, along with riparian wetland alteration. We located four research studies on the impacts of watershed urbanization on amphibian populations; only one was related to streams (Boward *et al.,* 1999), while others were related to wetlands (Table 53).

A primary factor influencing amphibian diversity appears to be water level fluctuations (WLF) in urban wetlands that occur as a result of increased stormwater discharges. Chin (1996) hypothesized that increased WLF and other hydrologic factors affected the abundance of egg clutches and available amphibian breeding habitat, thereby ultimately influencing amphibian richness. Increased WLF can limit reproductive success by eliminating mating habitat and the emergent vegetation to which amphibians attach their eggs.

Taylor (1993) examined the effect of watershed development on 19 freshwater wetlands in King County, WA and concluded that the additional stormwater contributed to greater annual WLF. When annual WLF exceeded about eight inches, the richness of both the wetland plant and amphibian communities dropped sharply. Large increases in WLF were consistently observed in freshwater wetlands when IC in upstream watersheds exceeded 10 to 15%. Further research on streams and wetlands in the Pacific northwest by Horner *et al.* (1997) demonstrated the correlation between watershed IC and diversity of amphibian species. Figure 54 illustrates the relationship between amphibian species abundance and watershed IC, as documented in the study.

Table 53: Recent Research on the Relationship Between Percent Watershed Urbanization and the Amphibian Community

Indicator	Key Finding(s)	Reference Year	Location
% IC			
Reptile and Amphibian Abundance	In a three-year stream sampling across the state (approximately 1000 sites), MBSS found only hardy pollution-tolerant reptiles and amphibians in stream corridors with >25% IC drainage area.	Boward *et al.*, 1999	MD
Amphibian Density	Mean annual water fluctuation inversely correlated to amphibian density in urban wetlands. Declines noted beyond 10% IC.	Taylor, 1993	WA
Other Studies			
Species Richness	In 30 wetlands, species richness of reptiles and amphibians was significantly related to density of paved roads on lands within a two kilometer radius.	Findlay and Houlahan, 1997	Ontario
Species Richness	Decline in amphibian species richness as wetland WLF increased. While more of a continuous decline rather than a threshold, WLF = 22 centimeters may represent a tolerance boundary for amphibian community.	Horner *et al.*, 1997	WA
Amphibian Density	Mean annual water fluctuation inversely correlated to amphibian density in urban wetlands.	Taylor, 1993	WA

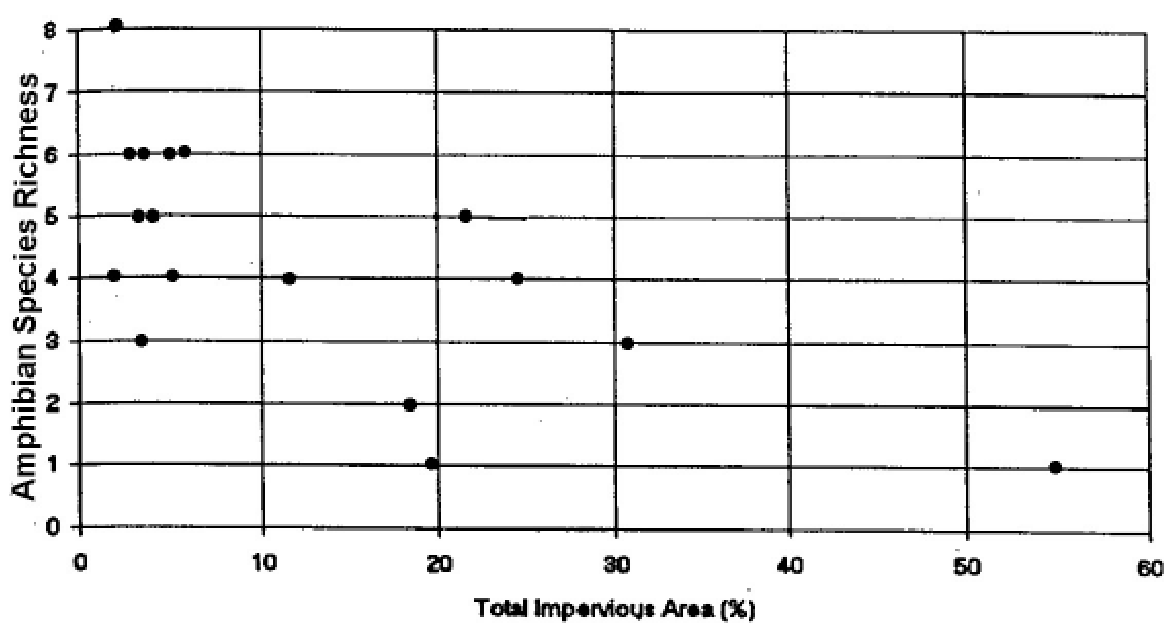


Figure 54: Amphibian Species Richness as a Function of Watershed IC in Puget Sound Lowland Wetlands (Horner *et al.*, 1997)

5.6 Effects on Wetland Diversity

We found a limited number of studies that evaluated the impact of watershed urbanization on wetland plant diversity (Table 54). Two studies used IC as an index of watershed development and observed reduced wetland plant diversity around or below 10% IC (Hicks and Larson, 1997 and Taylor, 1993). WLF and road density were also used as indicators (Findlay and Houlahan, 1997; Horner *et al.*, 1997; Taylor, 1993).

Horner *et al.* (1997) reported a decline in plant species richness in emergent and scrub-shrub wetland zones of the Puget Sound region as WLF increased. They cautioned that species numbers showed a continuous decline rather than a threshold value; however, it was indicated that WLF as small as 10 inches can represent a tolerance boundary for wetland plant communities. Horner further stated that in 90% of the cases where WLF exceeded 10 inches, watershed IC exceeded 21%.

Table 54: Recent Research Examining the Relationship Between Watershed Development and Urban Wetlands

Watershed Indicator Biotic	Key Finding(s)	Reference	Location
% IC			
Insect Community	Significant declines in various indicators of wetland aquatic macro-invertebrate community health were observed as IC increased to 8-9%.	Hicks and Larson, 1997	CT
WLF, Water Quality	There is a significant increase in WLF, conductivity, fecal coliform bacteria, and total phosphorus in urban wetland as IC exceeds 3.5%.	Taylor *et al.*, 1995	WA
Plant Density	Declines in urban wetland plant density noted in areas beyond 10% IC.	Taylor, 1993	WA
Other Watershed Indicators			
Plant Density	Mean annual water fluctuation inversely correlated to plant density in urban wetlands.	Taylor, 1993	WA
Plant Species Richness	Decline in plant species richness in emergent and scrub-shrub wetland zones as WLF increased. While more of a continuous decline, rather than a threshold, WLF=22 centimeters may represent a tolerance boundary for the community	Horner *et al.*, 1997	WA
Plant Species Richness	In 30 wetlands, species richness was significantly related to density of paved roads within a two kilometer radius of the wetland. Model predicted that a road density of 2kilometers per hectare in paved road within 1000 meters of wetland will lead to a 13% decrease in wetland plant species richness.	Findlay and Houlahan,1997	Ontario

5.7 Effects on Freshwater Mussel Diversity

Freshwater mussels are excellent indicators of stream quality since they are filter-feeders and essentially immobile. The percentage of imperiled mussel species in freshwater ecoregions is high (Williams *et al.*, 1993). Of the 297 native mussel species in the United States, 72% are considered endangered, threatened, or of special concern, including 21 mussel species that are presumed to be extinct. Seventy mussel species (24%) are considered to have stable populations, although many of these have declined in abundance and distribution. Modification of aquatic habitats and sedimentation are the primary reasons cited for the decline of freshwater mussels (Williams *et al.,* 1993).

Freshwater mussels are very susceptible to smothering by sediment deposition. Consequently, increases in watershed development and sediment loading are suspected to be a factor leading to reduced mussel diversity. At sublethal levels, silt interferes with feeding and metabolism of mussels in general (Aldridge *et al.*, 1987). Major sources of mortality and loss of diversity in mussels include impoundment of rivers and streams, and eutrophication (Bauer, 1988). Changes in fish diversity and abundance due to dams and impoundments can also influence the availability of mussel hosts (Williams *et al.*, 1992).

Freshwater mussels are particularly sensitive to heavy metals and pesticides (Keller and Zam, 1991). Although the effects of metals and pesticides vary from one species to another, sub-lethal levels of PCBs, DDT, Malathion, Rotenone and other compounds are generally known to inhibit respiratory efficiency and accumulate in tissues (Watters, 1996). Mussels are more sensitive to pesticides than many other animals tested and often act as “first-alerts” to toxicity long before they are seen in other organisms.

We were unable to find any empirical studies relating impacts of IC on the freshwater mussel communities of streams.

5.8 Conclusion

The scientific record is quite strong with respect to the impact of watershed urbanization on the integrity and diversity of aquatic communities. We reviewed 35 studies that indicated that increased watershed development led to declines in aquatic insect diversity and about 30 studies showing a similar impact on fish diversity. The scientific literature generally shows that aquatic insect and freshwater fish diversity declines at fairly low levels of IC (10 to 15%), urban land use (33%), population density (1.5 to eight people/acre) and housing density (>1 du/ac). Many studies also suggest that sensitive elements of the aquatic community are affected at even lower levels of IC. Other impacts include loss of sensitive species and reduced abundance and spawning success. Research supports the ICM, although additional research is needed to establish the upper threshold at which watershed development aquatic biodiversity can be restored.

One area where more research is needed involves determining how regional and climatic variations affect aquatic diversity in the ICM. Generally, it appears that the 10% IC threshold applies to streams in the East Coast and Midwest, with Pacific Northwest streams showing impacts at a slightly higher level. For streams in the arid and semi-arid Southwest, it is unclear what, if any, IC threshold exists given the naturally stressful conditions for these intermittent and ephemeral streams (Maxted, 1999). Southwestern streams are characterized by seasonal bursts of short but intense rainfall and tend to have aquatic communities that are trophically simple and relatively low in species richness (Poff and Ward, 1989).

Overall, the following conclusions can be drawn:

- IC is the most commonly used index to assess the impacts of watershed urbanization on aquatic insect and fish diversity. Percent urban land use is also a common index.
- The ICM may not be sensitive enough to predict biological diversity in watersheds with low IC. For example, below 10% watershed IC, other watershed variables such as riparian continuity, natural forest cover, cropland, ditching and acid rain may be better for predicting stream health.
- More research needs to be done to determine the maximum level of watershed development at which stream diversity can be restored or maintained. Additionally, the capacity of stormwater treatment practices and stream buffers to mitigate high levels of watershed IC warrants more systematic research.
- More research is needed to test the ICM on amphibian and freshwater mussel diversity.

References

Aldridge, D., B. Payne and A. Miller. 1987. “The Effects of Intermittent Exposure to Suspended Solids and Turbulence on Three Species of Freshwater Mussels.” *Environmental Pollution* 45:17-28.

Allen, P. and R. Narramore. 1985. “Bedrock Controls on Stream Channel Enlarement with Urbanization, North Central Texas.” *American Water Resource Association* 21(6).

Allmendinger, N.L., J.E. Pizzuto, T.E. Johnson and W.C. Hession. 1999. “Why Channels with ‘Grassy’ Riparian Vegetation Are Narrower than Channels with Forested Riparian Vegetation.” *Eos (Transactions, American Geophysical Union)*, v. 80, Fall Meeting Supplement, Abstract H32D-10.

Association of California Water Agencies (ACWA). 2000. Website. http://www.acwanet.com/news_info/testimony/tsca5-00.doc

Ayers, M., R. Brown and G. Oberts. 1985. *Runoff and Chemical Loading in Small Watersheds in the Twin Cities Metropolitan Area, Minnesota*. U.S. Geological Survey Water Resources Investigations Report 85-4122.

Bagley, S., M. Aver, D. Stern and M. Babiera. 1998. “Sources and Fate of Giardia Cysts and Cryptosporidium Oocysts in Surface Waters.” *Journal of Lake and Reservoir Management* 14(2-3): 379-392.

Baird, C., T. Dybala, M. Jennings and D.Ockerman. 1996. *Characterization of Nonpoint Sources and Loadings to Corpus Christi National Estuary Program Study Area*. Corpus Christi Bay National Estuary Program. City of Corpus Christi, TX.

Bannerman, R., A. Legg and S. Greb. 1996. *Quality of Wisconsin Stormwater 1989-1994*. U.S. Geological Survey. Reston, VA.Open File Report 96-458.

Bannerman, R., D. Owens, R. Dodds and N. Hornewer. 1993. “Sources of Pollutants in Wisconsin Stormwater.” *Water Science and Technology* 28(3-5): 241-259.

Barbour, M., J. Gerritsen, B. Snyder and J. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*. 2nd Edition. EPA 841-B-99-002. U.S. EPA Office of Water. Washington, D.C.

Barfield, B. and M. Clar. 1985. *Development of New Design Criteria for Sediment Traps and Basins*. Prepared for the Maryland Resource Administration. Annapolis, MD.

Barr, R. 1997. *Maryland NPDES Phase I Monitoring Data*. Maryland Department of the Environment. Baltimore, MD.

Barrett, M. and J. Malina. 1998. *Comparison of Filtration Systems and Vegetated Controls for Stormwater Treatment.* 3rd International Conference on Diffuse Pollution. Scottish Environment Protection Agency, Edinburg Scotland.

Barrett, M., R. Zuber, E. Collins and J. Malina. 1995. *A Review and Evaluation of Literature Pertaining to the Quantity and Control of Pollution from Highway Runoff and Construction.* CRWR Online Report 95-5.

Bauer, G. 1988. “Threats to the Freshwater Pearl Mussel Margaritifera *margaritifera* L. in Central Europe.” *Biological Conservation* 45: 239-253.

Bay, S. and J. Brown. 2000. *Assessment of MTBE Discharge Impacts on California Marine Water Quality*. State Water Resources Control Board. Southern California Coastal Water Research Project. Westminster, California.

Beeson, C. and P. Doyle. 1995. "Comparison of Bank Erosion at Vegetated and Non-vegetated Bends." *Water Resources Bulletin* 31(6).

Benke, A., E. Willeke, F. Parrish and D. Stites. 1981. *Effects of Urbanization on Stream Ecosystems*. Office of Water Research and Technology. US Department of the Interior. Completion Report Project No. A-055-GA.

Bicknell, B., J. Imhoff, J. Kittle, A. Donigian and R. Johanson. 1993. *Hydrologic Simulation Program-Fortran-HSPF.* Users Manual for Release 10.0. EPA 600/3-84-066. Environmental Research Laboratory, U.S. EPA, Athens, GA.

Bisson, P., K. Sullivan, and J. Nielsen. 1988. "Channel Hydraulics, Habitat Use, and Body Form of Juvenile Coho Salmon, Steelhead, and Cutthroat Trout in Streams." *Transactions of the American Fisheries Society* 117:262-273.

Black and Veatch. 1994. *Longwell Branch Restoration-Feasibility Study* Vol. 1. Carroll County, MD Office of Environmental Services.

Blankenship, K. 1996. "Masked Bandit Uncovered in Water Quality Theft." *Bay Journal* 6(6).

Bledsoe, B. 2001. "Relationships of Stream Response to Hydrologic Changes." *Linking Stormwater BMP Designs and Performance to Receiving Water Impacts Mitigation* Proceedings. Snowmass, CO.

Blood, E. and P. Smith. 1996. "Water Quality in Two High-Salinity Estuaries: Effects of Watershed Alteration." *Sustainable Development in the Southeastern Coastal Zone*. F.J. Vernberg, W.B. Vernberg and T. Siewicki (eds.). Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.

Boom, A. and J. Marsalek. 1988. "Accumulation of Polycyclic Aromatic Hydrocarbons. (PAHs) in an Urban Snowpack." *Science of the Total Environment* 74:148.

Booth, D. 2000. "Forest Cover, Impervious Surface Area, and the Mitigation of Urbanization Impacts in King County, WA." Prepared for King County Water and Land Resource Division. University of Washington.

Booth, D. 1991. "Urbanization and the Natural Drainage System-Impacts, Solutions and Prognoses." *Northwest Environmental Journal* 7(1): 93-118.

Booth, D. 1990. "Stream Channel Incision Following Drainage Basin Urbanization." *Water Resources Bulletin* 26(3): 407-417.

Booth, D. and P. Henshaw. 2001. "Rates of Channel Erosion in Small Urban Streams." *Water Science and Application* 2:17-38.

Booth, D. and C. Jackson. 1997. "Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection and the Limits of Mitigation." *Journal AWRA* 33(5): 1077- 1089.

Booth, D. and L. Reinelt. 1993. *Consequences of Urbanization on Aquatic Systems - Measured Effects, Degradation Thresholds, and Corrective Strategies*. Watershed '93 Proceedings. Alexandria, Virginia.

Booth, D., D. Montgomery and J. Bethel. 1997. "Large Woody Debris in the Urban Streams of the Pacific Northwest." *Effects of Watershed Development and Management on Aquatic Ecosystems.* Roesner, L.A. Editor. Proceedings of the ASCE Conference. Snowbird, Utah.

Boughton, C. and M. Lico. 1998. *Volatile Organic Compounds in Lake Tahoe, Nevada and California*. United States Geological Survey. Fact Sheet FS-055-98.

Boward, D., P. Kazyak, S. Stranko, M. Hurd and T. Prochaska. 1999. *From the Mountains to the Sea: The State of Maryland's Freshwater Streams.* EPA 903-R-99-023. Maryland Deparment of Natural Resources. Annapolis, MD.

Bowen, J. and I. Valiela. 2001. " The Ecological Effects of Urbanization of Coastal Watersheds: Historical Increases in Nitrogen Loads and Eutrophication of Waquiot Bay Estuaries." *Canadian Journal of Fisheries and Aquatic Sciences* 58(8):1489-1500.

Brown, K. 2000. "Housing Density and Urban Land Use as Stream Quality Indicators." *Watershed Protection Techniques* 3(3): 735-739.

Brown, W. 2000. "A Study of Paired Catchments Within Peavine Creek, Georgia." *Watershed Protection Techniques* 3(2):681-684.

Brush, S., M. Jennings, J. Young and H. McCreath. 1995. NPDES Monitoring – Dallas – Ft. Worth, Texas Area. *In Stormwater NPDES Related Monitoring Needs.* Proceedings of an Engineering Foundation Conference. Edited by Harry Torno. New York, NY.

Campbell, K.R. 1995. "Concentrations of Heavy Metals associated with Urban Runoff in Fish Living in Stormwater Ponds." *Archives of Environmental Contamination and Toxicology 27:352-356.*

Cappiella, K. and K. Brown. 2001. *Impervious Cover and Land Use in the Chesapeake Bay Watershed*. Center for Watershed Protection. Ellicott City, MD.

Caraco, D. 2000a. "Stormwater Strategies for Arid and Semi-arid Watersheds." *Watershed Protection Techniques* 3(3):695-706.

Caraco, D. 2000b. "The Dynamics of Urban Stream Channel Enlargement." *Watershed Protection Techniques* 3(3):729-734.

Center for Watershed Protection (CWP). *In press. Smart Watersheds: Integrating Local Programs to Achieve Measurable Progress in Urban Watershed Restoration*. Ellicott City, MD.

CWP. 2001a. "Managing Phosphorus Inputs Into Lakes." *Watershed Protection Techniques* 3(4): 769-796.

CWP. 2001b. *Watts Branch Watershed Study and Management Plan.* Prepared for City of Rockville, Maryland. Ellicott City, MD.

CWP. 1998. *Rapid Watershed Planning Manual*. Ellicott City, MD.

Chang G., J. Parrish and C. Souer. 1990. *The First Flush of Runoff and its Effect on Control Structure Design.* Environmental Resource Management Division - Department of Environmental and Conservation Services. Austin, TX.

Chessman, B., P. Hutton and J. Burch. 1992. "Limiting Nutrients for Periphyton Growth in Sub-alpine Forest, Agricultural and Urban Streams." *Freshwater Biology* 28: 349-361.

Chin, N. 1996. *Watershed Urbanization Effects on Palustrine Wetlands: A Study of the Hydrologic, Vegetative, and Amphibian Community Response Over Eight Years.* M.S. Thesis. Department of Civil Engineering. University of Washington.

Collins, A, D. Walling and G. Leeks. 1997. "Source Type Ascription for Fluvial Suspended Sediment Based on a Quantitative Composite Fingerprinting Technique." *Catena* 29:1-27.

Connor, V. 1995. *Pesticide Toxicity in Stormwater Runoff. Technical Memorandum*. California Regional Water Quality Control Board, Central Valley Region. Sacramento, California.

Corsi, S., D. Hall and S. Geis. 2001. "Aircraft and Runway Deicers at General Mitchell International Airport, Milwaukee, Wisconsin, USA. 2. Toxicity of Aircraft and Runway Deicers." *Environmental Toxicology and Chemistry* 20(7):1483-1490.

Couch, C. *et al*. 1997. "Fish Dynamics in Urban Streams Near Atlanta, Georgia." Technical Note 94. *Watershed Protection Techniques*. 2(4): 511-514.

Crawford, J. and D. Lenat. 1989. *Effects of Land Use on Water Quality and the Biota of Three Streams in the Piedmont Province of North Carolina*. United States Geological Service.Raleigh, NC. Water Resources Investigations Report 89-4007.

Crippen and Waananen. 1969. *Hydrologic Effects of Suburban Development Near Palo Alto, California.* Open file report. U.S. Geologic Survey, Menlo Park, Califronia.

Crunkilton, R., J. Kleist, J. Ramcheck, W. DeVita and D. Villeneuve. 1996. "Assessment of the Response of Aquatic Organisms to Long-term In Situ Exposures of Urban Runoff." *Effects of Watershed Development and Management on Aquatic Ecosystems.* Roesner, L.A. Editor. Proceedings of the ASCE Conference. Snowbird, Utah.

Dail, H., P. Kazyak, D. Boward and S. Stranko. 1998. *Patapsco River Basin: Environmental Assessment of Stream Conditions*. Maryland Department of Natural Resources. Chesapeake Bay and Watershed Programs CBP-MANTA-EA-98-4.

Dartiguenave, C., I. ECLille and D. Maidment. 1997. *Water Quality Master Planning for Austin, TX*. CRWR Online Report 97-6.

Davis, J. 2001. Personal communication. Department of Rural Sociology, University of Missouri, Columbia, MO.

Delzer, G.C. 1999. *National Water-Quality Assessment Program: Quality of Methyl Tert-Butyl Ether (MTBE) Data for Ground-water Samples Collected During 1993-95.* United States Geological Survey Fact Sheet. FS-101-99.

Delzer, G.C. 1996. *Occurrence of the Gasoline Oxygenate MTBE and BTEX Compounds in Urban Stormwater in the United States, 1991-95*. Untied States Geological Survey Water-Resources Investigation Report. WRIR 96-4145.

Denver Regional Council of Governments (DRCOG). 1983. *Urban Runoff Quality in the Denver Region.* Denver, CO.

DeVivo, J., C. Couch and B. Freeman. 1997. *Use of Preliminary Index of Biotic Integrity in Urban Streams Around Atlanta, Georgia.* Georgia Water Resources Conference. Atlanta, Georgia.

Dindorf, C. 1992. *Toxic and Hazardous Substances in Urban Runoff*. Hennepin Conservation District. Minnetonka, MN.

Doerfer, J. and B. Urbonas. 1993. *Stormwater Quality Characterization in the Denver Metropolitan Area.* Denver NPDES. Denver, CO.

Doll, B., D. Wise-Frederick, C. Buckner, S. Wilkerson, W. Harman and R. Smith. 2000. "Hydraulic Geometry Relationships for Urban Streams Throughout the Piedmont of North Carolina." *Source unknown*.

Donigian, A and W. Huber. 1991. *Modeling of Nonpoint Source Water Quality in Urban and Non-urban Areas.* EPA/600/3-91/-39. U.S. EPA. Washington, D.C.

Dreher, D. 1997. "Watershed Urbanization Impacts on Stream Quality Indicators in Northeastern Illinois." *Assessing the Cumulative Impacts of Watershed Development on Aquatic Ecosystems and Water Quality*. D. Murray and R. Kirshner (ed.). Northeastern Illinois Planning Commission. Chicago, IL.

Driscoll, E. 1983. *Rainfall/ Runoff Relationships from the NURP Runoff Database*. Stormwater and Quality Models Users Group Meeting. Montreal, Quebec.1983.

Driver, N. 1988. *National Summary and Regression Models of Storm-Runoff Loads and Volumes in Urban Watersheds in the United States*. Thesis. Colorado School of Mines. Golden, Colorado.

Duda, A.M. and K.D. Cromartie. 1982. "Coastal Pollution from Septic Tank Drainfields." *Journal of the Environmental Engineering Division* ASCE. 108:1265-1279.

Dunne, T. and L. Leopold. 1978. *Water in Environmental Planning*. W. Freeman and Company, New York, NY.

Ellis, J. 1986. "Pollutional Aspects of Urban Runoff." In *Urban Runoff Pollution*. (eds.) H. Torno, J. Marsalek and M. Desbordes. Springer-Verlag, Berlin.

Environment Canada. 2001. *Priority Substances List Assessment Reports*. Road Salt. Ministry of Environment. Toronto, Canada.

EOA, Inc. 2001. *Stormwater Environmental Indicators*. Pilot Demonstration Project. Final Report. Water Environment Research Foundation. Santa Clara Urban Runoff Pollution Prevention Project. Santa Clara, CA.

Evaldi, R., R. Burns and B. Moore. 1992. *Stormwater Data for Jefferson County, Kentucky, 1991-1992*. U.S. Geological Survey. Open File Report 92-638.

Evett, J., M. Love and J. Gordon. 1994. *Effects of Urbanization and Land Use Changes on Low Stream Flow.* North Carolina Water Resources Research Institute. Report No. 284.

Evgenidou, A., A. Konkle, A. D'Ambrosio, A. Corcoran, J. Bowen, E. Brown, D. Corcoran, C. Dearholt, S. Fern, A. Lamb, J. Michalowski, I. Ruegg and J. Cebrian. 1997. "Effects of Increased Nitrogen Loading on the Abundance of Diatoms and Dinoflagellates in Estuarine Phytoplanktonic Communities." *The Biological Bulletin* 197(2):292.

Fairfax County Department of Public Works and Environmental Services (Fairfax Co). 2001. *Fairfax County Stream Protection Strategy Baseline Study*. Stormwater Management Branch, Stormwater Planning Division, Fairfax County, VA.

Ferrari, M., S. Altor, J. Blomquist and J. Dysart. 1997. *Pesticides in the Surface Water of the Mid-Atlantic Region*. United States Geological Survey. Water-Resources Investigations Report 97-4280.

Field, R. and R. Pitt. 1990. "Urban Storm-induced Discharge Impacts: US Environmental Protection Agency Research Program Review." *Water Science Technology* (22): 10-11.

Findlay, C. and J. Houlahan. 1997. "Anthropogenic Correlates of Species Richness in Southeastern Ontario Wetlands." *Conservation Biology* 11(4):1000-1009.

Finkenbine, J., J. Atwater and D. Mavinic. 2000. "Stream Health After Urbanization." *Journal of the American Water Resources Association* 36(5): 1149-1160.

Fongers, D.and J. Fulcher. 2001. *Hydrologic Impacts Due to Development: The Need for Adequate Runoff Detention and Stream Protection*. Michigan Department of Environmental Quality.

Fortner, A.R., M. Sanders and S.W. Lemire. 1996. "Polynuclear Aromatic Hydrocarbon and Trace Metal Burdens in Sediment and the Oyster, *Crassostrea virginica* Gmelin, from Two High-Salinity Estuaries in South Carolina." In *Sustainable Development in the Southeastern Coastal Zone*. F.J. Vernberg, W.B. Vernberg and T. Siewicki (eds.). Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.

Fulton, M., G. Chandler and G. Scott. 1996. "Urbanization Effects on the Fauna of a Southeastern U.S.A. Bar-Built Estuary." In *Sustainable Development in the Southeastern Coastal Zone*. F.J. Vernberg, W.B. Vernberg and T. Siewicki (eds.). Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.

Galli, F. 1988. *A Limnological Study of an Urban Stormwater Management Pond and Stream Ecosystem*. M.S. Thesis. George Mason University.

Galli, J. 1994. Personal communication. Department of Environmental Programs. Metropolitan Washington Council of Governments. Washington, DC.

Galli, J. 1990. *Thermal Impacts Associated with Urbanization and Stormwater Management Best Management Practices*. Metropolitan Washington Council of Governments. Maryland Department of Environment. Washington, D.C.

Garie, H. and A. McIntosh. 1986. "Distribution of Benthic Macroinvertebrates in Streams Exposed to Urban Runoff." *Water Resources Bulletin* 22:447-458.

Garn, H. 2002. *Effects of Lawn Fertilizer on Nutrient Concentrations in Runoff from Lakeshore Lawns, Lauderdale Lakes, Wisconsin*. USGS Water-Resources Investigation Report 02-4130.

Gavin, D. V. and R.K. Moore. 1982. *Toxicants in Urban Runoff.* Prepared for the U.S. Environmental Protection Agency's Nationwide Urban Runoff Program. Seattle, WA.

Good, J. 1993. "Roof Runoff as a Diffuse Source of Metals and Aquatic Toxicology in Stormwater." *Waterscience Technology* 28(3-5):317-322.

Graczyk, T. K., R. Fayer, J. M Trout, E. J. Lewis, C. A. Farley, I. Sulaiman and A.A. Lal. 1998. "Giardia sp. Cysts and Infectious Cryptosporidium parvum Oocysts in the Feces of Migratory Canada geese (Branta canadensis)." *Applied and Environmental Microbiology* 64(7):2736-2738.

Haith, D., R. Mandel and R. Wu. 1992. GWLF-Generalized Watershed Loading Functions. Version 2.0 Users Manual. Cornell University. Agricultural Engineering Department.

Hall, K. and B. Anderson. 1988. "The Toxicity and Chemical Composition of Urban Stormwater Runoff." *Canadian Journal of Civil Engineering* 15:98-106.

Hammer, T. 1972. "Stream Channel Enlargement Due to Urbanization." *Water Resources Research* 8(6): 1530-1540.

Hart, D. and C. Finelli. 1999. "Physical-Biological Coupling in Streams: the Pervasive Effects of Flow on Benthic Organisms." *Annu. Rev. Ecol. Syst.* 30:363-95.

Hartwell S., D. Jordahl, J. Evans and E. May. 1995. "Toxicity of Aircraft De-icer and Anti-icer Solutions to Aquatic Organisms." *Environmental Toxicology and Chemistry* 14:1375-1386.

Heaney, J. and W. Huber. 1978. *Nationwide Assessment of Receiving Water Impacts from Urban Storm Water Pollution*. United States Environmental Protection Agency. Cincinnati, OH.

Herlihy, A, J. Stoddard and C. Johnson. 1998. "The Relationship Between Stream Chemistry and Watershed Land Cover in the Mid-Atlantic Region, U.S." *Water, Air and Soil Pollution 105: 377-386.*

Henshaw, P. and D. Booth, 2000. "Natural Restabilization of Stream Channels in Urban Watersheds." *Journal of the American Water Resources Association* 36(6):1219-1236.

Hession, W., J. Pizzuto, T. Johnson and R. Horowitz. *In press*. *Influence of Bank Vegetation on Channel Morphology in Rural and Urban Watersheds.*

Hicks, A. and J. Larson. 1997. *The Impact of Urban Stormwater Runoff on Freshwater Wetlands and the Role of Aquatic Invertebrate Bioassessment*. The Environment Institute, University of Massachusetts. Amherst, MA.

Hirsch, R., J. Walker, J. Day and R. Kallio. 1990. "The Influence of Man on Hydrologic Systems." *Surface Water Hydrology* O-1:329-347.

Hollis, F. 1975. "The Effects of Urbanization on Floods of Different Recurrence Intervals." *Water Resources Research* 11:431-435.

Holland, F., G. Riekerk, S. Lerberg, L. Zimmerman, D. Sanger, G. Scott, M. Fulton, B. Thompson, J. Daugomah, J. DeVane, K. Beck and A. Diaz. 1997. *The Tidal Creek Project Summary Report*. Marine Resources Research Institute, SC Department of Natural Resources.

Horkeby, B. and P. Malmqvist. 1977. *Microsubstances in Urban Snow Water*. IAHS-AISH. Publication 123:252-264.

Horner, R. and C. May. 1999. "Regional Study Supports Natural Land Cover Protection as Leading Best Management Practice for Maintaining Stream Ecological Integrity." In: *Comprehensive Stormwater & Aquatic Ecosystem Management Conference Papers*. First South Pacific Conference, February 22-26, New Zealand. Vol 1. p. 233-247.

Horner, R., D. Booth, A. Azous and C. May. 1997. "Watershed Determinants of Ecosystem Functioning." In Roesner, L.A. Editor. *Effects of Watershed Development and Management on Aquatic Ecosystems*. Proceedings of the ASCE Conference. Snowbird, Utah. 1996.

Horner, R., J. Guerdy and M. Kortenhoff. 1990. *Improving the Cost Effectiveness of Highway Construction Site Erosion and Pollution Control*. Washington State Transportation Center and the Federal Highway Administration. Seattle, WA.

Horner, R., C. May, E. Livingston and J. Maxted. 1999. "Impervious Cover, Aquatic Community Health, and Stormwater BMPs: Is There a Relationship?" *In Proceedings of The Sixth Biennial Stormwater Research and Watershed Management Conference*. Sept 14-17. 1999. Tampa Florida. Soutwest Florida Water Management District. Available on-line: http://www.stormwater-resources.com/proceedings_of_the_sixth_biennia.htm

Horner, R., C. May, E. Livingston, D. Blaha, M. Scoggins, J. Tims and J. Maxted. 2001. "Structural and Non-structural BMPs for Protecting Streams." *in Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation*. B. Urbonas (editor). Proceedings of an Engineering Research Foundation Conference. Smowmass, CO. American Society of Civil Engineers (TRS). pp. 60-77.

Huber, W. and R. Dickinson. 1988. *Storm Water Management Model (SWMM).* Version 4. Users Manaul. EPA/600/3-88/001a). US EPA. Athens, GA.

Hydrologic Engineering Center (HEC). 1977. *Storage, Treatment, Overflow and Runoff Model (STORM)*. Users Manual. Generalized Computer Program. 7233-S8-L7520.

Hydroqual, Inc. 1996. *Design Criteria Report: Kensico Watershed Stormwater Best Management Facilities: Appendix C.* Report prepared for City of New York. Department of Environmental Protection.

Immerman, F. and D. Drummon. 1985. *National Urban Pesticide Applications Survey*. Research Triangle Institute. Publication No. 2764/08-01F.

Ireland, D., G. Burton, Jr. and G. Hess. 1996. "In Situ Toxicity Evaluations of Turbidity and Photoinduction of Polycyclic Aromatic Hydrocarbons." *Environmental Toxicology and Chemistry* 15(4): 574-581.

Islam, M., D. Tuphron and H. Urata-Halcomb. 1988. *Current Performance of Sediment Basins and Sediment Yield Measurement in Unincorporated Hamilton County, OH.* Hamilton County Soil and Water Conservation District.

Jarrett, A. 1996. *Sediment Basin Evaluation and Design Improvements*. Pennsylvania State University. Prepared for Orange County Board of Commissioners.

Johnson, K. 1995. *Urban Storm Water Impacts on a Coldwater Resource.* Presentation to the Society of Environmental Toxicology and Chemistry (SETAC) Second World Congress. Vancouver, B.C., Canada..

Jones, R., A. Via-Norton and D. Morgan. 1996. "Bioassessment of the BMP Effectiveness in Mitigating Stormwater Impacts on Aquatic Biota." In Roesner, L.A. Editor. *Effects of Watershed Development and Management on Aquatic Ecosystems.* Proceedings of the ASCE Conference. Snowbird, Utah.

Jones, R. and C. Clark. 1987. "Impact of Watershed Urbanization on Stream Insect Communities." *Water Resources Bulletin* 15(4).

Karouna-Renier, N. 1995. *An Assessment of Contaminant Toxicity to Aquatic Macro-Invertebrates in Urban Stormwater Treatment Ponds*. M.S. Thesis. University of Maryland. College Park, MD.

Keller, A. and S. Zam. 1991. "The Acute Toxicity of Selected Metals to the Freshwater Mussel, Anodonta imbecillis." *Environmental Toxicology and Chemistry* 10: 539-546.

Kemp, S. and J. Spotila. 1997. "Effects of Urbanization on Brown Trout *Salmo trutta*, Other Fishes and Macroinvertebrates in Valley Creek, Valley Forge, PA." *American Midl. Nat*. 138:55-68.

Kennen, J. 1999. "Relation of Macroinvertebrate Community Impairment to Catchment Characteristics in New Jersey Streams." *Journal of the American Water Resources Association* 35(4):939-955.

Kibler, D., D. Froelich and G. Aron. 1981. "Analyzing Urbanization Impacts on Pennsylvania Flood Peaks." *Water Resources Bulletin* 17(2):270-274.

Kitchell, A. 2001. "Managing for a Pure Water Supply." *Watershed Protection Techniques* 3(4): 797-812.

Kjelstrom, L. 1995. *Data for Adjusted Regional Regression Models of Volume and Quality of Urban Stormwater Runoff in Boise and Garden City, Idaho, 1993-94*. United States Geological Survey. Water Resources Investigations Report 95-4228.

Klein, R. 1979. "Urbanization and Stream Quality Impairment." *Water Resources Bulletin* 15(4):948-963.

Konrad, C. and D. Booth. 2002. *Hydrologic Trends Associated with Urban Development for Selected Streams in the Puget Sound Basin - Western Washington.* USGS Water Resources Investigation Report 02-4040.

Kucklick, J.K., S. Silversten, M. Sanders and G.I. Scott. 1997. "Factors Influencing Polycyclic Aromatic Hydrocarbon Distributions in South Carolina Estuarine Sediments." *Journal of Experimental Marine Biology and Ecology* 213:13-30.

Kundell, J. and T. Rasmussen. 1995. *Recommendations of the Georgia Board of Regent's Scientific Panel on Evaluating the Erosion Measurement Standard Defined by the Georgia Erosion and Sedimentation Act*. Proceedings of the 1995 Georgia Water Resources Conference. Athens, Georgia.

La Barre, N., J. Milne and B. Oliver. 1973. "Lead Contamination of Snow." *Water Research* 7:1,215-1,218.

LeBlanc, R., R. Brown and J. FitzGibbon. 1997. "Modeling the Effects of Land Use Change on the Water Temperature in Unregulated Urban Streams." *Journal of Environmental Management* 49: 445-469.

Leopold, L. 1994. *A View of the River*. Harvard University Press, Cambridge, MA.

Leopold, L. 1973. "River Change with Time: An Example." *Geological Society of America Bulletin* 84: 1845-1860.

Leopold, L. 1968. *Hydrology for Urban land Use Planning - A Guidebook on the Hydrologic Effects of Urban Land Use.* Washington, D.C. Geological Survey Circular 554.

Lerberg, S., F. Holland and D. Sanger. 2000. "Responses of Tidal Creek Macrobenthic Communities to the Effects of Watershed Development." *Estuaries* 23(6):838-853.

Lim, S. and V. Olivieri. 1982. *Sources of Microorganisms in Urban Runoff*. Johns Hopkins School of Public Health and Hygiene. Jones Falls Urban Runoff Project. Baltimore, MD.

Limburg, K. and R. Schmidt. 1990. "Patterns of Fish Spawning in Hudson River Tributaries-Response to an Urban Gradient?" *Ecology* 71(4): 1231-1245.

Liu, Z., D. Weller, D. Correll and T. Jordan. 2000. "Effects of Land Cover and Geology on Stream Chemistry in Watersheds of Chesapeake Bay." *Journal of American Water Resources Association* 36(6): 1349-1365.

Livingston, R. 1996. "Eutrophication in Estuaries and Coastal Systems: Relationship of Physical Alterations, Salinity Stratification, and Hypoxia." In *Sustainable Development in the Southeastern Coastal Zone*. F.J. Vernberg, W.B. Vernberg and T. Siewicki (eds.). Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.

Lopes, T. and S. Dionne. 1998. *A Review of Semi-Volatile and Volatile Organic Compounds in Highway Runoff and Urban Stormwater.* USGS Open file report 98-409.

Lopes, T., K. Fossum, J. Phillips and J. Marical. 1995. *Statistical Summary of Selected Physical, Chemical, and Microbial Contaminants and Estimates of Constituent Loads in Urban Stormwater in Maricopa County, Arizona*. USGS Water Resources Investigations Report 94-4240.

Luchetti, G. and R. Feurstenburg. 1993. *Relative Fish Use in Urban and Non-urban Streams Proceedings*. Conference on Wild Salmon. Vancouver, British Columbia.

MacCoy, D. and R. Black. 1998. *Organic Compounds and Trace Elements in Freshwater Streambed Sediment and Fish from the Puget Sound Basin*. USGS Fact Sheet 105-98.

MacRae, C. 1996. "Experience From Morphological Research on Canadian Streams: Is Control of the Two-year Frequency Runoff Event the Best Basis for Stream Channel Protection?" In Roesner, L.A. Editor. *Effects of Watershed Development and Management on Aquatic Ecosystems.* Proceedings of the ASCE Conference. Snowbird, Utah.

MacRae, C. and M. DeAndrea. 1999. *Assessing the Impact of Urbanization on Channel Morphology.* 2nd International Conference on Natural Channel Systems. Niagra Falls, OT.

MacRae, C. and A. Rowney. 1992. *The Role of Moderate Flow Events and Bank Structure in the Determination of Channel Response to Urbanization*. 45th Annual Conference. Resolving Conflicts and Uncertainty in Water Management. Proceeding of the Canadian Water Resources Association, Kingston, Ontario.

Maiolo, J. and P. Tschetter. 1981. "Relating Population Growth to Shellfish Bed Closures: a Case Study from North Carolina." *Coastal Zone Management Journal* 9(1).

Mallin, M., E. Esham, K. Williams and J. Nearhoof. 1999. "Tidal Stage Variability of Fecal Coliform and Chlorophyll *a* Concentrations in Coastal Creeks." *Marine Pollution Bulletin* 38 (5):414-422.

Mallin, M., K. Williams, E. Esham and R. Lowe. 2000. "Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds." *Ecological Applications* 10(4) 1047-1056.

Mallin, M., S. Ensign, M. McIver, G. Swank and P. Fowler. 2001. "Demographic, Landscape and Metrologic Factors Controlling the Microbial Pollution of Coastal Waters." *Hydrobiologia* 460:185-193.

Malmqvist, P. 1978. "Atmospheric Fallout and Street Cleaning- Effects on Urban Snow Water and Snow." *Progress in Water Technology* 10(5/6):495-505.

Maryland-National Capital Park and Planning Commission (MNCPPC). 2000. *Stream Condition Cumulative Impact Models For the Potomac Subregion*. Prepared for the Maryland- National Park and Planning Commission, Silver Spring, MD.

Masterson, J. and R. Bannerman. 1994. *Impact of Stormwater Runoff on Urban Streams in Milwaukee County, Wisconsin*. Wisconsin Department of Natural Resources. Madison, WI.

Maxted, J. 1999. "The Effectiveness of Retention Basins to Protect Downstream Aquatic Life in Three Regions of the United States." *In* Conference Proceedings. Volume one. *Comprehensive Stormwater and Aquatic Ecosystem Management*. First South Pacific Conference. 22-26 February, 1999. Auckland Regional Council. Auckland, New Zealand pp. 215- 222.

Maxted, J. and E. Shaver. 1997. "The Use of Retention Basins to Mitigate Stormwater Impacts on Aquatic Life." In Roesner, L.A. Editor. *Effects of Watershed Development and Management on Aquatic Ecosystems.* Proceedings of the ASCE Conference. Snowbird, Utah.

May, C., R. Horner, J. Karr, B. Mar and E. Welch. 1997. "Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion." *Watershed Protection Techniques* 2(4): 483-494.

McCuen R. and G. Moglen. 1988. "Multicriterion Stormwater Management Methods." *Journal of Water Resources Planning and Management* 4 (114).

Menzie-Cura & Associates. 1995. *Measurements and Loadings of Polycyclic Aromatic Hydrocarbons (PAH) in Stormwater, Combined Sewer Overflows, Rivers, and Publically Owned Treatment Works (POTWs) Discharging to Massachusetts Bays.* Report to the Massachusetts Bay Program, August 1995, MBP-95-06.

Metropolitan Washington Council of Governments (MWCOG). 1992. *Watershed Restoration Sourcebook*. Department of Environmental Programs. MWCOG, Washington, DC.

MWCOG. 1983. *Urban runoff in Washington Metropolitan Area- Final Report.* Washington. D.C Area Urban Runoff Program. Prepared for USEPA. WRPB.

Meyer, J. and C. Couch. 2000. *Influences of Watershed Land Use on Stream Ecosystem Structure and Function*. NCERQA Grant Final Report.

Montgomery County Department of Environmental Protection (MCDEP). 2000. *Special Protection Area Report*.

Morisawa, M. and E. LaFlure. 1979. *Hydraulic Geometry, Stream Equalization and Urbanization*. Proceedings of the Tenth Annual Geomorphology Symposia Series: Adjustments of the Fluvial System. Binghamton, New York.

Moring, J. and D. Rose. 1997. "Occurrence and Concentrations of Polycyclic Aromatic Hydrocarbon in Semipermeable Membrane Devices and Clams in Three Urban Streams of the Dallas-Fort Worth Metropolitan Area, Texas." *Chemosphere* 34(3): 551-566.

Morse, C. 2001. *The Response of First and Second Order Streams to Urban Land-use in Maine, USA*. Masters Thesis, The University of Maine, Orono, ME.

Moscript, A. and D. Montgomery. 1997. "Urbanization, Flood Frequency, and Salmon Abundance in Puget Lowland Streams." *Journal of the American Water Resources Association*. 33:1289-1297.

Neller, R. 1989. "Induced Channel Enlargement in Small Urban Catchments, Armidale, New South Wales." *Environmental Geology and Water Sciences* 14(3): 167-171.

Neller, R. 1988. "A Comparison of Channel Erosion in Small Urban and Rural Catchments, Armidale, New South Wales." *Earth Surface Processes and Landforms* 13:1-7.

New Mexico Surface Water Quality Bureau (NMSWQB). 1999. *Total Maximum Daily Load for Fecal Coliform on Canadian River Basin Six Mile, Cieneguilla and Moreno Creeks* (Cimarron).

Northern Virginia Planning District Commission (NVPDC). 1987. *BMP Handbook for the Occoquan Watershed*. Annandale, VA.

NVPDC. 1979. *Guidebook for Evaluating Urban Nonpoint Source Strategies.* Prepared for the Metropolitan Washington Council of Governments.

Northern Virginia Regional Commission (NVRC). 2001. *The Effect of Urbanization on the Natural Drainage Network in the Four Mile Run Watershed.*

Novotny, V. and G. Chester. 1989. "Delivery of Sediment and Pollutants from Nonpoint Sources: a Water Quality Perspective." *Journal of Soil and Water Conservation* 44:568-576.

Novotny, V. and G. Chester. 1981. *Handbook of Nonpoint Pollution: Sources and Management.* Van Nostrand Reinhold Company. NY.

Novotny, V., D. W. Smith, D. A. Kuemmel, J. Mastriano and A. Bartosova. 1999. *Urban and Highway Snowmelt: Minimizing the Impact on Receiving Water*. Water Environment Research Foundation. Alexandria, VA.

Obert, G. 1999. "Return to Lake McCarrons: Does the Performance of Wetlands Hold up Over Time?" *Watershed Protection Techniques* 3(1):597-600.

Oberts, G. 1994. "Influence of Snowmelt Dynamics on Stormwater Runoff Quality." *Watershed Protection Techniques* 1(2):55-61.

Oberts, G., P. Wotzka and J. Hartsoe.1989. *The Water Quality Performance of Select Urban Runoff Treatment Systems.* Metropolitan Council, St. Paul, MN. Publ. No. 590-89-062a.

Occoquan Watershed Monitoring Lab (OWML). 1983. *Washington Area NURP Report VPISU: Final Report*. Metropolitan Washington Council of Governments. Manassas, VA.

Ohrel, R. 1995. "Rating Deicer Agents – Road Salts Stand Firm." *Watershed Protection Techniques* 1(4):217-220.

Oliver, G., P. Milene and N. La Barre. 1974. "Chloride and Lead in Urban Snow." *Journal Water Pollution Control Federation* 46(4):766-771.

Overton, D. and M. Meadows. 1976. *Storm Water Modeling*. Academic Press. New York, NY.

Paul, M., D. Leigh and C. Lo. 2001. *Urbanization in the Etowwah River Basin: Effects on Stream Temperature and Chemistry.* Proceedings of the 2001 Georgia Water Resources Conference. University of Georgia, Athens, GA.

Pedersen, E. and M. Perkins. 1986. "The Use of Benthic Invertebrate Data for Evaluating Impacts of Urban Runoff." *Hydrobiologia* 139: 13-22.

Pierstorff, B. and P. Bishop. 1980. " Water Pollution From Snow Removal Operation." *Journal of Environmental Engineering Division* 106 (EE2):377-388.

Pitt, R. 1998. "Epidemiology and Stormwater Managment." In *Stormwater Quality Management*. CRC/Lewis publishers. New York, NY.

Pitt, R. and M. Bozeman. 1982. "Sources of Urban Runoff Pollution and Its Effects on an Urban Creek." EPA-600/52-82-090. U.S. Environmental Protection Agency. Cincinnati, OH.

Pitt, R. and J. Voorhees. 1989. *Source Load and Management Model (SLAMM) – An Urban Nonpoint Source Water Quality Model*. Wisconsin Department of Natural Resources, v. I-III, PUBL-WR-218-89.

Pizzuto, J., W. Hession and M. McBride. 2000. "Comparing Gravel-Bed Rivers in Paired Urban and Rural Catchments of Southeastern Pennsylvannia." *Geology* 28(1):79-82.

Poff, N. and J. Ward. 1989. "Implications of Stream Flow Variability and Predictability for Lotic Community Structure: A Regional Analysis of Streamflow Patterns." *Canadian Journal of Fisheries and Aquatic Science* 46:1805-1818.

Porter, D.E., D. Edwards, G. Scott, B. Jones and S. Street. 1997. "Assessing the Impacts of Anthropogenic and Physiographic Influences on Grass Shrimp in Localized Salt Marsh Estuaries: a Multi-Disciplinary Approach." *Aquatic Botany* 58:289-306.

Rabanal, F. and T. Grizzard. 1995."Concentrations of Selected Constituents in Runoff from Impervious Surfaces in Urban Catchments of Different Land Use." *In Proceedings of the 4th Biennial Conference on Stormwater Research*. Oct 18-20.Clearwater, Florida. Southwest Florida Water Management District. pp. 42-52.

Reice, S. 2000. "Regulating Sedimentation and Erosion Control into Streams: What Really Works and Why?" In *Proceedings of the National Conference on Tools for Urban Water Resource Management & Protection*. Published by the US Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Richards, C., L. Johnson and G. Host. 1993. *Landscape Influence on Habitat, Water Chemistry, and Macroinvertebrate Assemblages in Midwestern Stream Ecosystems*. Center for Water and the Environment. Natural Resources Research Institute (NRRI) Technical Report TR-93-109.

Richey, J. 1982. *Effects of Urbanization on a Lowland Stream in Urban Washington.* PhD Dissertation. University of Washington.

Roth, N., M. Southerland, D. Stebel and A. Brindley. 1998. *Landscape Model of Cumulative Impacts: Phase I Report.* Maryland Department of Natural Resources.

Roth, N., J. David and D. Erickson. 1996. "Landscape Influences on Stream Biotic Integrity Assessed at Multiple Spatial Scales." *Landscape Ecology* 11(3):141-156.

Rutkowski, C., W. Burnett, R. Iverson and J. Chanton. 1999. "The Effect of Groundwater Seepage on Nutrient Delivery and Seagrass Distribution in the Northeastern Gulf of Mexico." *Estuaries* 22(4):1033-1040.

S.R. Hanson and Associates. 1995. *Final Report: Identification and Control of Toxicity in Stormwater Discharges to Urban Creeks*. Prepared for Alameda County Urban Runoff Clean Water Program.

Samadpour, M. and N. Checkowitz. 1998. "Little Soos Creek Microbial Source Tracking." *Washington Water Resource.* (Spring) University of Washington Urban Water Resources Center.

Salt Institute. 2001. Data on U.S. Salt Sales. Available on-line: www.saltinstitute.org

Sanger, D., F. Holland and G. Scott. 1999. "Tidal Creek and Salt Marsh Sediment in South Carolina Coastal Estuaries: I. Distribution of Trace Metals." *Archive of Environmental Contamination and Toxicology* (37):445-457.

Saravanapavan, T. 2002. Personal communication.

Sauer, V., T. Stricker and K. Wilson. 1983. *Flood Characteristics of Urban Watersheds in the United States*. US Geological Survey Water Supply Paper 2207.

Scanlin, J. and A. Feng. 1997. *Characterization of the Presence and Sources of Diazinon in the Castro Valley Creek Watershed.* Alameda Countywide Clean Water Program and Alameda County Flood Control and Water Conservation District, Oakland, CA.

Schiff, K. 1996. *Review of Existing Stormwater Monitoring Programs for Estimating Bight-Wide Mass Emissions from Urban Runoff.*

Schrimpff, E. and R. Herrman. 1979. "Regional Patterns of Contaminants (PAH, Pesticides and Trace metals) in Snow of Northeast Bavaria and their Relationship to Human Influence and Orogeographic Effects." *Water, Air and Soil Pollution* 11:481-497.

Schueler, T. 2001. "The Environmental Impact of Stormwater Ponds." *The Practice of Watershed Protection.* T. Schueler and H. Holland (Eds). Center for Watershed Protection. Ellicott City, MD.

Schueler, T. 2000. "The Compaction of Urban Soils." *Watershed Protection Techniques* 3(3):661-665.

Schueler, T. 1999. "Microbes and Urban Watersheds." *Watershed Protection Techniques* 3(1): 551-596.

Schueler, T. 1994a. "The Importance of Imperviousness." *Watershed Protection Techniques* 2(4): 100-111.

Schueler, T. 1994b. "Pollutant Dynamics of Pond Muck." *Watershed Protection Techniques* 1(2).

Schueler, T. 1987. *Controlling Urban Runoff: a Practical Manual for Planning and Designing Urban Best Management Practices*. Metropolitan Washington Council of Governments. Washington, D.C.

Schueler, T. and D. Caraco. 2001. "The Prospects for Low Impact Land Development at the Watershed Level." In *Linking Stormwater BMP Designs and Performance to Receiving Water Impacts Mitigation*. United Engineering Foundation. Snowmass, CO.

Schueler, T. and J. Galli. 1992. "Environmental Impacts of Stormwater Ponds." *Watershed Restoration Sourcebook*. Anacostia Restoration Team Metropolitan Washington Council Government. Washington D.C.

Schueler, T. and H. Holland. 2000. *The Practice of Watershed Protection- Techniques for Protecting Our Nations, Streams, Rivers, Lakes and Estuaries*. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. and J. Lugbill. 1990. *Performance of Current Sediment Control Measures at Maryland Construction Sites*. Metropolitan Washington Council of Governments (MWCOG).

Schueler, T. and D. Shepp. 1993. *The Quantity of Trapped Sediments in Pool Water Within Oil Grit Separators in Suburban MD.* Metropolitan Washington Council of Governments (MWCOG).

Scott, J., C. Steward and Q. Stober. 1986. "Effects of Urban Development on Fish Population Dynamics in Kelsey Creek, Washington." *Transactions of the American Fisheries Society*. 115:555-567.

Scott, W. and N. Wylie. 1980. "The Environmental Effects of Snow Dumping: A Literature Review." *Journal of Environmental Management* 10:219-240.

Shaver, E., J. Maxted, G. Curtis and D. Carter. 1995. "Watershed Protection Using an Integrated Approach." In B. Urbonas and L. Roesner Editors. *Stormwater NPDES-related Monitoring Needs*. Proceedings of an Engineering Foundation Conference. Crested Butte, CO.

Sherman, K. 1998. *Severn Sound Urban Stormwater Pollution Control Planning Report*. Ontario, Canada.

Short, F. and S. Wyllie-Echeverria. 1996. "Natural and Human-Induced Disturbance of Seagrasses." *Environmental Conservation* 23(1): 17-27.

Sills, R. and P. Blakeslee. 1992. "Chapter 11: The Environmental Impact of Deicers in Airport Stormwater Runoff." *Chemical Deicers and the Environment.* Lewis Publishers. Ann Arbor, MI.

Silverman, G., M. Stenstrom and S. Fam. 1988. "Land Use Considerations in Reducing Oil and Grease in Urban Stormwater Runoff." *Journal of Environmental Systems* 18(1): 31-46.

Simmons, D and R. Reynolds. 1982. "Effects of Urbanization on Baseflow of Selected South-Shore Streams, Long Island, NY." *Water Resources Bulletin* 18(5): 797-805.

Smullen, J. and K. Cave. 1998. *Updating the U.S. Nationwide Urban Runoff Quality Database.* 3rd International Conference on Diffuse Pollution. Scottish Environment Protection Agency, Edinburg Scotland. 1998.

Spence, B., G. Lomnicky, R. Hughes and R. Novitzki. 1996. *An Ecosystem Approach to Salmonid Conservation*. TR-401-96-6057. ManTech Environmental Research Services Corporation, Corvallis, OR. (Available on the NMFS-NWR website:

Spinello, A.G. and D.L. Simmons. 1992. *Baseflow of 10 South Shore Streams, Long Island, New York 1976-85 and the Effects of Urbanization on Baseflow and Flow Duration*. USGS. Water Resources Investigation Report 90-4205.

Squillace, P., D. Pope and C.V. Price. 1995. *Occurrence of the Gasoline Additive MTBE in Shallow Groundwater in Urban and Agricultural Areas*. USGS Fact Sheet 114-95.

States, S., K. Stadterman, L. Ammon, P. Vogel, J. Baldizar, D. Wright, L. Conley and J. Sykora. 1997. "Protozoa in River Water: Sources, Occurrence and Treatment" *Journal of the American Water Works Association* 89(9):74-83.

Steedman, R. J. 1988. "Modification and Assessment of an Index of Biotic Integrity to Quantify Stream Quality in Southern Ontario." *Canadian Journal of Fisheries and Aquatic Sciences* 45:492-501.

Stern, D. 1996. "Initial Investigation of the Sources and Sinks of Cryptosporidium and Giardia Within the Watersheds of the New York City Water Supply System." In McDonnel *et al.* Editors. *New York City Water Supply Studies*. Proceedings of an American Water Resources Association Symposium. Herndon, VA.

Steuer, J., W. Selbig, N. Hornewer and Jeffrey Prey. 1997. *Sources of Contamination in an Urban Basin in Marquette, Michigan and an Analysis of Concentrations, Loads, and Data Quality*. U.S. Geological Survey, Water-Resources Investigations Report 97-4242.

Steward, C. 1983. *Salmonoid Populations in an Urban Environment—Kelsey Creek., Washington.* Masters Thesis. University of Washington.

Stormwater Assessment Monitoring Performance (SWAMP). 2000a. *Performance Assessment of a Highway Stormwater Quality Retention Pond - Rouge River, Toronto, Ontario*. SWAMP Program. Ontario Ministry of the Environment. Toronto and Region Conservation Authority. Toronto, Canada.

SWAMP. 2000b. *Performance Assessment of a Stormwater Retrofit Pond - Harding Park, Richmond Hill, Ontario*. SWAMP Program. Ontario Ministry of the Environment. Town of Richmond Hill. Toronto and Region Conservation Authority. Toronto, Canada.

Stranko, S. and W. Rodney. 2001. *Habitat Quality and Biological Integrity Assessment of Freshwater Streams in the Saint Mary's River Watershed.* Maryland Department of Natural Resources. CBWP-MANTA-EA-01-2.

Stribling, J., E. Leppo, J. Cummins, J. Galli, S. Meigs, L. Coffman and M.Cheng. 2001. "Relating Instream Biological Conditions to BMP Activities in Streams and Watersheds." In *Linking Stormwater BMP Designs and Performance to Receiving Water Impacts Mitigation*. United Engineering Foundation. Snowmass, CO.

Sturm, T. and R. Kirby. 1991. *Sediment Reduction in Urban Stormwater Runoff from Construction Sites*. Georgia Institute of Technology. Atlanta, GA.

Swann, C. 2001. "The Influence of Septic Systems at the Watershed Level." *Watershed Protection Techniques* 3(4):821-834.

Swietlik, W. 2001. "Urban Aquatic Life Uses - a Regulatory Perspective." In *Linking Stormwater BMP Designs and Performance to Receiving Water Impacts Mitigation*. United Engineering Foundation. Snowmass, CO.

Taylor, B.L. 1993. *The Influences of Wetland and Watershed Morphological Characteristics and Relationships to Wetland Vegetation Communities*. Master's Thesis. Dept. of Civil Engineering. University of Washington, Seattle, WA.

Taylor, B., K. Ludwa and R. Horner. 1995. *Third Puget Sound Research Meeting Urbanization Effects on Wetland Hydrology and Water Quality*. Proceedings of the Puget Sound Water Quality Authority Meeting. Olympia, WA.

Thomas, P. and S. McClelland. 1995. "NPDES Monitoring - Atlanta, Georgia Region." *In Stormwater NPDES Related Monitoring Needs.* Proceedings of an Engineering Foundation Conference. Edited by Harry Torno. New York, NY.

Trimble, S. 1997. "Contribution of Stream Channel Erosion to Sediment Yield from an Urbanizing Watershed." *Science* 278: 1442-1444.

U.S. Department of Agriculture (USDA). 1992. *Computer Program for Project Formulation-Hydrology (TR-20)*. Hydrology Unit. Natural Resources Conservation Service. Washington, D.C.

USDA. 1986. *Urban Hydrology for Small Watersheds*. Technical Release 55. (TR-55). Soil Conservation Service Engineering Division. Washington, D.C.

United States Environmental Protection Agency (USEPA). 2000. Mid-Atlantic Integrated Assessment *(MAIA) Project Summary: Birds Indicate Ecological Condition of the Mid-Atlantic Highlands*. U.S.EPA, Office of Research and Development, Washington, DC.

USEPA. 1998. *The Quality of Our Nation's Waters: 1996*. U.S.EPA, Office of Water, Washington, DC. EPA-841-S-97-001.

USEPA. 1993. *Guidance Specifying Management Measures for Sources of Non-point Pollution in Coastal Waters.* U.S.EPA, Office of Water, Washington, DC. 840-B-92-002.

USEPA. 1988. *Dissolved Solids. Water Quality Standards Criteria Summaries: A Compilation of State/Federal Criteria*. Office of Water, Regulations, and Standards, Washington, DC.

USEPA. 1983. *Results of the Nationwide Urban Runoff Project: Final Report*. U.S.EPA, Office of Water, Washington, DC.

USEPA. 1982. *Sources of Urban Runoff Pollution and Its Effects on an Urban Creek*. U.S.EPA, Washington, DC. -600/S2-82-090.

United States Geological Survey (USGS). 2001a. *Selected Findings and Current Perspectives on Urban and Agricultural Water Quality.* National Water-Quality Assessment Program. USGS Fact Sheet. FS-047-01.

USGS. 2001b. *The Quality of Our Nation's Waters: Nutrients and Pesticides*. USGS. FS-047-01.

USGS. 1999a. *Pesticides and Bacteria in an Urban Stream - Gills Creek, Columbia, South Carolina*. USGS. Fact Sheet FS-131-98.

USGS. 1999b. *Pesticides Detected in Urban Streams During Rainstorms and Relations to Retail Sales of Pesticides in King County, Washington*. USGS. Fact Sheet 097-99.

USGS. 1998. *Pesticides in Surface Waters of the Santee River Basin and Coastal Drainages, North and South Carolina*. USGS Fact Sheet. FS-007-98.

USGS. 1996. *Effects of Increased Urbanizaton from 1970s to 1990s on Storm Runoff Characteristics in Perris Valley, California*. USGS Water Resources Investigations Report 95-4273.

University of California at Davis (UC Davis). 1998. *UC Report: MTBE Fact Sheet*. Available online: http://tsrtp.ucdavis.edu/mtberpt

Valiela, I., J. McClelland, J. Hauxwell, P. Behr, D. Hersh and K. Foreman. 1997. "Macroalgal Blooms in Shallow Estuaries: Controls and Ecophysiological and Ecosystem Consequences." *Limonology and Oceanography* 42(5, part 2): 1105-1118.

Valiela, I. and J. Costa. 1988. "Eutrophication of Buttermilk Bay, a Cape Cod Embaymnet: Concentrations of Nutrients and Watershed Nutrient Budgets." *Environmental Management* 12(4):539-553.

Van Loon, J. 1972. "The Snow Removal Controversy." *Water Pollution Control* 110:16-20.

Varner, 1995. *Characterization and Source Control of Urban Stormwater Quality.* City of Bellevue Utilities Department. City of Bellevue, Washington.

Velinsky, D. and J.Cummins. 1994. *Distribution of Chemical Contaminants in Wild Fish Species in the Washington, D.C. Area*. Interstate Commission on the Potomac River Basin, ICPRB., Rockville, MD. Report No. 94-1.

Vernberg, W., G. Scott, S. Stroizer, J. Bemiss and J. Daugomah. 1996a. "The Effects of Coastal Development on Watershed Hydrography and Transport of Organic Carbon." In *Sustainable Development in the Southeastern Coastal Zone*. F.J. Vernberg, W.B. Vernberg and T. Siewicki (eds.). Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.

Vernberg, F., W. Vernberg and T. Siewicki. 1996b. *Sustainable Development in the Southeastern Coastal Zone.* Editors. Belle W. Baruch Library in Marine Science. No. 20. University of South Carolina Press. Columbia, SC.

Vernberg, F.J., W.B. Vernberg, E. Blood, A. Fortner, M. Fulton, H. McKellar, W. Michener, G. Scott, T. Siewicki and K. El-Figi. 1992. "Impact of Urbanization on High-Salinity Estuaries in the Southeastern United States." *Netherlands Journal of Sea Research* 30:239-248.

Walling, D. and J.Woodward. 1995. "Tracing Sources of Suspended Sediment in River Basins: A Case Study of the River Culm, Devon, UK." *Marine and Freshwater Research* 46: 324-336.

Wahl, M., H. McKellar and T. Williams. 1997. "Patterns of Nutirent Loading in Forested and Urbanized Coastal Streams." *Journal of Experimental Marine Biology and Ecology* 213:111-131.

Wang, L., J. Lyons, P. Kanehl and R. Bannerman. 2001. "Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales." *Environmental Management*. 28(2):255-266.

Wang, L., J. Lyons, P. Kanehl and R. Gatti. 1997. “Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams.” *Fisheries* 22(6): 6-11.

Ward, J. and J. Stanford. 1979. *The Ecology of Regulated Streams. Plenum Press.* New York, NY.

Waschbusch R., W. Selbig and R. Bannerman. 2000. “Sources of Phosphorus in Stormwater and Street Dirt from Two Urban Residential Basins in Madison, Wisconsin, 1994-1995.” In: *National Conference on Tools for Urban Water Resource Management and Protection*. US EPA February 2000: pp. 15-55.

Washington Department of Fish and Wildlife (WDFW). 1997. *Final Environmental Impact Statement for the Wild Salmonid Policy*. Olympia, Washington.

Water Environment Research Foundation (WERF). 1999. Chapter 4: Accumulation of Pollutants in Snowpack. *Urban and Highway Snowmelt: Minimizing the Impact on Receiving Water.* Alexandria, VA.

Water, B. 1999. *Ambient Water Quality Guidelines for Organic Carbon*. Water Mangement Branch Environment and Resource Management. Ministry of Environment, Lands and Parks.

Watters, G. 1996. *Reasons for Mussel Decline and Threats to Continued Existence.* Academy of Natural Sciences, Philadelphia. Available at http://coa.acnatsci.org/conchnet/uniowhat.html

Weaver, L. 1991. *Low-Intensity Watershed Alteration Effects on Fish Assemblage Structure and Function in a Virginia Piedmont Stream*. Masters Thesis. Virginia Commonwealth University. VA.

Weaver, L. and G. Garman. 1994. “Urbanization of a Watershed and Historical Changes in Stream Fish Assemblage.” *Transactions of the American Fisheries Society* 123: 162-172.

Weiskel, P., B. Howes and G.. Heufelder. 1996. “Coliform Contamination of a Coastal Embayment: Sources and Transport Pathways.” *Environmental Science and Technology* 30:1871-1881.

Wernick, B.G., K.E. Cook, and H. Schreier. 1998. “Land Use and Streamwater Nitrate-N Dynamics in an Urban-rural Fringe Watershed.” J*ournal of the American Water Resources Association 34*(3): 639-650.

Williams, J., S. Fuller and R. Grace. 1992. “Effects of Impoundment on Freshwater Mussels (Mollusca: Bivalvia: Unionidae) in the Main Channel of the Black Warrior and Tombigbee Rivers in Western Alabama.” *Bulletin of the Alabama Museum of Natural History* 13: 1-10.

Williams, J., M. Warren, Jr., K. Cummings, J.Harris and R. Neves. 1993. “Conservation Status of Freshwater Mussels of the United States and Canada.” *Fisheries* 18(9): 6-22.

Winer, R. 2000. *National Pollutant Removal Performance Database for Stormwater Treatment Practices*, *2nd Edition*. Center for Watershed Protection. Ellicott City, MD.

Wotzka, P., J. Lee, P. Capel and M. Lin.1994. *Pesticide Concentrations and Fluxes in an Urban Watershed.* Proceedings AWRA 1994 National Symposium on Water Quality.

Wood, P. and P. Armitage. 1997. “Biological Effects of Fine Sediment in the Lotic Environment.” *Environmental Management* 21(2):203-217.

Woodward-Clyde Consultants. 1992. *Source Identification and Control Report*. Prepared for the Santa Clara Valley Nonpoint Source Control Program. Oakland, California.

Xiao, L., A. Singh, J. Limor, T. Graczyk, S. Gradus and A. Lal. 2001. "Molecular Characterization of Cryptosporidium Oocysts in Samples of Raw Surface Water and Wastewater." *Applied and Environmental Microbiology* 67(3):1097-1101.

Yoder, C. 1991. "The Integrated Biosurvey As a Tool for Evaluation of Aquatic Life Use Attainment and Impairment in Ohio Surface Waters." In *Biological Criteria: Research and Regulation*, Proceedings of a Symposium, 12-13 December 1990, Arlington, VA, U.S. EPA, Office of Water, Washington, DC, EPA-440/5-91-005:110.

Yoder, C. and R. Miltner. 2000. "Using Biological Criteria to Assess and Classify Urban Streams and Develop Improved Landscape Indicators." In *Proceedings of the National Conference on Tools for Urban Water Resource Management & Protection*: Published by the US Environmental Protection Agency, Office of Research and Development, Washington, DC.

Yoder, C., R. Miltner and D.White. 1999. "Assessing the Status of Aquatic Life Dsignated Uses in urban and Suburban Watersheds." In Everson *et al.* Editors. *National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments, Chicago*, IL. EPA/625/R-99/002.

York, T. H. and W. J. Herb. 1978. "Effects of Urbanization and Streamflow on Sediment Transport in the Rock Creek and Anacostia River Basins. Montgomery County, MD 1972-1974." *USGS Professional Paper* 1003.

Young, K. and E. Thackston. 1999. "Housing Density and Bacterial Loading in Urban Streams." *Journal of Environmental Engineering* December:1177-1180.

Zapf-Gilje, R., S. Russell and D. Mavinic. 1986. "Concentration of Impurities During Melting Snow Made From Secondary Sewage Effluent." *Waterscience Technology* 18:151-156.

Zielinski, J. 2001. *Watershed Vulnerability Analysis*. Prepared for Wake County (NC). Center for Watershed Protection. Ellicott City, MD.

Zielinski, J. 2000. "The Benefits of Better Site Design in Residential Subdivision and Commercial Development." *Watershed Protection Techniques* 3(2): 633-656.

Glossary

1st order stream: The smallest perennial stream. A stream that carries water throughout the year and does not have permanently flowing tributaries.

2nd order stream: Stream formed by the confluence of two 1st order streams.

3rd order stream: Stream formed by the confluence of two 2nd order streams.

Acute toxicity: Designates exposure to a dangerous substance or chemical with sufficient dosage to precipitate a severe reaction, such as death.

Alluvial: Pertaining to processes or materials associated with transportation or deposition by running water.

Anadromous: Organisms that spawn in freshwater streams but live most of their lives in the ocean.

Annual Pollutant Load: The total mass of a pollutant delivered to a receiving water body in a year.

Bankfull: The condition where streamflow just fills a stream channel up to the top of the bank and at a point where the water begins to overflow onto a floodplain.

Baseflow: Stream discharge derived from ground water that supports flow in dry weather.

Bedload: Material that moves along the stream bottom surface, as opposed to suspended particles.

Benthic Community: Community of organisms living in or on bottom substrates in aquatic habitats, such as streams.

Biological Indicators: A living organism that denotes the presence of a specific environmental condition.

Biological Oxygen Demand (BOD): An indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by bacterial processes breaking down organic waste.

Carcinogen: A cancer-causing substance or agent.

Catchment: The smallest watershed management unit. Defined as the area of a development site to its first intersection with a stream, usually as a pipe or open channel outfall.

Chemical Oxygen Demand (COD): A chemical measure of the amount of organic substances in water or wastewater. Non-biodegradable and slowly degrading compounds that are not detected by BOD are included.

Chronic Toxicity: Showing effects only over a long period of time.

Combined Sewer Overflow (CSO): Excess flow (combined wastewater and stormwater runoff) discharged to a receiving water body from a combined sewer network when the capacity of the sewer network and/or treatment plant is exceeded, typically during storm events.

Combined Indices (C-IBI or CSPS): Combined indices that use both fish and aquatic insect metrics and a variety of specific habitat scores to classify streams.

Cryptosporidium parvum: A parasite often found in the intestines of livestock which contaminates water when animal feces interacts with a water source.

Deicer: A compound, such as ethylene glycol, used to melt or prevent the formation of ice.

Dissolved Metals: The amount of trace metals dissolved in water.

Dissolved Phosphorus: The amount of phosphorus dissolved in water.

Diversity: A numerical expression of the evenness and distribution of organisms.

Ecoregion: A continuous geographic area over which the climate is uniform to permit the development of similar ecosystems on sites with similar geophysical properties.

Embeddedness: Packing of pebbles or cobbles with fine-grained silts and clays.

EPT Index: A count of the number of families of each of the three generally pollution-sensitive orders: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).

Escherichia coli (E. coli): A bacteria that inhabits the intestinal tract of humans and other warm-blooded animals. Although it poses no threat to human health, its presence in drinking water does indicate the presence of other, more dangerous bacteria.

Eutrophication: The process of over-enrichment of water bodies by nutrients, often typified by the presence of algal blooms.

Fecal coliform: Applied to E. coli and similar bacteria that are found in the intestinal tract of humans and animals. Coliform bacteria are commonly used as indicators of the presence of pathogenic organisms. Their presence in water indicates fecal pollution and potential contamination by pathogens.

Fecal streptococci: Bacteria found in the intestine of warm-blooded animals. Their presence in water is considered to verify fecal pollution.

Fish Blockages: Infrastructures associated with urbanization, such as bridges, dams, and culverts, that affect the ability of fish to move freely upstream and downstream in watersheds. Can prevent re-colonization of resident fish and block the migration of anadromous fish.

Flashiness: Percent of flows exceeding the mean flow for the year. A flashy hydrograph would have larger, shorter-duration hydrograph peaks.

Geomorphic: The general characteristic of a land surface and the changes that take place in the evolution of land forms.

Giardia lamblia: A flagellate protozoan that causes severe gastrointestinal illness when it contaminates drinking water.

Herbicide: Chemicals developed to control or eradicate plants.

Hotspot: Area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

Hydrograph: A graph showing variation in stage (depth) or discharge of a stream of water over a period of time.

Illicit discharge: Any discharge to a municipal separate storm sewer system that is not composed entirely of storm water, except for discharges allowed under an NPDES permit.

Impervious Cover: Any surface in the urban landscape that cannot effectively absorb or infiltrate rainfall.

Impervious Cover Model (ICM): A general watershed planning model that uses percent watershed impervious cover to predict various stream quality indicators. It predicts expected stream quality declines when watershed IC exceeds 10% and severe degradation beyond 25% IC.

Incision: Stream down-cuts and the channel expands in the vertical direction.

Index of Biological Integrity (IBI): Tool for assessing the effects of runoff on the quality of the aquatic ecosystem by comparing the condition of multiple groups of organisms or taxa against the levels expected in a healthy stream.

Infiltration: The downward movement of water from the surface to the subsoil. The infiltration capacity is expressed in terms of inches per hour.

Insecticide: Chemicals developed to control or eradicate insects.

Large Woody Debris (LWD): Fundamental to stream habitat structure. Can form dams and pools; trap sediment and detritus; provide stabilization to stream channels; dissipate flow energy and promote habitat complexity.

Mannings N: A commonly used roughness coefficient; actor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water.

Methyl Tertiary-Butyl Ether: An oxygenate and gasoline additive used to improve the efficiency of combustion engines in order to enhance air quality and meet air pollution standards. MTBE has been found to mix and move more easily in water than many other fuel components, thereby making it harder to control, particularly once it has entered surface or ground waters.

Microbe: Short for microorganism. Small organisms that can be seen only with the aid of a microscope. Most frequently used to refer to bacteria. Microbes are important in the degradation and decomposition of organic materials.

Nitrate: A chemical compound having the formula NO_3. Excess nitrate in surface waters can lead to excessive growth of aquatic plants.

Organic Matter: Plant and animal residues, or substances made by living organisms. All are based upon carbon compounds.

Organic Nitrogen: Nitrogen that is bound to carbon-containing compounds. This form of nitrogen must be subjected to mineralization or decomposition before it can be used by the plant community.

Overbank Flow: Water flow over the top of the bankfull channel and onto the floodplain.

Oxygenate: To treat, combine, or infuse with oxygen.

Peak Discharge: The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

Pesticides: Any chemical agent used to control specific organisms, for example, insecticides, herbicides, fungicides and rodenticides.

Piedmont: Any plain, zone or feature located at the foot of a mountain. In the United States, the Piedmont (region) is a plateau extending from New Jersey to Alabama and lying east of the Appalachian Mountains.

Pool: A stream feature where there is a region of deeper, slow-moving water with fine bottom materials. Pools are the slowest and least turbulent of the riffle/run/pool category.

Protozoan: Any of a group of single-celled organisms.

Rapid Bioassessment Protocols (RBP): An integrated assessment, comparing habitat, water quality and biological measures with empirically defined reference conditions.

Receiving Waters: Rivers, lakes, oceans, or other bodies of water that receive water from another source.

Riffle: Shallow rocky banks in streams where water flows over and around rocks disturbing the water surface; often associated with whitewater. Riffles often support diverse biological communities due to their habitat niches and increased oxygen levels created by the water disturbance. Riffles are the most swift and turbulent in the riffle/run/pool category.

Roughness: A measurement of the resistance that streambed materials, vegetation, and other physical components contribute to the flow of water in the stream channel and floodplain. It is commonly measured as the Manning's roughness coefficient (Manning's N).

Run: Stream feature characterized by water flow that is moderately swift flow, yet not particularly turbulent. Runs are considered intermediate in the riffle/run/pool category.

Runoff Coefficient: A value derived from a site impervious cover value that is applied to a given rainfall volume to yield a corresponding runoff volume.

Salmonid: Belonging to the family Salmonidae, which includes trout and salmon.

Sanitary Sewer Overflow (SSO): Excess flow of wastewater (sewage) discharged to a receiving water body when the capacity of the sewer network and/or treatment plant is exceeded, typically during storm events.

Semi-arid: Characterized by a small amount of annual precipitation, generally between 10 and 20 inches.

Simple Method: Technique used to estimate pollutant loads based on the amount of IC found in a catchment or subwatershed.

Sinuosity: A measure of channel curvature, usually quantified as the ratio of the length of the channel to the length of a straight line along the valley axis. It is, in essence, a ratio of the stream's actual running length to its down-gradient length.

Soluble Phosphorus: The amount of phosphorus available for uptake by plants and animals.

Stormwater: The water produced as a result of a storm.

Subwatershed: A smaller geographic section of a larger watershed unit with a drainage area of between two to 15 square miles and whose boundaries include all the land area draining to a point where two 2^{nd} order streams combine to form a 3^{rd} order stream.

Total Dissolved Solids (TDS): A measure of the amount of material dissolved in water (mostly inorganic salts).

Total Kjeldhal Nitrogen (TKN): The total concentration of nitrogen in a sample present as ammonia or bound in organic compounds.

Total Recoverable Metals: The amount of a metal that is in solution after a representative suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances).

Total Maximum Daily Load (TMDL): The maximum quantity of a particular water pollutant that can be discharged into a body of water without violating a water quality standard.

Total Nitrogen (Total N): A measure of the total amount of nitrate, nitrite and ammonia concentrations in a body of water.

Total Organic Carbon (TOC): A measure of the amount of organic material suspended or dissolved in water.

Total Phosphorous (Total P): A measure of the concentration of phosphorus contained in a body of water.

Total Suspended Solids (TSS): The total amount of particulate matter suspended in the water column.

Trophic Level: The position of an organism in a food chain or food pyramid.

Turbidity: A measure of the reduced transparency of water due to suspended material which carries water quality and aesthetic implications. Applied to waters containing suspended matter that interferes with the passage of light through the water or in which visual depth is restricted.

Volatile Organic Compounds (VOC): Chemical compounds which are easily transported into air and water. Most are industrial chemicals and solvents. Due to their low water solubility they are commonly found in soil and water.

Chapter 1
Summary

1.1 Introduction

Discharges from agricultural lands include irrigation return flow; flows from tile drains; and storm water runoff from fields, managed wetlands, nurseries, and water districts that accept agricultural discharges. These discharges can affect water quality by transporting constituents of concern including pesticides, sediment, nutrients, salts (including selenium and boron), pathogens, and heavy metals from cultivated fields into surface waters. Many surface water bodies are impaired because of pollutants from agricultural sources. Groundwater bodies also have suffered pesticide, nitrate, and salt contamination. Statewide, approximately 9,493 miles of rivers/streams and some 513,130 acres of lakes/reservoirs are listed on the Section 303(d) list as being impaired by irrigated agriculture. Of these, approximately 2,800 miles, or approximately 28 percent, have been identified as impaired by pesticides.

Since 1982, the Central Valley Regional Water Quality Control Board (Central Valley Water Board) has regulated nonpoint source (NPS) discharges from agricultural lands through a waiver of waste discharge requirements (WDRs). Senate Bill (SB) 390, signed into law on October 6, 1999, amended Section 13269 of the California Water Code (Water Code) to require the State Water Resources Control Board (State Water Board) and Regional Water Quality Control Boards (Regional Water Boards) to review their existing waivers and to renew them or replace them with WDRs. Under SB 390, waivers not reissued automatically expired on January 1, 2003. To comply with SB 390, the Regional Water Boards adopted revised waivers. To comply with the requirements of SB 390, the Central Valley Water Board adopted a Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Conditional Waiver).

Under the 2003 Conditional Waiver, the Central Valley Water Board directed staff to prepare an Environmental Impact Report (EIR) for a long-term Irrigated Lands Regulatory Program (ILRP). The 2003 Conditional Waiver expired in 2006, and a revised Conditional Waiver was adopted that continues the Conditional Waiver until June 2011**.** With adoption of the 2006 Conditional Waiver, the Central Valley Water Board reaffirmed its goal of analyzing the environmental effects of alternatives for a long-term ILRP through development and public review of a Program Environmental Impact Report (EIR or PEIR). This draft PEIR analyzes the environmental impacts of five program alternatives and will assist the Central Valley Water Board in determining which alternative, or elements of alternatives, would best meet applicable statutory requirements and the goals and objectives of the ILRP.

1.2 Overview of Central Valley Agriculture

The Central Valley is a large, flat, fertile valley that dominates the central portion of California. The northern half of the Central Valley is referred to as the Sacramento Valley, and the southern half is referred to as the San Joaquin Valley. The two halves meet at the shared delta of the Sacramento and San Joaquin Rivers, which flow through the northern and southern halves of the valley, respectively.

The Central Valley is one of the most productive agricultural regions in the world. Crops produced in the Central Valley include land planted to vineyard, row, pasture, field, and tree crops; commercial nurseries; nursery stock production; rice production; greenhouse operations; and livestock.

The program area encompasses the jurisdiction of the Central Valley Water Board, shown in Figure 2-1. The Central Valley Water Board's region stretches from the Oregon border to the northernmost tip of Los Angeles County. Three major watersheds have been delineated within this region: the Sacramento River Basin, the San Joaquin River Basin, and the Tulare Lake Basin. These three basins cover approximately 40 percent of the total area of the state and include approximately 75 percent of California's irrigated acreage (Central Valley Water Board 2002a). Much of the surface water supplies in the Central Valley originate north of the Sacramento–San Joaquin River Delta (Delta), while much of the water use is south of the Delta. Although the surface water in the Sacramento River Basin is adequate to meet the present level of demand, surface water supplies in the San Joaquin River and Tulare Lake Basins are inadequate to support the present level of agricultural and development use. In these basins, groundwater resources are being used to meet existing water supply demands.

1.3 Program Purpose and Objectives

The proposed goals and objectives of the ILRP are those recommended by the Stakeholder Advisory Workgroup (Workgroup) (Central Valley Water Board and ICF Jones & Stokes 2009). *Irrigated agricultural lands* include lands where water is applied to produce crops, fiber, or livestock for commercial sale or use. For the purposes of this draft PEIR, irrigated agricultural lands also include managed wetlands, nurseries, and water districts that accept discharges from irrigated lands. Understanding that irrigated agriculture in the Central Valley provides valuable food and fiber products to communities worldwide, the overall goals of the ILRP are to (1) restore and/or maintain the highest reasonable quality of state waters considering all the demands being placed on the water; (2) minimize waste discharge from irrigated agricultural lands that could degrade the quality of state waters; (3) maintain the economic viability of agriculture in California's Central Valley; and (4) ensure that irrigated agricultural discharges do not impair access by Central Valley communities and residents to safe and reliable drinking water. In accordance with these goals, the objectives of the ILRP are to:

- Restore and/or maintain appropriate beneficial uses established in Central Valley Water Board water quality control plans by ensuring that all state waters meet applicable water quality objectives.
- Encourage implementation of management practices that improve water quality in keeping with the first objective without jeopardizing the economic viability for all sizes of irrigated agricultural operations in the Central Valley or placing an undue burden on rural communities to provide safe drinking water.
- Provide incentives (i.e., financial assistance, monitoring reductions, certification, or technical help) for agricultural operations to minimize waste discharge to state waters from their operations.
- Coordinate with other Central Valley Water Board programs (e.g., the Grasslands Bypass Project WDRs for agricultural lands, efforts by the Westlands Water District to develop WDRs for

agricultural lands, development of total maximum daily loads [TMDLs] for Central Valley Salinity Alternatives for Long-Term Sustainability [CV-SALTS], and WDRs for dairies).

- Promote coordination with other regulatory and non-regulatory programs associated with agricultural operations to minimize duplicative regulatory oversight while ensuring program effectiveness (e.g., U.S. Department of Agriculture [USDA] National Organic Program, State Water Board Groundwater Ambient Monitoring and Assessment Program).

1.4 Program Description

The alternatives analyzed in this draft PEIR are the result of an intensive workgroup process described in Chapter 2, Introduction. The Central Valley Water Board intends to consider the analysis in this draft PEIR in selecting a preferred alternative, either one considered in this document directly or a staff-recommended program comprised of elements from multiple considered alternatives. Therefore, the document does not identify a “preferred alternative.” All alternatives selected for analysis are analyzed to an equal level of detail. The alternatives are described in greater detail in Chapter 3.

1.4.1 Alternative 1 – Full Implementation of Current Program (No Project Alternative)

Under Alternative 1, the Central Valley Water Board would renew the current program and continue to implement it into the future. This would be considered the “No Project” Alternative per California Environmental Quality Act (CEQA) guidance at Title 14 California Code of Regulations (CCR) Section 15126.6(e)(3)(A): “When the project is the revision of an existing land use or regulatory plan, policy or ongoing operation, the ‘No Project’ Alternative will be the continuation of the existing plan, policy, or operation into the future.” Given the ministerial nature of the extension or renewal of the ongoing waiver, which would allow continuation of the existing program, Alternative 1 is best characterized as the “No Project” Alternative. This approach best serves the purpose of allowing the Central Valley Water Board to compare the impacts of revising the ILRP with those of continuing the existing program (14 CCR Section 15126.6[e][1]).[1]

Coalition groups would continue to function as lead entities representing growers (owners of irrigated lands, wetland managers, nursery owners, and water districts). This alternative is based on continuing watershed monitoring to determine whether operations are causing water quality problems. Where monitoring indicates a problem, third-party groups and growers would be required to implement management practices to address the problem and work toward compliance with applicable water quality standards. This alternative would not establish any new Central Valley Water Board requirements for discharges to groundwater from irrigated agricultural lands.

Under this alternative, the Central Valley Water Board would renew the current program through WDRs or a waiver of the WDRs. Water quality coalition groups have formed throughout the Central Valley to function as representative or “lead” entities in administration of the current ILRP.

[1] The existing environmental setting, not the “No Project” Alternative, constitutes the baseline for determining whether a project’s environmental impacts may be significant (14 CCR Section 15126.5[e][1]). Therefore, defining the “No Project” Alternative as continuing the existing program does not change the analysis of the environmental impacts under the remaining alternatives.

Coalitions represent growers, provide education, organize monitoring, and work with the Central Valley Water Board to help ensure that the current program is effectively implemented. These third-party water quality coalition groups would continue to function as lead entities for their members to ensure that all Central Valley Water Board requirements are met.

Monitoring under this alternative would be the same as the watershed-based assessment and core monitoring required under the current ILRP. Under this monitoring scheme, coalition groups would work with the Central Valley Water Board to develop monitoring plans for Central Valley Water Board approval. These plans would specify monitoring parameters and site locations.

1.4.2 Alternative 2 – Third-Party Lead Entity

Under Alternative 2, the Central Valley Water Board would develop a single mechanism or a series of regulatory mechanisms for waste discharge from irrigated agricultural lands to groundwater and surface water. The series of regulatory mechanisms would be designed to provide flexibility in establishing requirements for growers considering the variety of environmental conditions and agricultural operations throughout the Central Valley. These could include WDRs, conditional waivers of WDRs, or conditional prohibitions of discharge.

Under Alternative 2, third-party groups (e.g., water quality coalitions) would function as lead entities representing growers. Regulation of discharges to surface water would be similar to Alternative 1 (the current ILRP). However, this alternative allows for a reduction in monitoring under lower threat circumstances and where watershed or area management objective plans are being developed. This alternative also includes requirements for development of groundwater quality management plans (GQMPs) to minimize discharge of waste to groundwater from irrigated lands. However, GQMPs under this alternative would not involve monitoring of groundwater to determine the performance of these management plans. These GQMPs would be reviewed every 5 years by the Central Valley Water Board and the third-party groups to determine whether and how the GQMPs should be updated. This alternative also relies on coordination with the California Department of Pesticide Regulation (DPR) for regulating discharges of pesticides to groundwater.

Under this alternative, water quality coalitions or other third-party groups would be responsible for general administration of the ILRP and would need to agree to assume greater responsibilities than under Alternative 1. (See Chapter 3 for a detailed list of these responsibilities.)

Third-party groups would have the option of developing a watershed or area management objectives plan. The goal of this plan would be to meet source control management objectives that would reduce the threat to surface water quality from waste discharge associated with irrigated agriculture. In areas implementing a Central Valley Water Board-approved watershed or area management objectives plan, surface water monitoring would be reduced. Plans would specify optional water quality management practices that could be implemented to achieve plan objectives. Further, the plan would be developed consistent with the area or watershed commodity types, common agricultural practices, pesticides commonly used, and local land characteristics. Optional practices would be provided to allow growers to adapt to their specific conditions for compliance with the ILRP. The plan also would consider the results of previous water quality sampling.

Growers would be required to track implemented management practices and submit the results to the third-party group. The third-party group would report summary results to the Central Valley Water Board. The third-party group would be required to summarize the results of groundwater and surface water monitoring and tracking in an annual monitoring report to the Central Valley Water Board.

1.4.3 Alternative 3 – Individual Farm Water Quality Management Plan

Under Alternative 3, growers would have the option of working directly with the Central Valley Water Board or another implementing entity (e.g., county agricultural commissioners [CACs]) in development of a farm water quality management plan (FWQMP). Growers would individually apply for a conditional waiver or WDRs that would require Central Valley Water Board approval of their FWQMP.

On-farm implementation of effective water quality management practices would be the mechanism to reduce or eliminate waste discharged to state waters. This alternative would provide incentive for individual growers to participate by providing growers with Central Valley Water Board certification that they are implementing farm management practices to protect state waters. This alternative relies on coordination with DPR for regulating discharges of pesticides to groundwater.

Under Alternative 3, growers would be the lead entities working directly with the Central Valley Water Board and would be responsible for applying for coverage, developing FWQMPs, and conducting any required reporting.

Unless specifically required in response to water quality problems, owners/operators would not be required to conduct water quality monitoring of adjacent receiving waters or underlying groundwater. Required monitoring would include evaluation of management practice effectiveness. The Central Valley Water Board, or a designated third-party entity, would conduct annual site inspections on a selected number of operations. They also would review available applicable water quality monitoring data as additional means of monitoring the implementation of management practices and program effectiveness.

1.4.4 Alternative 4 – Direct Oversight with Regional Monitoring

Under this alternative, the Central Valley Water Board would develop WDRs and/or a conditional waiver of WDRs for waste discharge from irrigated agricultural lands to groundwater and surface water. As in Alternative 3, growers, or legal entities responsible for waste discharges by a group of growers, would apply directly to the Central Valley Water Board in order to obtain coverage (“direct oversight”). As in Alternative 3, growers would be required to develop and implement individual FWQMPs in order to minimize discharge of waste to groundwater and surface water from irrigated agricultural lands. However, Alternative 4 would include an option for regional monitoring run by a third party instead of monitoring conducted by individual growers.

Discharge of waste to groundwater and surface water would be regulated using a tiered approach. Fields would be placed in one of three tiers based on their threat to water quality. The tiers represent fields with minimal (Tier 1), low (Tier 2), and high (Tier 3) potential threat to water quality. Requirements to avoid or minimize discharge of waste would be the least stringent for Tier 1 fields and the most stringent for Tier 3 fields. This would allow for less regulatory oversight for low-threat operations while establishing necessary requirements to protect water quality from higher-threat discharges. This alternative relies on coordination with DPR for regulating discharges of pesticides to groundwater.

Growers would be lead entities working directly with the Central Valley Water Board; they would be responsible for applying for coverage, developing FWQMPs, and conducting any required monitoring and reporting. This alternative would allow for formation of responsible legal entities that could serve a group of growers who discharge to the same general location and thus could share monitoring locations. In such cases, the legal entity would be required to assume responsibility for the waste discharges of member growers, to be approved by the Central Valley Water Board, and ultimately to be responsible for compliance with ILRP requirements.

For monitoring, growers would have the option of enrolling in a third-party group regional monitoring program instead of conducting individual monitoring. In cases where responsible legal entities were formed, these entities would be responsible for conducting monitoring. All growers would be required to track nutrient, pesticide, and implemented management practices and submit the results to the Central Valley Water Board (or an approved third-party monitoring group) annually. Other monitoring requirements would depend on designation of the fields as Tier 1, Tier 2, or Tier 3. (See Chapter 3 for a full description of this alternative.)

1.4.5 Alternative 5 – Direct Oversight with Farm Monitoring

Alternative 5 would consist of general WDRs designed to protect groundwater and surface water from discharges associated with irrigated agriculture.

All growers would be required to apply for and obtain coverage under the general WDRs. This alternative would include requirements to (1) develop and implement a FWQMP; (2) monitor (a) discharges of tailwater, drainage water, and storm water to surface water; (b) applications of irrigation water, nutrients, and pesticides; and (c) groundwater; (3) keep records of (a) irrigation water; (b) pesticide applications; and (c) the nutrients applied, harvested, and moved off the site; and (4) submit an annual monitoring report to the Central Valley Water Board.

Alternative 5 relies on coordination with DPR for regulating discharges of pesticides to groundwater. The Central Valley Water Board would develop general WDRs for irrigated agriculture. Growers would be the lead entity in working with the Central Valley Water Board. The Central Valley Water Board would adopt the WDRs, enroll individual growers under the program, provide regulatory oversight, and enforce the requirements of the program.

Each grower would be required to monitor tailwater discharges, storm water discharges, and drainage system discharges. In addition, each grower would be required to conduct nutrient and pesticide tracking as well as groundwater monitoring.

1.5 CEQA Process

1.5.1 Purpose of This Draft PEIR

The Lead Agency, the Central Valley Water Board, will consult this draft PEIR in determining which alternative, or elements of alternatives, would best meet applicable statutory requirements and the goals and objectives of the ILRP.

1.5.2 Public Outreach

As the ILRP has been developed, the Central Valley Water Board has sought public input on many occasions, as described at length in Chapter 2, Introduction. Public comment on this draft PEIR has been requested through a scoping process described below and is again invited during the public comment period.

Notice of Preparation

The Central Valley Water Board released a Notice of Preparation (NOP) on February 14, 2003.

Scoping

On March 5 and 6, 2003, CEQA scoping meetings were held in Fresno and Sacramento to solicit and receive public comment on the scope of the EIR as described in the NOP. Following the scoping meetings, the Central Valley Water Board began preparation of the draft *Existing Conditions Report* (ECR) in 2004 to assist in defining the baseline condition for the EIR's environmental analyses. The draft ECR was circulated in 2006, public comment on the document was received and incorporated, and it was released in 2008 (ICF Jones & Stokes 2008).

In March and April 2008, the Central Valley Water Board staff conducted another series of CEQA scoping meetings to generate recommendations on the scope and goals of the long-term ILRP. Information also was gathered as to how stakeholders would like to be involved in development of the long-term program. Stakeholders indicated in these scoping meetings that they would like to be actively involved in developing the program. To address this interest, the Central Valley Water Board initiated a series of Workgroup meetings, described below.

1.5.3 Scope of Draft PEIR Analysis

All CEQA-recognized environmental resources were analyzed for possible environmental impacts resulting from the ILRP alternatives. The alternatives were determined to have possible significant effects on several resource areas, which are discussed at length in Chapter 5. Likewise, the alternatives were determined to have no significant impact on other resources, which are discussed in Section 5.11, Minimally Impacted Resources.

Resources with Potentially Significant Impacts

The Central Valley Water Board determined that the program could result in potentially significant impacts on the following resources, which thus warrant close scrutiny:

- Cultural resources
- Noise
- Air quality
- Climate change
- Vegetation and wildlife
- Fisheries
- Hydrology and water quality

- Agriculture resources

Resources Not Significantly Impacted

The Central Valley Water Board has determined that the program will result in no or less-than-significant direct impacts and no indirect impacts on the following resources, which thus do not warrant close scrutiny:

- Aesthetics
- Geology and soils
- Hazards and hazardous materials
- Land use and planning
- Mineral resources and energy
- Population and housing
- Public services
- Recreation
- Transportation and circulation
- Utilities and service systems

Known Areas of Controversy

In accordance with State CEQA Guidelines Section 15123(b)(2), the areas of controversy known to the lead agency, including issues raised by agencies and the public, shall be identified in the EIR. Through public scoping, the efforts of the Workgroup, and other outreach efforts, the following areas of controversy were identified:

- The costs to growers of implementing a more stringent ILRP will be prohibitive and suppress the economic sustainability or growth of agriculture.
- Adding a groundwater monitoring element to the ILRP would be unnecessarily duplicative of existing monitoring efforts.
- The alternatives do not contain a clear methodology for defining a groundwater discharger or determining the nature of discharges to groundwater.
- The program does not take adequate steps to offset the costs to rural communities for cleanup of existing water quality impairments that can be linked back to historical agricultural discharges.

1.5.4 Public Comment on the Draft PEIR

This draft PEIR was made available for public review and comment on July 28, 2010. In addition, the Central Valley Water Board will conduct public hearings on the draft document. Comments received at the hearings or received in written form will be considered in development of a final PEIR.

Comments may be sent to:

ILRP Comments
Ms. Megan Smith
630 K Street, Suite 400
Sacramento, CA 95814

Email: ILRPcomments@icfi.com

Fax: (916) 456-6724

1.6 Summary of Program Environmental Impacts and Mitigation

Table 1-1 provides a summary of the potential impacts and mitigation measures for the ILRP.

Table 1-1. Summary of Impacts and Mitigation Measures for the Irrigated Lands Regulatory Program

Impact	Applicable Alternative	Significance before Mitigation	Mitigation Measures	Significance after Mitigation
CULTURAL RESOURCES				
CUL-1. Physical Destruction, Alteration, or Damage of Cultural Resources from Implementation of Management Practices	1, 2, 3, 4, 5	Significant	CUL-MM-1: Avoid Impacts to Cultural Resources	Less than significant
CUL-2. Potential Damage to Cultural Resources from Construction Activities and Installation of Groundwater Monitoring Wells	5	Significant	CUL-MM-1: Avoid Impacts to Cultural Resources	Less than significant
NOISE				
NOI-1. Exposure of Sensitive Land Uses to Noise from Construction Activities in Excess of Applicable Standards	1, 2, 3, 4, 5	Potentially significant	NOI-MM-1: Implement Noise–Reducing Construction Practices	Less than significant
NOI-2. Exposure of Sensitive Land Uses to Noise from Operational Activities in Excess of Applicable Standards	1, 2, 3, 4, 5	Potentially significant	NOI-MM-1: Implement Noise–Reducing Construction Practices NOI-MM-2: Reduce Noise Generated by Individual Well Pumps	Less than significant
AIR QUALITY				
AQ-1. Generation of Construction Emissions in Excess of Local Air District Thresholds	1, 2, 3, 4, 5	Potentially significant	AQ-MM-1: Apply Applicable Air District Mitigation Measures to Reduce Construction Emissions below the District Thresholds	Less than significant
AQ-2. Generation of Operational Emissions in Excess of Local Air District Thresholds	1, 2, 3, 4, 5	Potentially significant	AQ-MM-2: Apply Applicable Air District Mitigation Measures to Reduce Operational Emissions below the District Thresholds	Less than significant

Impact	Applicable Alternative	Significance before Mitigation	Mitigation Measures	Significance after Mitigation
AQ-3. Elevated Health Risks from Exposure of Nearby Sensitive Receptors to TACs/HAPs	1, 2, 3, 4, 5	Potentially significant	AQ-MM-1: Apply Applicable Air District Mitigation Measures to Reduce Construction Emissions below the District Thresholds AQ-MM-2: Apply Applicable Air District Mitigation Measures to Reduce Operational Emissions below the District Thresholds AQ-MM-3: Apply Applicable Air District Mitigation Measures to Reduce TAC/HAP Emissions	Less than significant
CLIMATE CHANGE				
CC-1. Generation of Greenhouse Gas Emissions Resulting in Global Climate Change	1, 2, 3, 4, 5	Less than significant	No mitigation is required. CC-MM-1: Apply Applicable Air District Mitigation Measures to Reduce Construction and Operational GHG Emissions (recommended) CC-MM-2: Apply Applicable California Attorney General Mitigation Measures to Reduce Construction and Operational GHG Emissions (recommended)	–
VEGETATION AND WILDLIFE				
BIO-1. Loss of Downstream Habitat from Reduced Field Runoff	1, 2, 3, 4, 5	Potentially significant	BIO-MM-2: Determine Extent of Wetland Loss and Compensate for Permanent Loss of Wetlands	Less than significant
BIO-2. Improved Water Quality in Natural Communities Adjacent to Agricultural Lands and Managed Wetlands	1, 2, 3, 4, 5	Beneficial	No mitigation is required.	–
BIO-3. Potential Loss of Sensitive Natural Communities and Special-Status Plants from Construction Activities	1, 2, 3, 4, 5	Potentially significant	BIO-MM-1: Avoid and Minimize Impacts on Sensitive Biological Resources	Less than significant
BIO-4. Potential Loss of Wetland Communities due to Loss of Existing Sedimentation Ponds	2, 3, 4, 5	Potentially significant	BIO-MM-2: Determine Extent of Wetland Loss and Compensate for Permanent Loss of Wetlands	Less than significant
BIO-5. Impacts to Special-Status Wildlife Species due to Loss of Existing Sedimentation Ponds	2, 3, 4, 5	Potentially significant	BIO-MM-1: Avoid and Minimize Impacts on Sensitive Biological Resources	Less than significant
BIO-6. Loss of Sensitive Natural Communities and Special-Status Plants from Construction Activities and Installation of Groundwater Monitoring Wells	5	Potentially significant	BIO-MM-1: Avoid and Minimize Impacts on Sensitive Biological Resources	Less than significant

Impact	Applicable Alternative	Significance before Mitigation	Mitigation Measures	Significance after Mitigation
BIO-7. Loss of Special-Status Wildlife from Construction Activities and Installation of Groundwater Monitoring Wells	5	Potentially significant	BIO-MM-1: Avoid and Minimize Impacts on Sensitive Biological Resources	Less than significant
FISHERIES				
FISH-1. Improvement to Surface Water Quality in Water Bodies Receiving Inputs from Agricultural Lands and Managed Wetlands	1, 2, 3, 4, 5	Beneficial	No mitigation is required.	–
FISH-2. Temporary Loss or Alteration of Fish Habitat during Construction of Facilities for Management Practices	1, 2, 3, 4, 5	Potentially significant	FISH-MM-1: Avoid and Minimize Impacts to Fish and Fish Habitat	Less than significant
FISH-3. Permanent Loss or Alteration of Fish Habitat during Construction of Facilities for Management Practices	1, 2, 3, 4, 5	Potentially significant	FISH-MM-2: Educate Growers on the Use of Polyacrylamides for Sediment Control	Less than significant
FISH-4. Toxicity to Fish or Fish Prey from Particle-Coagulant Water Additives	1, 2, 3, 4, 5	Potentially significant	FISH-MM-2: Educate Growers on the Use of Polyacrylamides for Sediment Control	Less than significant
FISH-5. Temporary Loss or Alteration of Fish Habitat during Wellhead Protection Construction Required by Groundwater Quality Management Plans	2, 3, 4, 5	Less than significant	No mitigation is required.	–
FISH-6. Temporary Loss or Alteration of Fish Habitat during Construction of Facilities for Management Practices and Groundwater Monitoring Wells	5	Potentially significant	FISH-MM-1: Avoid and Minimize Impacts to Fish and Fish Habitat	Less than significant
FISH-7. Permanent Loss or Alteration of Fish Habitat during Construction of Facilities for Management Practices and Groundwater Monitoring Wells	5	Potentially significant	FISH-MM-1: Avoid and Minimize Impacts to Fish and Fish Habitat	Less than significant
HYDROLOGY AND WATER QUALITY				

SWQ = surface water quality
HWQ = groundwater quality

Impact	Applicable Alternative	Significance before Mitigation	Mitigation Measures	Significance after Mitigation
HYD-1. Change in Quality of State Waters from Agricultural Discharge or Alteration of Hydrologic Patterns of Runoff or Infiltration	1	SWQ: Beneficial GWQ: Potentially significant	SWQ: No mitigation is required. GWQ: Mitigation Measure HYD-MM-1: Develop and Implement a Groundwater Quality Management Plan	SWQ: – GWQ: Less than significant
HYD-1. Change in Quality of State Waters from Agricultural Discharge or Alteration of Hydrologic Patterns of Runoff or Infiltration	2, 3, 4, 5	Beneficial	No mitigation is required.	–
AGRICULTURE RESOURCES				
AG-1. Conversion of Prime Farmland, Unique Farmland, and Farmland of Statewide Importance to Nonagricultural Use	1, 2, 3, 4, 5	Significant	AG-MM-1: Assist the Agricultural Community in Identifying Sources of Financial Assistance That Would Allow Growers to Keep Important Farmland in Production	Significant and unavoidable

NOVEMBER 2003

FINAL

Storm Water Monitoring &
Data Management

Discharge Characterization Study Report

CTSW-RT-03-065.51.42

California Department of Transportation

Caltrans

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Appendices

Executive Summary

The California Department of Transportation ("the Department", or "Caltrans") has completed a comprehensive set of studies designed to characterize stormwater runoff from transportation facilities throughout the state of California. This report includes an overview of the Department's stormwater characterization activities; descriptions of the methods used to produce and evaluate the data; the results of the characterization monitoring and data analysis; and conclusions pertinent to management of stormwater runoff from transportation facilities.

OVERVIEW

Since 1998, the California Department of Transportation has conducted monitoring of runoff from representative transportation facilities throughout California. The key objectives of this characterization monitoring include:

1. Achieve compliance with NPDES Permit requirements;
2. Produce data that are scientifically credible and representative of runoff from the Department's facilities;
3. Provide information that can be useful to the Department in designing effective stormwater management strategies.

In May, 1999, the Department was issued its first statewide NPDES stormwater permit. In response to the requirements of this new permit, the Department initiated in 2000 a three-year Statewide Characterization Study. This comprehensive study was designed to systematically characterize representative sites for each of the Department's major transportation facility types.

In addition to runoff quality monitoring, the Department also implemented monitoring programs to characterize runoff sediment/particle quality, as well as litter studies and runoff toxicity studies. These additional studies are not covered by the current report.

The characterization monitoring data presented in this report include both the results of the three-year statewide study, and the results of other studies conducted prior to or in parallel with the statewide study. In all, over 60,000 data points from over 180 monitoring sites were included in the presentation of monitoring results.

The report includes an in-depth statistical analysis of the factors affecting the quality of runoff from transportation facilities. This statistical analysis is focused on the data from the three-year statewide study, as that data set was designed to be representative of transportation facilities throughout the state, and the data collection was performed using consistent monitoring protocols and data management procedures.

METHODS

To provide for consistent, standardized stormwater data collection and reporting, the Department developed a comprehensive set of monitoring protocols and data management tools. These protocols and tools were designed to ensure the scientific validity and representativeness of the data produced by the Department's monitoring programs. The standard protocols are supported and enforced by a comprehensive data management and quality control program implemented by the Department. Together, these measures enhance the value and usefulness of the Department's monitoring programs, and ensure effective use of taxpayer funds.

The Department's monitoring studies have provided broad geographic coverage throughout the State of California (see Figure 1). Facilities monitored by the Department as part of its discharge characterization activities include:

- Highways
- Maintenance stations
- Park and ride lots
- Rest areas
- Toll plazas
- Weigh stations

In addition to the monitoring conducted at representative, fully operational facilities, additional monitoring and special studies were conducted to address specific issues. For example, highway sites in the Tahoe Basin were monitored for snowmelt runoff quality and for rainfall and snowfall precipitation characteristics, in addition to rainfall runoff. Other specialized studies included microbiological (pathogen indicator) studies, construction site runoff studies, and an in-depth, "first flush" highway runoff study.

The standard list of water quality constituents monitored in the Department's runoff characterization studies includes:

- conventional parameters (pH, temperature, TSS, TDS, conductivity, hardness, TOC, and DOC),
- nutrients (nitrate, TKN, orthophosphate-P, and total P), and
- total and dissolved metals (As, Cd, Cr, Cu, Pb, Ni, and Zn).

Oil and grease and selected herbicides were also included for a subset of specific sites. Other constituents were included in earlier (pre-2000) characterization studies, including selected pesticides and other organic compounds, iron, turbidity, and total and fecal coliform.

The scientifically-valid data gained from the Department's runoff characterization activities may be used to design and evaluate existing and potential new BMPs. The information presented in this report also may be used to assist the Department in assessing the effectiveness of the current stormwater management program, and to provide a foundation for long-term management decision-making.

SUMMARY OF FINDINGS

The major findings of this study are summarized below.

Characterization of Runoff Quality

The quality of stormwater runoff was characterized for each transportation facility type through calculation of summary statistics and data distribution parameters. Statistics were calculated using methods appropriate for data sets that include values below detection ("non-detect data"). The data presented in this report are considered to adequately characterize the quality of runoff from the edge of pavement for highways and other transportation facilities operated by the California Department of Transportation.

Relationships Between Runoff Quality and Other Factors

Multiple Linear Regression (MLR) analysis was employed to assess the factors that influence the quality of runoff from transportation facilities. The results indicated that several environmental and site-specific factors have a significant influence on runoff pollutant concentrations. The effects of AADT, total event rainfall, seasonal cumulative rainfall, and antecedent dry period were statistically significant for nearly all of the constituents evaluated, and were very consistent across pollutant categories. The specific effects of the factors evaluated can be summarized as follows:

- Pollutant concentrations in stormwater runoff increase with higher traffic levels. Sites with higher *AADT* have higher concentrations of nearly every pollutant evaluated.
- As *Cumulative Seasonal Precipitation* increases, pollutant concentrations decrease. This is evidence of pollutant "wash-off" during the wet season, as pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. This effect was consistent for all pollutant categories and constituents.
- Longer *Antecedent Dry Periods* result in higher pollutant concentrations in runoff. This factor provides a measure of the "buildup" of pollutants during dry periods between storms.
- As *Total Event Rainfall* increases, pollutant concentrations tend to decrease; *i.e.*, runoff from larger storms tends to be diluted. This phenomenon is consistent with the interpretation that concentrations tend to be highest in the initial portion of the runoff and are diluted as the storm event continues (i.e., it is consistent with a storm event "first flush" effect).
- *Maximum Rainfall Intensity* was highly correlated with *Event Rainfall* and generally had a similar effect, but was less consistent and significant for fewer constituents.
- Larger *Drainage Areas* tended to result in lower concentrations of a few pollutants for highways, but this effect was not consistent for pollutants at other (non-highway) facilities.

- *Impervious Fraction of the Drainage Area* did not have a consistent effect on pollutant concentrations. Higher imperviousness tended to increase concentrations of some pollutants and decrease others. *Impervious Fraction* had the weakest effect of all the factors evaluated.

Event and Seasonal "First Flush" Effects

The results provide conclusive evidence of both intra-event and seasonal "first flush" effects for conventional parameters, trace metals, and nutrients. The first flush effect results in higher concentrations of pollutants in runoff from the initial phases of a storm and during the early part of the storm season.

In California the lengthy dry season leads to an annual build-up of pollutants on surfaces (such as highways), as evidenced by the positive correlation between runoff pollutant concentrations and antecedent dry period. As the wet season progresses, pollutants are progressively washed off, as evidenced by the negative correlation between cumulative seasonal rainfall and runoff pollutant concentrations. Together these phenomena produce what is known as a "seasonal first flush" effect.

The "event first flush" effect recapitulates the build-up/wash-off phenomena on an event basis, as pollutant concentrations tend to be higher in the earlier stages of rainfall/runoff events. Inferential evidence for this effect is provided by the negative correlation between event rainfall and runoff pollutant concentrations. This finding is corroborated by the preliminary results of a Caltrans "First Flush Characterization Study" designed specifically to answer this question.

Comparisons of Runoff from Different Facility Types

Pollutant concentrations were generally highest in runoff from facilities with higher vehicle traffic. Pollutant concentrations in runoff from lower-traffic facilities (maintenance facilities, park-and-ride lots, vehicle inspection facilities, and rest areas) were generally similar to each other and lower than runoff from highways and toll plazas. This pattern was consistent across the categories of conventional constituents, trace metals, and nutrients. The results for facility types confirm the importance of AADT as a predictor of pollutant concentrations in runoff.

Effect of Local Land Use on Runoff Quality

Pollutant concentrations were generally higher in highway runoff from predominantly agricultural and commercial areas. Pollutant concentrations in highway runoff from residential areas, transportation corridors, and open land use areas were generally similar to each other, and lower than agricultural and commercial land uses. These differences were generally consistent for conventional pollutants, trace metals, and nutrients.

Effect of Geographic Regions on Runoff Quality

Although there were some significant differences, geographic region does not appear to have a consistent, predictable effect on runoff quality, and there was no consistent pattern in the runoff quality from different geographic regions. In general, regions with pollutant concentrations that were significantly higher than average or lower than average tended to be represented by relatively few sites with high or low AADT respectively. These results appear to be more reflective of the effect of AADT on runoff quality than a consistent effect of geographic region.

Trends and Annual Variability

Although there was significant annual variability in runoff quality for most constituents and facilities, there were no consistent patterns or trends in the data over the several years studied. Annual variability typically accounted for less than 10% of the overall variability in runoff quality.

Comparisons with Water Quality Objectives

For the purpose of prioritizing constituents for future pilot monitoring, runoff quality data were compared to California Toxics Rule (CTR) objectives (USEPA 2000) and other receiving water quality objectives considered potentially relevant to stormwater runoff quality. A few parameters exceeded these objectives in a majority of runoff samples. It should be noted that the receiving water quality objectives cited are not intended to apply directly to stormwater runoff discharges, and are used here only in the context of establishing priorities for monitoring. It should also be noted that many constituents monitored do not have relevant water quality objectives. The most notable results of comparisons with the most stringent CTR and other relevant water quality objectives are summarized below.

- Copper, lead, and zinc were estimated to exceed the California Toxics Rule (CTR) objectives for dissolved and total fractions in greater than 50% of samples.
- Based on a relatively small number of samples, diazinon was estimated to exceed the California Department of Fish and Game (CDFG) recommended chronic criterion in 79% of stormwater runoff samples, and chlorpyrifos was estimated to exceed the CDFG recommended chronic criterion in 73% of samples. Neither of these pesticides are routinely applied by the Department to highways or other transportation facilities.

Correlations Between Constituents

Correlations between runoff quality parameters were evaluated to identify relationships that are strong enough for one constituent to serve as a monitoring surrogate for another. Significant correlations were considered to support reduction of the list of standard monitoring constituents.

Correlations were generally strongest within pollutant categories, with few strong correlations between constituents in different categories. Within the conventional parameters, the strongest correlations were observed among parameters associated with dissolved minerals (EC, TDS, and chloride), organic carbon (TOC and DOC), and suspended particulate materials (TSS and turbidity). Within the metals category, total concentrations of most metals were highly correlated, but correlations between total and dissolved concentrations were generally lower, even between total and dissolved concentrations of the same metals. Total petroleum hydrocarbons were generally poorly correlated with all other parameters, but did exhibit a strong correlation between the diesel and heavy oil fractions. Nutrients were generally not strongly correlated within the nutrient category or with other categories (with the odd exception of ammonia and dissolved aluminum). Total and fecal coliform bacteria exhibited no significant correlations within or outside the microbiological category.

Monitoring Constituents

As a means of determining the relative importance of specific constituents for continued monitoring, a multi-tiered approach was used to evaluate the Department's stormwater runoff quality data. The constituents monitored were evaluated with respect to frequency of detection and identification of a transportation-related source for the constituent, as well as comparisons to water quality objectives and correlation with other measured parameters, as summarized above.

The following constituents remain high priorities for monitoring, due to their relatively high levels in runoff and their ongoing usefulness in runoff characterization:

- Copper, lead, and zinc
- Aluminum and iron
- Electrical conductivity, TOC, TSS, pH and temperature

The following constituents receive lower priorities for continued monitoring, due to their relatively low concentrations in runoff, their correlations with other parameters, or the lack of an obvious transportation-related source:

- Arsenic, cadmium, chromium, and nickel
- TDS, ammonia, and nitrite
- Diazinon and chlorpyrifos
- Nitrate, TKN, total phosphorous, and dissolved ortho-phosphate
- Semi-volatile organic compounds, including PAHs
- Pathogen indicator bacteria

Percentage of Metals in the Particulate Fraction

A large proportion of the concentrations of most metals are bound to particulate matter in runoff. Based on data from the Statewide Study for metals with data available for both dissolved and total analyses, lead is present in the highest proportion as particulates (86% on average). Cadmium, chromium, and zinc average between 60-70% in the particulate fraction, and arsenic, copper and nickel average between 50-55% as particulates.

CONCLUSIONS

The extensive monitoring performed by the Department over the past several years, and particularly the recently-completed, three-year Statewide Characterization Study, have provided sufficient data with which to characterize the quality of runoff from Caltrans facilities throughout the State of California, in accordance with the approved Characterization Monitoring Plan (Caltrans, 2002, CTSW-RT-02-004).

The primary environmental factors affecting the quality of edge-of-pavement runoff have been identified and quantified, and major patterns of temporal variability (seasonal and intra-storm) have been characterized. The monitoring conducted to date has focused on runoff from paved surfaces.

AADT is the most important site characteristic in predicting highway runoff quality. Although facility type, geographic region and contributing land use were determined to have some statistically significant effects on runoff quality, these effects are less consistent than AADT.

Pollutant build-up and wash-off are evident in the statistical analysis of the highway runoff quality data, providing support for the concepts of seasonal and event first flush effects.

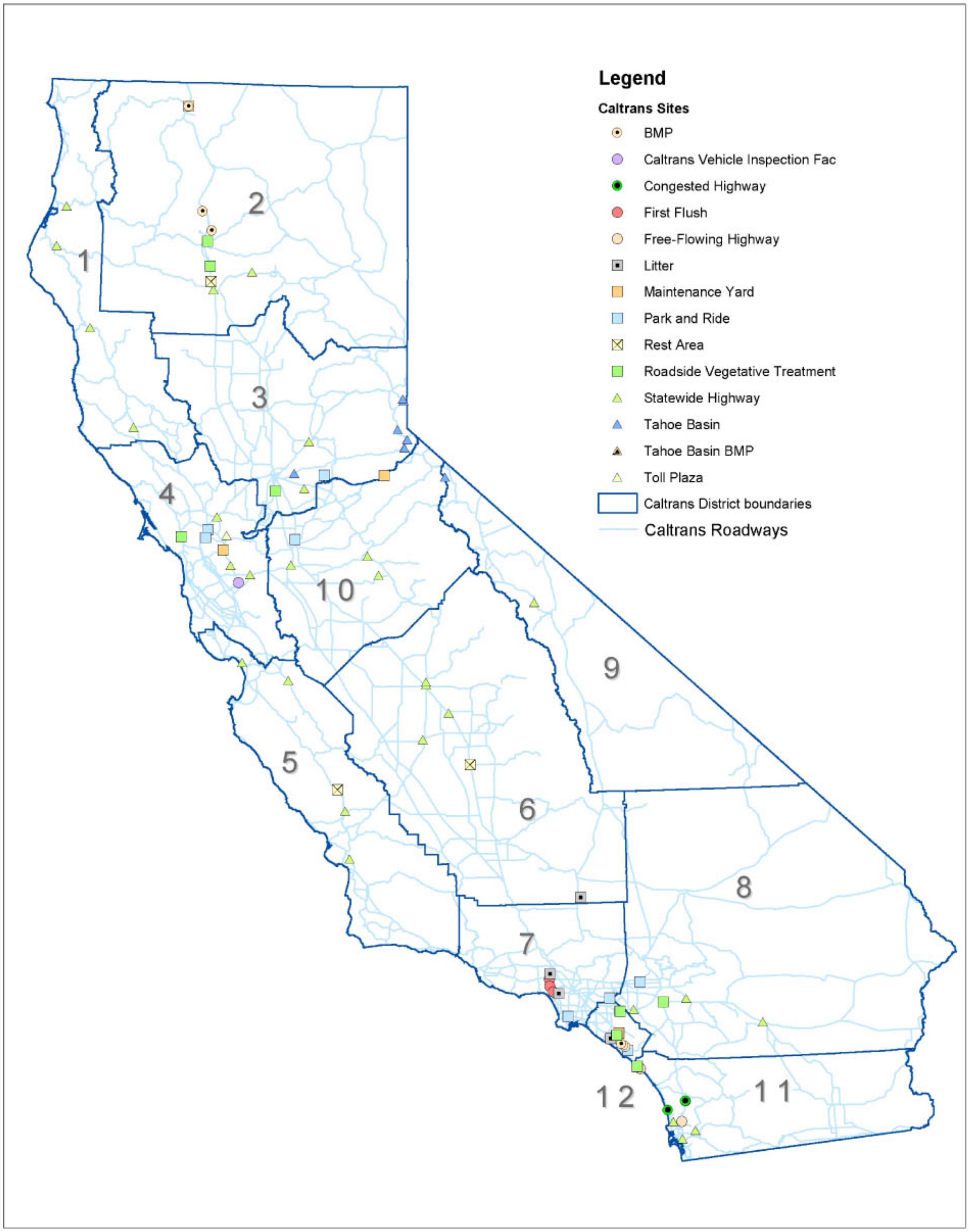

Figure 1 Stormwater Monitoring Sites

SECTION 1 INTRODUCTION

The California Department of Transportation (the Department, or Caltrans) has completed a comprehensive study designed to characterize stormwater discharges from transportation facilities throughout the state of California. This report includes a presentation of the methods used to produce and analyze the data, the results of the various monitoring and research studies, and the conclusions derived from those studies.

CALTRANS STORMWATER CHARACTERIZATION

The California Department of Transportation has taken a multi-faceted approach to stormwater quality monitoring. This approach results in data that can be placed into four categories, encompassing a wide range of stormwater quality issues: Runoff Water Quality, Litter Characterization, Sediment/Particle Quality, and Toxicity Studies (Figure 1-1). This comprehensive approach to stormwater runoff monitoring is further described in "Improving Stormwater Monitoring" (Ruby and Kayhanian 2003). The Department's characterization monitoring studies have been specified annually in the *Characterization Monitoring Plan* (Caltrans, 2002; CTSW-RT-02-004).

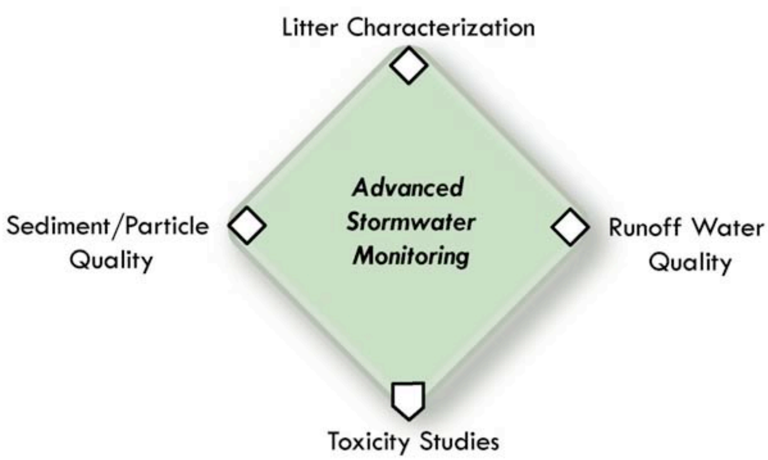

Figure 1-1 Covering the Bases: the Department's Multi-Faceted Approach To Stormwater Quality Monitoring.

Since 1998, the California Department of Transportation has conducted monitoring of runoff from representative transportation facilities throughout California. The key objectives of this characterization monitoring include:

1. Achieve compliance with NPDES Permit requirements;
2. Produce data that are scientifically credible and representative of runoff from the Department’s facilities, and can be used to define future monitoring needs;
3. Provide information that can be useful to the Department in designing effective stormwater management strategies.

In May, 1999, the Department was issued its first statewide NPDES stormwater permit. In response to the requirements of this new permit, the Department initiated in 2000 a Statewide Stormwater Runoff Characterization Study. This comprehensive study was designed to systematically characterize, through collection and analysis of representative samples, the quality of stormwater runoff from specific types of transportation facilities. The sites monitored for the Statewide Study were selected to provide representative characterization of the Department’s facilities throughout California. Furthermore, this study was conducted to generate sufficient water quality data to satisfy NPDES permit requirements, support research and development needs, provide inputs for load assessment and modeling efforts, provide useful information for watershed planning, and allow for scientifically-sound statistical data quantification.

The data presented and evaluated in this report were gathered principally from The *Caltrans Statewide Stormwater Runoff Characterization Study* (Caltrans, 2003a; CTSW-RT-03-052) . For purposes of general statistical characterization, data from other Department monitoring efforts were also included where appropriate. Stormwater runoff was monitored from over 50 sites in the Statewide Study, representing six different types of facilities: highways, maintenance stations, park and ride lots, rest areas, toll plazas, and vehicle inspection facilities. The study was designed to produce representative data for each facility type nominally over a three-year period, during several storm events annually. The three-year study commenced during the 2000-01 wet season, and was concluded at the end of the 2002-03 wet season (Caltrans, 2003a; CTSW-RT-03-052).

The statewide distribution of monitoring sites covered by this report is illustrated in Figure 1-2.

Monitoring Approach

Data were collected for the statewide characterization study and additional, specialized studies throughout California’s geographic and climatic regions, under wide ranges of weather and traffic conditions. Figure 1-3 depicts typical monitoring sites across the state.

Flow can vary significantly throughout a runoff event, and runoff quality is known to vary as well (Stenstrom *et al*. 2001). Flow-proportioned composite samples are therefore considered to be the most representative sampling regimen for runoff monitoring (Kayhanian, 2002). Department monitoring projects generally employ automated monitoring equipment to collect an equal-volume sample (aliquot) for every increment of a pre-set runoff flow volume. Automatic monitoring equipment was used to ensure representative and accurate collection of samples and data (see Section 2 for more detail), including information on flow and rainfall (see photo, Figure 1-4).

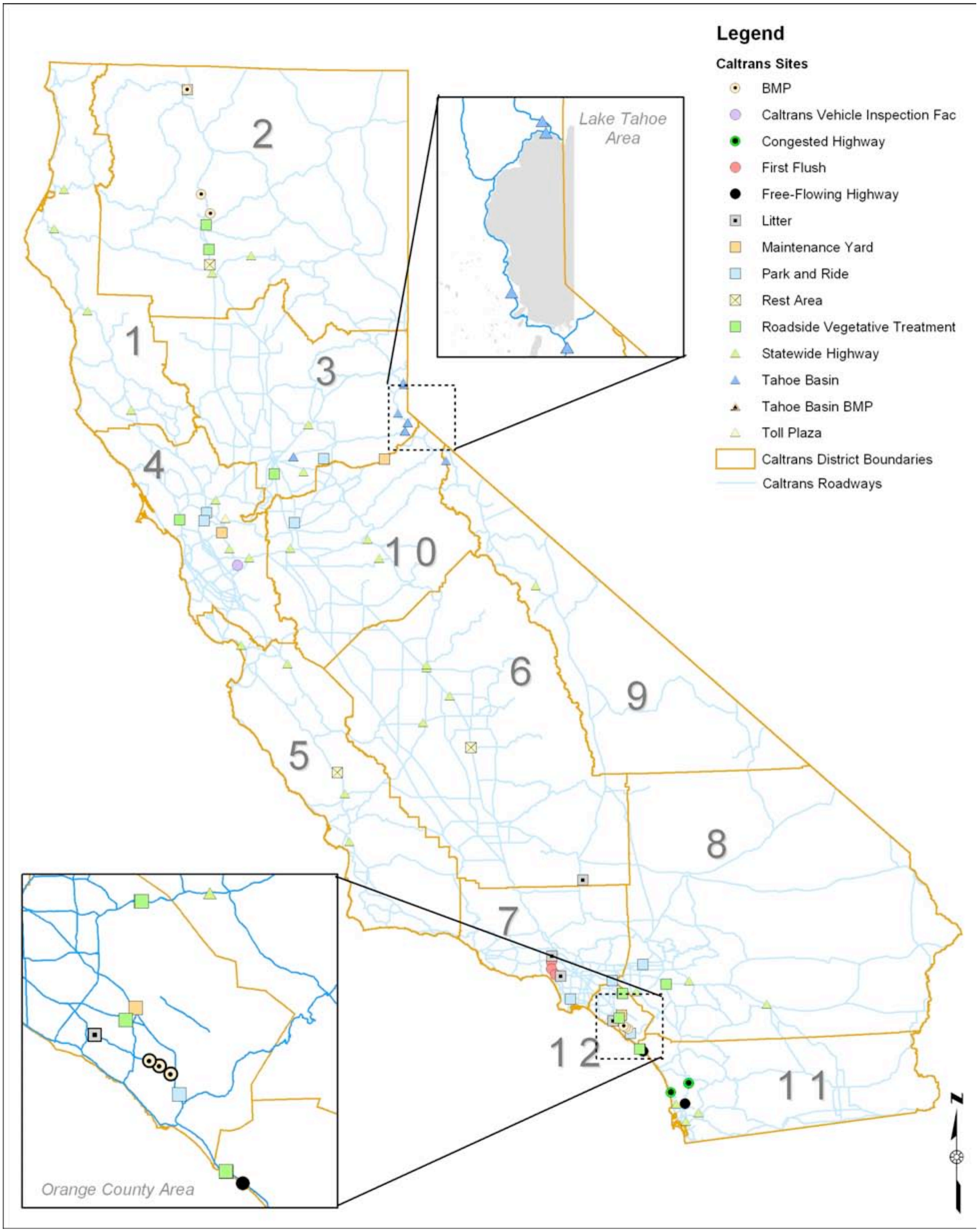

Figure 1-2 Caltrans Monitoring Sites

(a) North Coast Region, District 1

(b) Lake Tahoe, District 3

(c) Orange County Region, District 12

(d) Mojave Desert, District 8

Figure 1-3 (a)-(d). Typical monitoring facilities used in the statewide stormwater runoff characterization study

Figure 1-4 Typical monitoring equipment scenario at enclosed automated monitoring station. Shown are autosampler unit (lower right) and automatic flow meter (top left).

Comprehensive Program Management and Quality Control

To ensure that the Department's monitoring programs produce credible, verifiable and useful data, the Department has developed a comprehensive set of protocols and tools for stormwater monitoring and data management, which are believed to be unique in the field. These include:

- A set of ***planning documents*** that lay out the projects and their objectives;
- A set of detailed ***monitoring protocols guidance manuals***, covering:
  - Water quality (runoff) monitoring,
  - Sediment/particle monitoring,
  - Litter monitoring,
  - Runoff toxicity studies;
- A complete set of ***data reporting protocols*** for the above data categories to ensure consistency in data formatting;
- A comprehensive ***quality assurance/quality control system***;
- Laboratory ***data validation and error checker software***;
- A ***hydrologic software utility*** that converts rainfall, runoff flow, and sampling data into graphical and tabular summaries depicting sample timing and completeness, allowing assessment of compliance with the Department's criteria for composite sample representativeness;
- A ***relational database*** with a user-friendly, geo-referenced interface and menu-driven querying (Figure 1-5); and
- A ***data analysis software tool*** that allows rapid production of summary statistics for selected data sets and includes statistically-based handling of non-detect data (Figure 1-6).

This set of tools and protocols provides monitoring personnel with the means to plan and implement sound monitoring programs, and to verify and interpret the monitoring data. The data may then be used to help improve stormwater management at transportation facilities throughout California.

The software tools developed for the Department's monitoring programs are assembled in an "Electronic Tool Kit" (Caltrans, 2003b; CTSW-OT-02-002).

The monitoring protocols and data reporting protocols developed for the Department's various stormwater monitoring activities are compiled together in the *Comprehensive Guidance Manual for Stormwater Monitoring* (Caltrans. 2003c; CTSW-RT-03-055.36.19).

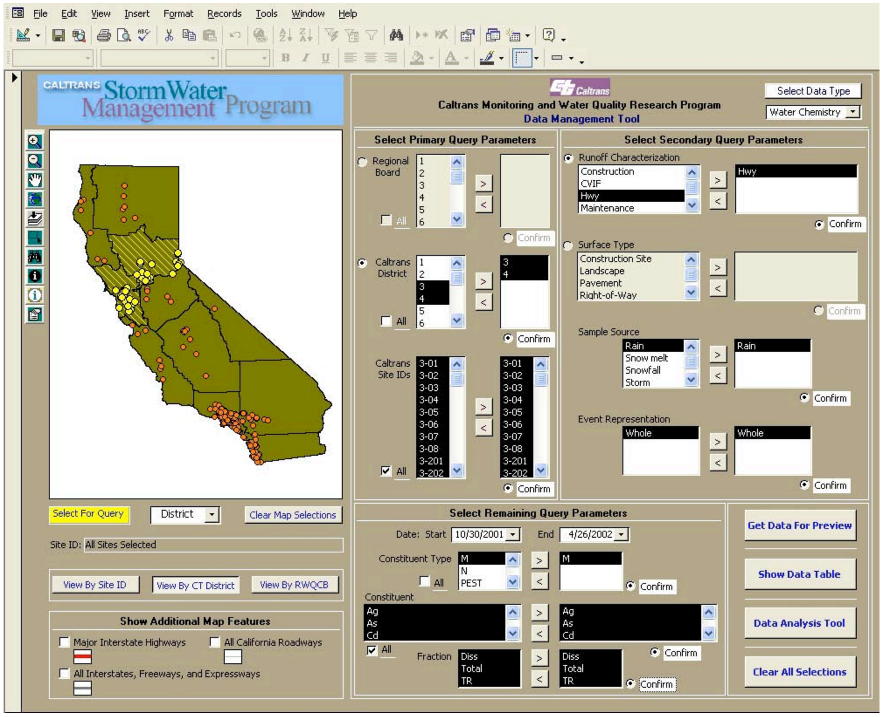

Figure 1-5 Example Screen Shot from Data Management Tool User Interface

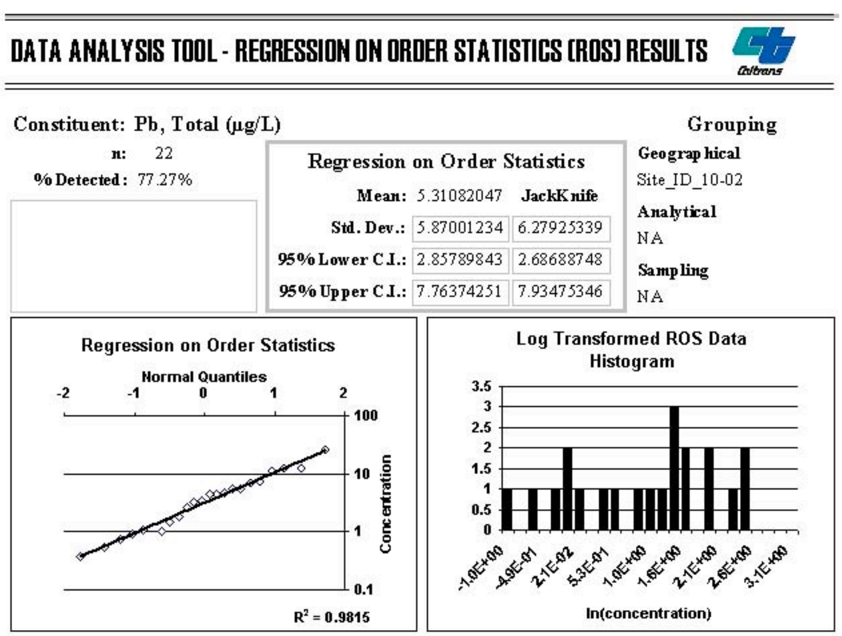

Figure 1-6 Example of Data Analysis Tool Output

CHARACTERIZATION STUDY REPORT OBJECTIVES

This report is designed to address the following objectives, using data generated from the three-year Statewide Stormwater Runoff Characterization Study:

- Quantify the distributional and statistical characteristics of runoff from the different Department facilities.
- Identify relationships between runoff quality and average annual daily traffic (AADT), drainage area, precipitation factors, and antecedent conditions.
- Update Multiple Linear Regression models of stormwater runoff quality produced previously (Kayhanian *et al*., 2003) using Statewide Study data.
- Identify significant differences in runoff quality from different facility types or from different predominant contributing land uses.
- Determine whether there are significant differences in runoff quality from different geographic regions.
- Determine whether there are significant trends or annual variation in runoff quality.
- Determine whether there are significant seasonal patterns in runoff quality (i.e., a seasonal "first flush" effect).
- Determine whether there are within-storm patterns in runoff quality. Specifically, determine if an intra-event "first flush" effect exists.
- Identify relationships (correlations) between runoff quality parameters. Determine if such relationships can be used to reduce the number of parameters monitored.
- Compare runoff quality to the water quality objectives within the California Toxics Rule and other relevant regulations to prioritize parameters selected for BMP management.

REPORT ORGANIZATION

This report includes:

- an overview of the Department's stormwater monitoring and research program and the objectives of the characterization study report (Section 1);
- descriptions of the methods used to produce and evaluate the characterization monitoring data (Section 2);
- the results of the characterization monitoring and data analysis (Section 3);
- discussion of the results (Section 4); and
- conclusions (Section 5).

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SECTION 2 METHODS

DATA COLLECTION

Data Collection for Stormwater Characterization

Sample Collection

To ensure that the data produced by the Department's various monitoring projects use consistent methods, produce scientifically valid data, and are cost-effective, the Department produced the *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005). The monitoring data presented in this report were produced according to the methods specified in this manuals.

Automated Composite Sampling

Because flow and pollutant concentrations vary throughout runoff events, the Department uses automated monitoring equipment to collect flow-proportioned composite samples. The key elements of the Department's standard automated set-up include an automated composite sampler, flow meter, rain gauge, and programmable data logger/controller. The runoff volume increment is set in advance based on the quantity of precipitation forecast, so that an adequate number of aliquots will be collected to provide sufficient composite sample volume for all planned analyses. The composite sample then represents the full event hydrograph – and accounts for variation in flow and/or runoff quality throughout event. See Figure 2-1 for a schematic representation of the typical monitoring set-up.

Clean Sampling Techniques

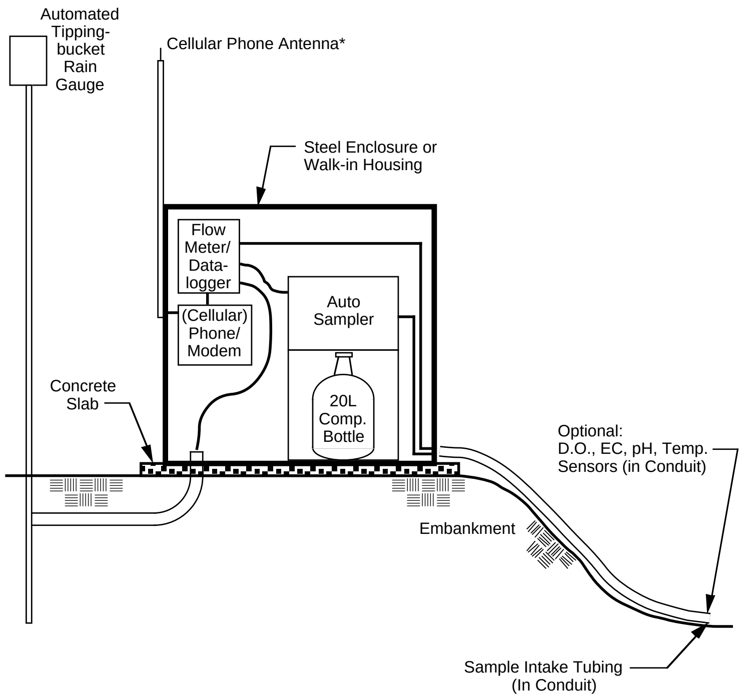
To provide superior quantification for analytical data, the Department's monitoring programs require low-level analytical reporting limits (see Table 2-1) in accordance with the Monitoring Protocols Guidance Manual. In turn, clean sample handling techniques are required to reduce the possibilities of sample contamination. The *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005) contains specific sampling instructions for clean sample handling methods to minimize sample contamination.

Constituents Monitored

Monitoring for the aforementioned studies was conducted in accordance with the *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005). Table 2-1 presents the minimum list of constituents used for the Department's stormwater monitoring projects by pollutant category.

Quality Assurance/Quality Control

The Department's monitoring projects include a comprehensive QA/QC program to ensure that sample contamination is minimized, and to provide data with recordable accuracy and precision. Within each Sampling and Analysis Plan, there is a schedule for the monitoring year listing the events and locations for collection of field blanks, field duplicates, laboratory duplicates, and matrix spike samples.



*Cellular phone module and antenna not needed if land line is available.

Note: 12 volt deep cycle marine batteries (with optional solar charging system) are required if AC power is not available.

Figure 2-1 Schematic representation of the typical monitoring set-up

Table 2-1 Water Quality Parameters Monitored in Stormwater Runoff, 1997 – 2003: Minimum Constituent List for Characterization (1)

Constituent	Units	Reporting Limit
Conventional Pollutants		
Conductivity	mmhos/cm	1 (2)
Hardness as $CaCO_3$	mg/L	2
pH	pH Units	± 0.1(2)
Temperature	°C +/-	± 0.1(2)
Total Dissolved Solids	mg/L	1
Total Suspended Solids	mg/L	1
Dissolved Organic Carbon (DOC)	mg/L	1
Total Organic Carbon	mg/L	1
Nutrients		
Nitrate as Nitrogen (NO_3-N)	mg/L	0.1
Total Kjeldahl Nitrogen (TKN)	mg/L	0.1
Total Phosphorous	mg/L	0.03
Dissolved Ortho-Phosphate	mg/L	0.03
Metals (total recoverable and dissolved)		
Arsenic	µg/L	1
Cadmium	µg/L	0.2
Chromium	µg/L	1
Copper	µg/L	1
Lead	µg/L	1
Nickel	µg/L	2
Zinc	µg/L	5
Herbicides (3)		
Diuron	µg/L	1
Glyphosate	µg/L	5
Oryzalin	µg/L	1
Oxadiazon	µg/L	0.05
Triclopyr	µg/L	0.1

(1) For analytical methods and other specifications, see Reference appropriate Caltrans document(s).

(2) Report to +/- 0.1 of the nearest standard measurement unit

(3)Analysis for the listed herbicides performed for Caltrans statewide characterization monitoring only.

Composite Sample Representativeness

Two measures are used in the Department's Stormwater Monitoring and Research Program to determine whether a composite sample is adequately representative of the runoff event from which it was collected. Each composite sample consists of a number of individual sample aliquots collected on a flow-proportioned basis throughout the runoff event; the aliquots are then mixed to form a composite sample that can be analyzed by the laboratory. The Department specifies a minimum number of sample aliquots that must be collected for the event, based on the overall rainfall amount. The Department also specifies a minimum "percent capture" for each event, which is essentially defined as the percentage of total event runoff flow during which composite sample collection occurred. These measures are evaluated upon completion of the monitoring event, and a decision on the acceptability of the composite sample representativeness is made prior to laboratory analysis of the samples. The Caltrans Hydrologic Utility (Caltrans, 2003b, CT-OT-02-002; also see description in Ruby and Kayhanian, 2003) is a software tool used by monitoring personnel to assess composite sample representativeness according to the prescribed criteria. This software utility is used to convert flow and sample aliquot data into usable information, and allow assessment of sampling representativeness on site.

Data Management and Validation

The Department's monitoring programs include a comprehensive data management and validation process (including QA/QC evaluation) that is an essential element in providing accurate, reliable, and representative data.

In addition to the Monitoring Protocols Guidance Manual, The Department has established a specific set of Data Reporting Protocols. These data reporting protocols provide detailed specifications for data fields and instructions for content. The protocols help ensure that data from all projects will be reported in consistent format – and that the data records will include sufficient information to permit their full use within the Department's Stormwater Database.

A thorough data quality evaluation is performed following receipt of the laboratory data, in which the results of QA/QC sample analyses are compared to the project's data quality objectives, and suspect data are qualified (flagged) as necessary, following guidelines established by the United States Environmental Protection Agency (EPA) for evaluation of inorganic and organic analyses.

The Department's Automated Data Validation (ADV) software (Amano *et al.*, 2001) is used to enhance the evaluation of the data. This automated program permits quick and efficient evaluation of lab data against data quality objectives and standard measures of data quality, and provides extensive error checking for a standard set of possible analytical or data transcription errors. The resulting electronic data deliverable (EDD) is then ready for final checking prior to entry into the Department's stormwater quality database.

The Hydrologic Utility also serves to standardize calculation of important storm and sampling parameters, such as total flow volume, total event rain, estimated percent capture, and others. In addition, the utility generates a hydrograph and a hyetograph in a standardized format from measured hydrologic data.

The final data validation step involves checking that the electronic data deliverable (EDD) conforms to the Department's Data Reporting Protocols for the specific data type; corrections are made as necessary to provide information for any missing or improperly populated data fields.

Characteristics of the Data Set

Table 2-2 provides an overview of the site characteristics of the data set, including the number of sites and monitoring events by facility type, as well as the range of AADT and catchment area sizes represented.

For the Statewide Runoff Characterization Study, representative sites were selected for each facility type and geographic area, according to pre-specified criteria. Refer to the *Caltrans Statewide Stormwater Runoff Characterization Study* report (Caltrans, 2003; CTSW-RT-03-052) for site selection methods.

An effort was made also to provide representative monitoring during the full range of hydrologic and antecedent conditions typically experienced within the various Caltrans Districts. Table 2-3 provides a summary of the monitoring event characteristics from 1997-2003.

Table 2-2 Summary of Site Characteristics and Events Monitored, 1997 – 2003 Monitoring Programs

			Annual Average Daily Traffic		Catchment Area, hectares	
CalTrans Facility Type	**Number of sites**	**Events Monitored**	**Min**	**Max**	**Min**	**Max**
Construction	21	118	NA	NA	0.04	8.5
Caltrans Vehicle Inspection Facility (CVIF)	2	32	2775	3503	0.97	1.68
Erosion	9	24	48000	13500	0.04	1.17
Highway (Statewide Characterization)	39	684	1800	259000	0.08	5.94
Highway (all other projects)	76	1157	3000	328000	0.03	17.32
Maintenance	17	NA	NA	251000	0.1	5.46
Parking	13	NA	NA	107000	0.06	1.13
Rest Area	3	NA	NA	41500	0.21	3.44
Toll Plaza	2	26	70000	100000	0.28	0.28
Summary for all facilities	*182*	*2626*				

"*NA*" indicates that AADT is *Not Applicable* to Facility type

Table 2-3 Summary of Event Characteristics, 1997 – 2003 Monitoring Events

Event Characteristics	Units	Monitoring Year	Number of Events	Min	Max	Median	Mean	Std. Dev.
Antecedent Dry Period	*days*	1998	253	0.6	290	5	15	36
	days	1999	329	0.7	100	4	10	16
	days	2000	646	0.3	121	8	13	17
	days	2001	565	0.2	202	10	13	17
	days	2002	488	0.4	234	11	17	21
	days	*Total*	*2281*	*0.2*	*290*	*7*	*14*	*21*
Cumulative Seasonal Precipitation	*mm*	1998	249	0	928	166	219	206
	mm	1999	312	0	2323	140	213	247
	mm	2000	579	0	1526	123	169	175
	mm	2001	519	0	1488	122	169	182
	mm	2002	436	0	915	121	166	158
	mm	*Total*	*2095*	*0*	*2323*	*127*	*181*	*191*
Event Rainfall	*mm*	1998	252	2.03	76	11	14	10
	mm	1999	329	0.25	104	16	22	19
	mm	2000	622	0.51	110	16	23	21
	mm	2001	550	0.51	97	11	16	14
	mm	2002	489	2	325	23	36	38
	mm	*Total*	*2242*	*0.25*	*325*	*15*	*23*	*25*
Maximum Intensity	*mm/hour*	1998	178	2.03	107	6	10	14
	mm/hour	1999	297	0.25	122	9	16	19
	mm/hour	2000	618	0.25	113	12	17	14
	mm/hour	2001	549	0.51	79	10	14	13
	mm/hour	2002	488	3	107	16	21	16
	mm/hour	*Total*	*2130*	*0.25*	*122*	*12*	*16*	*15*

STATISTICAL METHODS

Overview of Statistical Approach

The principal statistical methods used to address the objectives of this report consisted of Multiple Linear Regression (MLR), Analysis of Variance (ANOVA), and Analysis of Covariance (ANCOVA). Unless specified, thresholds for statistical significance were set at a confidence level of 95% ($p < 0.05$) for all analyses. MLR methods were used to evaluate the effects of precipitation factors, antecedent conditions, annual average daily traffic (AADT), and contributing drainage area on runoff quality. The MLR results were used in the ANCOVA analyses to evaluate the effects of facility type, land use, and geographic region on runoff quality. ANOVA methods were used to assess the contribution of annual variation to the overall variability of runoff quality. Relationships between pollutants in runoff were evaluated using non-parametric correlation methods. In addition to these analyses, summary statistics were calculated for runoff quality data, and distributions of these data were evaluated for normality prior to additional analyses.

MLR, ANCOVA, and ANOVA analyses were performed using only data from the Department's Statewide discharge characterization studies. This data set was used because the monitoring was more consistent in monitoring approach and methods (than earlier Department monitoring), and was specifically designed to be representative of the Department's facilities throughout the state. This consistent approach and design serves to optimize the consistency and representativeness of the results of the analyses.

The methods used to address specific objectives are summarized in Table 2-4. A summary of the analytical approach is also illustrated in Figure 2-2. Details of the statistical methods used are provided in following text.

Table 2-4 Project Objectives and Statistical Methods Used

Project Objectives	Statistical Methods
Describe distributional and statistical characteristics of runoff	Summary Statistics and frequency distribution plots
Update Multiple Linear Regression models with Statewide characterization studies data	Multiple Linear Regression
Identify relationships between runoff quality and site and environmental characteristics.	Multiple Linear Regression
Evaluate seasonal patterns in runoff quality	Multiple Linear Regression
Evaluate within-storm patterns in runoff quality (i.e., intra-event "first flush" effect)	Multiple Linear Regression
Evaluate differences in runoff quality from facility types and surrounding land uses.	ANCOVA
Evaluate differences in runoff quality from different geographic regions.	ANCOVA
Evaluate annual variation and trends in runoff quality	Non-parametric ANOVA
Evaluate relationships (correlations) between runoff quality parameters	Spearman's Rank Correlation Analysis
Compare runoff quality to water quality objectives and prioritize parameters for BMPs	Estimate percent exceedance from distribution characteristics

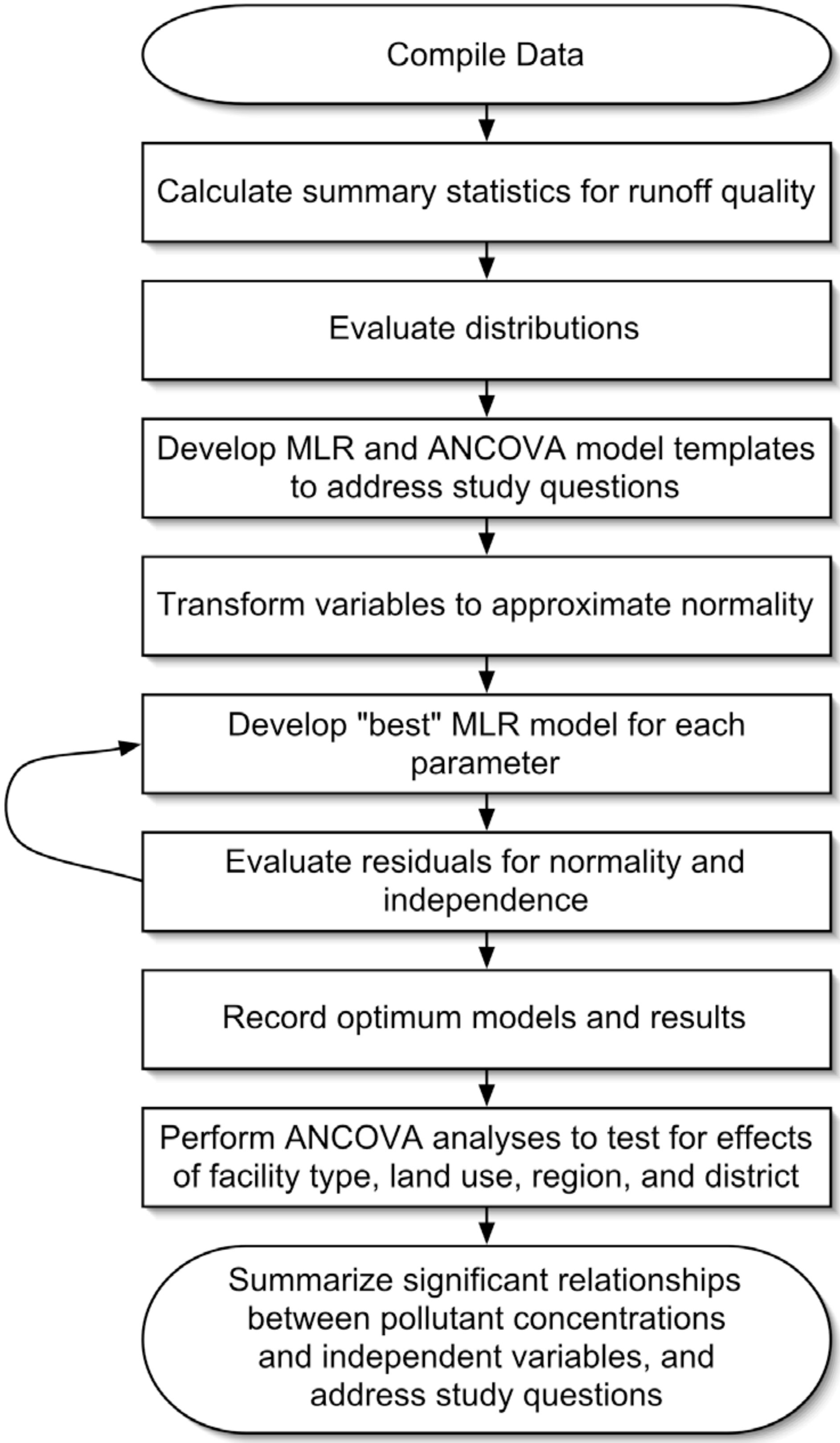


Figure 2-2 Data Evaluation Process

Summary Statistics

Summary statistics and frequency distributions were calculated to address the objectives of describing the distributional and statistical characteristics of stormwater runoff quality from the Department's facilities. Summary statistics were calculated for each constituent for the different facility types contributing the runoff to the sample. Facility types include highways, maintenance stations, Caltrans vehicle inspection facilities (CVIF), parking facilities, rest areas, toll plazas, construction zones, and erosion control sites.

The total number of data, the number and percent of detected data, minimum and maximum detected values, and minimum and maximum detection limits were generated for all data sets and categories. Distribution parameters (arithmetic mean and standard deviation, and 95% confidence limits for the arithmetic mean) were calculated for all categories with a minimum of 30% detected data.

For constituents with data below detection, summary statistics were calculated using the probability regression method described in Helsel and Cohn (1988) and Shumway *et al*. (2002). Use of these methods is important to accurately characterize stormwater runoff data (Kayhanian *et al*., 2002), and this approach is consistent with the methods used previously to analyze the Department's runoff quality (Kayhanian *et al*., 2003).

Summary statistics were also used to estimate the percentage of metals bound to particles in runoff. The percentage particulate fraction was calculated as:
100% x (*average of total metal minus average of dissolved metal) ÷ average of total metal.*

The distributions of runoff quality data for each constituent were evaluated for approximate normality prior to performing additional analyses. Distributions were evaluated using linear and exponential regressions of normal cumulative probability plots of untransformed data. These evaluations were performed using only detected data with probabilities adjusted for data below detection using the method of Helsel and Cohn (1988) and Shumway *et al*. (2002). The regression providing the best fit (as determined by the coefficient of determination or R^2 statistic) was selected as the appropriate starting point for additional analyses, with linear regressions indicating an approximately normal distribution and exponential regressions indicating an approximately log-normal distribution. The distributions of other continuous predictor variables (precipitation factors, antecedent conditions, AADT, and contributing drainage area) were also evaluated by inspection of cumulative probability plots, and were transformed to approximate normality, as follows: natural logarithms (event rainfall, maximum intensity, antecedent dry period, and drainage area), cube-roots (cumulative precipitation), or arcsin-square roots (impervious fraction). Note that these transformations required to satisfy the fundamental statistical assumptions of the analyses and are not necessarily indicative of any underlying physical properties of the predictor variables.

Multiple Linear Regression

Multiple Linear Regression (MLR) analyses were used to address several related objectives of this report:

- Update previously generated MLR models, using only the more consistently-collected Statewide characterization studies data

- Identify relationships between runoff quality and environmental and site characteristics
- Evaluate seasonal patterns in runoff quality
- Evaluate intra-event patterns in runoff quality (i.e., “first flush” effect)

Multiple Linear Regression models were generated using detected data for each constituent. The criteria for selection of constituents for MLR modeling was a minimum of 60% detected data overall, and at least 50 total detected data. Although using only detected data has the potential to bias MLR results by decreasing the magnitude of the model coefficients for the predictor variables, most parameters analyzed had at least 90% detected data and this effect was considered to be negligible for these parameters. There is a greater potential for bias for parameters with between 60% and 90% detected data (total arsenic, total cadmium, dissolved chromium, dissolved nickel, and dissolved orthophosphate), and MLR models for these parameters will provide less accurate predictions of runoff quality, particularly for conditions tending to result in lower pollutant concentrations in runoff. Note that the potential bias in magnitude of MLR coefficients does not effect the sign of the coefficient or invalidate the overall conclusions about the predominant effects of the predictor variables (*e.g.*, whether longer antecedent dry periods or smaller storm events tend to result in higher pollutant concentrations). Potential bias in concentration estimates could be moderated by performing logistic regression analyses in addition to the MLR analyses. Logistic regression models would provide estimates of the expected percent detection of each parameter under specific conditions. Because the conditions of greatest interest to the Department are those that result in the highest pollutant concentrations, the refinement of concentration estimates for conditions expected to result in a high proportion of concentrations below detection was considered not to be warranted for this study.

Methods used for MLR analyses followed standard statistical practice (Zar 1984, Sokal and Rohlf 1981, SPSS 2001). The primary assumptions of MLR analysis (equal variance, normality) were assessed by inspection of residual plots. Problems due to unequal variance and non-normality of residuals were largely avoided by transforming dependent and independent variables to approximate normality prior to analysis. Predictor variables were added to the models using a forward selection procedure that adds predictor variables to the model in the order of highest partial correlation with the dependent variable and retains only statistically significant ($p < 0.05$) variables. Generally, all significant predictor variables were included in the MLR model unless they exhibited symptoms of excessive collinearity or co-dependence in the set of predictors. Independence of predictor variables (the absence of collinearity) was assessed by evaluating several collinearity diagnostic values, including the Tolerance and Variance Inflation Factors (VIF) of each covariate in the model and the Condition Index for the overall model. The Tolerance statistic is interpreted as the proportion of a covariates variance not accounted for by other independent variables in the model. Variables with a low Tolerance statistic (less than 0.7) contribute little additional information to the model. The VIF statistic is the reciprocal of Tolerance and increasing VIF factors indicate increasing collinearity and an unstable estimate of the regression coefficient for that factor. When VIF values were greater than 1.4, at least one predictor variable was excluded from the MLR model to prevent collinearity. The model Condition Index was also used to screen for collinearity problems in the MLR models. Condition indices greater than 15 indicate possible collinearity problems and values greater than 30 indicate serious problems. The MLR models were optimized so that condition indices did not exceed a value of 20.

The validity of the MLR models was assessed in two ways. First, optimized MLR models were compared to models generated previously with the Department's runoff quality data (Kayhanian *et al*., 2003). These qualitative comparisons consisted of assessment of the consistency of the conclusions derived from the two sets of MLR models. Additionally, selected MLR models were evaluated by comparing MLR-predicted values for events and highways sites not used to develop the models (i.e. a new validation dataset) to the concentrations actually measured in runoff. Standard regression methods were used for this validation.

Temporal Trends Analysis

The objective of evaluating temporal trends was addressed using MLR methods (described previously) and non-parametric ANOVA methods. Temporal trends and patterns were assessed at three levels: annual (year-to-year), seasonal, and intra-event. The specific methods used to evaluate each level of temporal variation are as follows:

- The objective of evaluating the annual variability of runoff quality was addressed using non-parametric ANOVA analyses. These were standard ANOVA analyses performed using rank-transformed data for each parameter, with data below detection substituted with a value of zero before being converted to ranks. These analyses were performed separately for each facility type in the data set. The results of these analysis are expressed as the proportion of total variability in runoff quality attributable to annual variation. The statistical threshold for significance was set at the 95% confidence level.

- The effect of the seasonal variation on runoff quality was assessed by evaluating the effect of cumulative seasonal precipitation on runoff quality in the Multiple Linear Regression (MLR) models. Significant negative coefficients for cumulative seasonal precipitation are interpreted to indicate a significant "seasonal first flush" with a tendency for decreasing pollutant concentrations as the wet season progresses.

- The significance of an intra-event first flush was assessed using the MLR results for *Event Rainfall*. A statistically significant negative coefficient for *Event Rainfall* indicates that concentrations tend to decrease as total event rainfall increases. A significant negative coefficient is consistent with the interpretation that concentrations tend to be highest in the initial portion of the runoff and are diluted as the storm event continues (i.e., it is consistent with a storm event first flush effect).

Effects of Facilities, Geographic Region, and Surrounding Land Use

ANCOVA methods were used to address three objectives of this report:

- Evaluate differences in runoff quality from different Department facilities
- Evaluate differences in runoff quality from different geographic regions
- Evaluate differences in runoff quality from different surrounding land uses.

The final "optimized" MLR model was used to generate a new fitted variable calculated as the cumulative effects of the significant predictor variables in each model. This fitted variable was then included as the single covariate in the ANCOVA models used to evaluate the effects of categorical variables (facility, geographic region, and predominant surrounding land use). Interaction effects were evaluated for the cumulative covariate effects (expressed as the MLR-fitted variable) and each categorical variable using standard ANCOVA methods. Interaction effects were retained in the ANCOVA models if they were significant.

This method of ANCOVA analysis does have some drawbacks. Ideally, all of the covariate factors and explanatory factors would be included individually in the ANCOVA models. This method would allow simultaneous evaluation of a broader range of effects and interactions, and theoretically should result in the "best" predictive model. However, an adaptation of standard ANCOVA techniques was required to accommodate the unbalanced dataset, which was not designed to allow a complete and balanced ANCOVA analyses of potential explanatory factors such as geographic region or predominant surrounding land use. There are two specific areas that are compromised by this combined covariate ANCOVA method. The first is a slight inflation of the degrees of freedom used to calculate significance. However, because the degrees of freedom for the models was typically 500 or more, the loss of the few degrees of freedom that would result from including individual covariates has little effect on the overall model significance. More important is the inability to include and evaluate the full range of potential interactions between explanatory variables and individual covariates. Although this may have been partially accomplished by limiting the analyses to only a few specific facilities, georegions, and land uses, such a strategy would have unnecessarily excluded much data of interest to the Department and still resulted in incomplete evaluation of the effects of these factors. The adaptation of ANCOVA methods used for these analyses exchanged some statistical sophistication to allow more complete use of the data to address the Department's primary questions.

When the effects of facility, geographic region, or land use were significant, differences between facilities, regions, and land uses were assessed by comparing the residuals of the MLR models using the method of Least Significant Difference (i.e. without adjustment for multiple comparisons). Differences were generally summarized as significantly greater or less than the overall average for the parameter. The effects of geographic region and surrounding land use were evaluated using only the Statewide characterization studies data for highway runoff because the broad distribution of highway sites provided the most complete assessment of these categorical factors.

Comparisons to Water Quality Objectives

Summary statistics for 1998 – 2002 data were compared to relevant water quality objectives to determine which parameters should be considered highest priority for future BMP implementation or study. Summary statistics for each parameter were compared with California Toxics Rule objectives and relevant limits from several other sources. The sources of other water quality objectives considered were *National Primary Drinking Water Maximum Contaminant Levels* (USEPA, 2002), U.S. EPA *Action Plan for Beaches and Recreational Waters* (USEPA, 1999a), U.S. EPA Aquatic Life Criteria (USEPA, 1999b), California Department of Health Services Drinking Water MCLs (CDHS, 2002), and California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos (Siepman and Finlayson, 2000). In the case of CTR metals objectives that are adjusted for hardness, the objective was based on the lowest observed hardness for the data set in order to provide the most stringent assessment.

These water quality objectives were considered relevant for comparison to stormwater quality because they apply to surface waters which may receive stormwater discharges from highways and other Department facilities. Constituents were prioritized according to their estimated percent exceedance of the most stringent water quality objective. Estimated percent exceedance was calculated based on the distributional statistics calculated for each constituent, using the statistical methods described previously for characterization of runoff quality. The results of these comparisons were then used to rank parameters for monitoring priority, with higher estimated and observed exceedences receiving higher priorities for monitoring. Note that for constituents monitored by the Department, only trace metals and organics have CTR criteria.

Correlations Among Runoff Quality Parameters

Correlations between runoff quality parameters were first evaluated using Spearman's non-parametric rank correlation method, with data below detection set to a value of zero. This evaluation was performed to identify parameter pairs or groups with high correlations and therefore potentially high levels of redundancy for monitoring. The threshold used to identify potentially useful relationships was a Spearman's *rho* value greater than 0.8 and statistically significant at the 95% confidence level. (Spearman's *rho* is the non-parametric equivalent of the parametric Pearson's Product-Moment correlation coefficient, *R*.) After screening with Spearman's non-parametric method, the standard Pearson's Product-Moment correlation coefficient was calculated using only detected data to verify the linearity of the relationship. Statistically significant correlations greater than 0.8 were considered adequately strong for parameters to effectively serve as surrogates for each other. This information was used to prioritize pollutants for continued monitoring.

FACTORS LIMITING ANALYSIS

A number of factors may affect the ability to successfully analyze and interpret stormwater runoff quality data. These include data variability, "representativeness" of sampling methods and data collection, sampling design and pseudoreplication, lack of normality in dependent and predictor variables, collinearity of the predictor variables, and the overall size and quality of the data set.

Data Variability

The high degree of variability in runoff quality data increases the difficulty of demonstrating that significant differences in runoff quality are attributable to facility types, contributing land use, management efforts, or monitoring strategies. By modeling the relationships between runoff quality and precipitation factors through multiple regression analysis, some of the variability inherent in runoff quality data can be explained, thereby increasing the ability to detect effects from other site-specific characteristics. Some of the factors considered to contribute significantly to the variability of stormwater quality data are summarized in Table 2-1.

Sampling Design, Representativeness and Pseudoreplication

Sampling design and data collection methods are critical to the ability to analyze and interpret stormwater quality data correctly. Appropriate design and sampling methods will produce data that are representative of the range of hydrological conditions and runoff characteristics of interest. A good sampling design will also be based on the statistical methods needed to appropriately analyze the data. A poorly designed or biased monitoring program may produce runoff quality data that are not representative of the conditions of interest, or that represent only a limited range of the variability of the data. Even the most rigorous statistical methods can result in incorrect conclusions if based on biased or non-representative data. One of the more common symptoms of an inadequate sampling design is the phenomenon of pseudoreplication, which occurs when a particular treatment or category is represented by only a few sites (or only one site in the extreme case) that are sampled many times. The primary effect of pseudoreplication on statistical analyses is that it results in overestimation of the degrees of freedom used to calculate the error term for the statistical comparison being made (*e.g.* between facility types or land uses), and consequently leads to inflation of the estimated significance of statistical comparisons (Hurlbert, 1984). Data in the Department's Stormwater Quality Database are expected to be representative for the particular monitoring site because the Department's monitoring programs use consistent and well-documented sampling methods that are designed specifically for collection of representative stormwater samples. However, because the Department's monitoring programs were not designed specifically for this type of statistical comparison, pseudoreplication does occur to some degree in the data set used in these analyses. The effects of pseudoreplication manifests primarily in comparisons and conclusions of the effects of categorical variables (*e.g.* facility types) on runoff quality, particularly when one level of a category (*e.g.* rest areas) is represented by only a few sites, and indicates the need for caution in interpreting these comparisons. Problems with pseudoreplication for these analyses were partly controlled by using data from the Statewide characterization studies, which was designed to provide representative data for Department facilities and geographic regions throughout the state. However, although Statewide characterization studies monitoring sites were selected to be representative of "typical" Caltrans facilities, extrapolating results for a facility type with only a few representative sites (or a region with only a few representative highway sites) in the analysis to all such facilities should be done with caution. Note that pseudoreplication has little or no effect on the basic MLR analysis because each combination of event and sampling location is essentially treated as a unique independent observation.

Data Distributions

Normality and equal variance (homoscedasticity) of residuals are two central assumptions of the linear regression analysis and ANCOVA. Although these statistical methods are robust to minor violations, major deviations of these assumptions can reduce the power of these tests to detect significant effects or may lead to inaccurate characterization of effects. These potential limitations were controlled by evaluating data distributions for normality, transforming dependent and independent variables *a priori* to approximate normality if necessary, and finally by inspecting the residuals of the analyses for normality, equal variance, and nonlinearity.

Table 2-5 Factors Contributing to Stormwater Monitoring Data Variability

Category	Specific Factors
Site Specific Factors & Drainage Area Characteristics	• % imperviousness • gradients • vegetation types and coverage • runoff conveyance systems • structural controls • contributing land uses • climate
Meteorological and Storm Event Characteristics	• inter-storm precipitation factors • storm to storm variation • seasonal variation • annual variation
Pollutant Sources	• atmospheric • automotive • construction • building materials • household • commercial/industrial
Human Activities	• population density • traffic patterns • land use • public awareness
Monitoring Factors	• field sampling methods • laboratory and analytical methods

Collinearity

While not a strict requirement, independence of predictor variables (the absence of collinearity) provides an ideal condition for multiple linear regression analysis. Although collinearity does not seriously compromise the predictive value of a multiple regression model, highly correlated predictor variables can make it difficult to interpret the effect of a specific variable (*e.g.* whether it causes an increase or decrease in the dependent variable). As discussed previously, collinearity was assessed using diagnostic statistics for correlations and partial correlations among the predictor variables, and controlled by excluding highly correlated variables from the analysis. In cases where variables were highly correlated, the variable with the largest effect in the models was preferentially retained.

Data Set Quality and Size

Incomplete and censored data sets may also limit the effectiveness of statistical analyses. Incomplete data for storm event or site characteristics can eliminate an event or site from analysis. If these data are randomly missing, then this simply decreases the effective size of the data set and the power of statistical analyses. If the data are systematically missing (*e.g.*, only for storms with more than one inch of rainfall or for a particular type of facility), the data and conclusions based on the data will be biased. This particular type of non-random censoring bias was effectively controlled by the Statewide discharge characterization study's monitoring design, which ensured that runoff quality data were collected for a wide range of environmental and site-specific conditions.

Runoff quality data that are below analytical detection limits are another example of non-randomly censored data. If these data are excluded from the analysis or handled incorrectly, the data set will be biased and may violate the core distributional assumptions of the analyses. Potential biases were limited by restricting the analyses to parameters with low levels of censoring (described previously in this document) to minimize distortion of the underlying distribution characteristics of the data for each runoff quality parameter. While this method still allows for some potential bias of the results, it is preferable to simple substitution methods for censored data which introduce different and less easily predictable biases.

Another factor that can limit the effectiveness of any statistical analyses is a small data set. However, this is not a significant limitation of the Department's Stormwater Quality database. Over 60,000 total runoff quality data records were included in these analyses. In the Statewide characterization studies dataset used for MLR and ANCOVA analyses, total numbers of data points ("*n*") for individual parameters approached 1,000, and for individual parameters at specific facilities *n* ranged from 24 (*Toll Plazas*) to 635 (*Highways*). The large size of the available data set overcomes many of the other limitations by increasing statistical power and overall robustness of the analyses.

SECTION 3 RESULTS

SUMMARY STATISTICS FOR WATER QUALITY DATA

The quality of stormwater runoff was characterized primarily through calculation of summary statistics and distributional parameters for runoff from the different facilities. Statistics were calculated using methods appropriate for estimating these distributional parameters for data that include values below detection ("non-detect data"). Summary statistics for Statewide characterization studies data (monitoring years 2000/01-2002/03) are provided in the Tables 3-1 through 3-6. The statistics presented include the number of samples, minimum and maximum detected values, median, mean, and standard deviation. Statistics are presented for conventional parameters, total petroleum hydrocarbons, trace metals, nutrients, pesticides and herbicides, and semi-volatile organic compounds for the following Department facilities:

Facility	Table number	Page reference
Caltrans Vehicle Inspection Facilities	Table 3-1	Page 26
Highways	Table 3-2	Page 27
Maintenance Facilities	Table 3-3	Page 28
Park-And-Ride Facilities	Table 3-4	Page 29
Rest Areas	Table 3-5	Page 30
Toll Plazas	Table 3-6	Page 31

Percentages of total metals present as particulates are summarized in Table 3-7 for all facility types.

Statistics are also provided for the complete data set (monitoring years 1998/99-2002/03) in Appendix A. Note that all runoff quality parameters (i.e., the dependent variables) were approximately lognormally distributed, with the exceptions of pH and temperature, which were approximately normal.

For constituents with at least 30% detected data, plots of annual average water quality with 95% confidence limits are presented in Appendix A for the Department's facilities that were monitored for the Statewide characterization studies, 2000/01-2002/03.

Table 3-1 Summary Statistics for CALTRANS VEHICLE INSPECTION FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	31	2	100%	2.5	67.1	13.3	18.5	15.9
	EC	µS/cm	31	2	100%	10.9	690	82.1	113.3	137.3
	Hardness as CaCO3	mg/L	31	2	100%	5	120	28.6	33.5	22.1
	pH	pH	31	2	100%	6.2	8.15	7.1	7.1	0.4
	TDS	mg/L	31	2	97%	19	470	65.1	84.8	92.1
	Temperature	˚C	16	2	100%	7.7	19.3	12.1	12.5	3.3
	TOC	mg/L	31	2	100%	2.6	68	14.3	20.0	16.9
	TSS	mg/L	31	2	97%	20	200	67.3	83.4	53.0
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	31	2	42%	1	2.1	1.0	1.0	0.4
	As, total	µg/L	31	2	68%	1.2	64	1.3	3.4	16.1
	Cd, dissolved	µg/L	31	2	45%	0.2	0.7	0.16	0.20	0.16
	Cd, total	µg/L	31	2	87%	0.2	1.7	0.43	0.56	0.40
	Cr, dissolved	µg/L	31	2	68%	1.1	5.5	1.4	1.8	1.2
	Cr, total	µg/L	31	2	100%	2.1	21	6.7	8.1	4.8
	Cu, dissolved	µg/L	31	2	100%	2	51	11.0	15.6	13.3
	Cu, total	µg/L	31	2	100%	6.2	96	24.8	33.6	24.1
	Hg, dissolved	ng/L	3	1	0%	ND	ND	IDD	IDD	IDD
	Hg, total	ng/L	4	1	50%	12.5	120	IDD	IDD	IDD
	Ni, dissolved	µg/L	31	2	81%	1	9.9	2.7	3.5	2.4
	Ni, total	µg/L	31	2	100%	2.9	20	7.4	8.4	4.7
	Pb, dissolved	µg/L	31	2	55%	1	14	1.1	2.7	3.9
	Pb, total	µg/L	31	2	100%	1.6	180	10.9	21.9	37.7
	Zn, dissolved	µg/L	31	2	100%	23	380	66.1	88.2	79.1
	Zn, total	µg/L	31	2	100%	66	700	206.0	244.5	151.6
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	31	2	100%	0.15	3.53	0.62	0.89	0.81
	Ortho-P, dissolved	mg/L	30	2	73%	0.046	0.48	0.09	0.13	0.12
	P, total	mg/L	31	2	100%	0.046	0.67	0.23	0.28	0.16
	TKN	mg/L	30	2	87%	0.15	12.3	1.15	2.16	2.72
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	6	1	17%	0.1	0.1	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-2 Summary Statistics for HIGHWAY FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	635	46	100%	1.2	483	13.1	18.7	26.2
	EC	µS/cm	634	46	100%	5	743	72.7	96.1	73.4
	Hardness as CaCO3	mg/L	635	46	99%	2	400	26.9	36.5	34.2
	pH	pH	633	46	100%	4.47	10.1	7.0	7.1	0.7
	TDS	mg/L	635	46	97%	3.7	1800	60.3	87.3	103.7
	Temperature	˚C	183	30	100%	4.7	25.4	12.0	12.5	3.4
	TOC	mg/L	635	46	100%	1.6	530	15.3	21.8	29.2
	TSS	mg/L	634	46	99%	1	2988	59.1	112.7	188.8
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	49	10	29%	5	61	1.44	4.95	11.41
	TPH (Diesel)	mg/L	32	4	97%	0.22	13	2.52	3.72	3.31
	TPH (Gasoline)	mg/L	32	4	0%	ND	ND	ND	IDD	IDD
	TPH (Heavy Oil)	mg/L	20	4	95%	0.12	13	1.40	2.71	3.40
Metals	As, dissolved	µg/L	635	46	40%	0.5	20	0.7	1.0	1.4
	As, total	µg/L	635	46	62%	0.5	70	1.1	2.7	7.9
	Cd, dissolved	µg/L	635	46	42%	0.2	8.4	0.13	0.24	0.54
	Cd, total	µg/L	635	46	76%	0.2	30	0.44	0.73	1.61
	Cr, dissolved	µg/L	635	46	80%	1	23	2.2	3.3	3.3
	Cr, total	µg/L	635	46	97%	1	94	5.8	8.6	9.0
	Cu, dissolved	µg/L	635	46	100%	1.1	130	10.2	14.9	14.4
	Cu, total	µg/L	635	46	100%	1.2	270	21.1	33.5	31.6
	Hg, dissolved	ng/L	19	4	16%	2.5	110	IDD	IDD	IDD
	Hg, total	ng/L	23	4	39%	7.8	160	26.0	36.7	37.9
	Ni, dissolved	µg/L	635	46	79%	1.1	40	3.4	4.9	5.0
	Ni, total	µg/L	635	46	95%	1.1	130	7.7	11.2	13.2
	Pb, dissolved	µg/L	635	46	60%	1	480	1.2	7.6	34.3
	Pb, total	µg/L	635	46	94%	1	2600	12.7	47.8	151.3
	Zn, dissolved	µg/L	635	46	99%	3	1017	40.4	68.8	96.6
	Zn, total	µg/L	635	46	100%	5.5	1680	111.2	187.1	199.8
Micro-biological	Fecal Coliform	MPN/100 mL	32	5	97%	23	6000	362	1132	1621
	Total Coliform	MPN/100 mL	32	5	100%	34	160000	3966	13438	34299
Nutrients	NH3-N	mg/L	8	1	100%	0.33	3.9	0.77	1.08	1.46
	NO3-N	mg/L	634	46	90%	0.011	48	0.60	1.07	2.44
	Ortho-P, dissolved	mg/L	630	46	64%	0.014	2.4	0.06	0.11	0.18
	P, total	mg/L	631	46	89%	0.03	4.69	0.18	0.29	0.39
	TKN	mg/L	626	46	94%	0.1	17.7	1.40	2.06	1.90
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	34	5	21%	0.1	1.33	0.04	0.13	0.29
	Diuron	µg/L	367	30	44%	0.5	220	0.37	4.60	18.24
	Glyphosate	µg/L	541	30	56%	5.1	164	8.88	19.61	26.97
	Oryzalin	µg/L	361	30	16%	0.5	77.8	IDD	IDD	IDD
	Oxadiazon	µg/L	365	30	5%	0.05	0.8	IDD	IDD	IDD
	Triclopyr	µg/L	367	30	2%	0.3	830	IDD	IDD	IDD
Semi-volitile Organics	Acenaphthene	µg/L	32	6	3%	0.25	0.25	IDD	IDD	IDD
	Acenaphthylene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(a)Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(a)Pyrene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(b)Fluoranthene	µg/L	32	6	3%	0.05	0.05	IDD	IDD	IDD
	Benzo(ghi)Perylene	µg/L	32	6	19%	0.05	0.17	IDD	IDD	IDD
	Benzo(k)Fluoranthene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Chrysene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Dibenzo(a,h)Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Fluoranthene	µg/L	32	6	19%	0.05	0.1	IDD	IDD	IDD
	Fluorene	µg/L	32	6	3%	0.06	0.06	IDD	IDD	IDD
	Indeno(1,2,3-c,d)Pyrene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Naphthalene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Phenanthrene	µg/L	32	6	9%	0.05	0.14	IDD	IDD	IDD
	Pyrene	µg/L	32	6	25%	0.06	0.13	0.05	0.05	0.03

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-3 Summary Statistics for MAINTENANCE FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	75	7	100%	1.3	82	11.7	18.2	18.2
	EC	µS/cm	56	7	100%	12	660	49.4	80.9	110.6
	Hardness as CaCO3	mg/L	106	7	96%	2	208	17.4	26.7	28.7
	pH	pH	107	7	100%	3.5	8.5	6.8	6.8	0.6
	TDS	mg/L	106	7	97%	4	536	44.6	68.9	78.1
	Temperature	˚C	17	2	100%	8.5	16.5	12.2	12.5	2.8
	TOC	mg/L	107	7	100%	1.7	128	12.7	20.6	23.0
	TSS	mg/L	106	7	100%	6	420	62.4	96.4	95.0
	Turbidity	NTU	29	3	100%	36	430	122.95	144.83	92.23
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	106	7	82%	0.53	81	2.2	9.5	17.3
	As, total	µg/L	107	7	93%	0.585	91	3.4	12.8	23.1
	Cd, dissolved	µg/L	106	7	49%	0.2	1.2	0.19	0.27	0.22
	Cd, total	µg/L	107	7	84%	0.2	2.7	0.46	0.69	0.63
	Cr, dissolved	µg/L	106	7	53%	1	5.9	1.1	1.4	1.0
	Cr, total	µg/L	107	7	99%	1.01	28	3.9	5.1	4.3
	Cu, dissolved	µg/L	106	7	99%	2.4	100	8.8	14.3	17.6
	Cu, total	µg/L	107	7	100%	3	210	17.3	29.5	37.6
	Hg, dissolved	ng/L	7	1	43%	7.85	77	14.4	27.7	51.4
	Hg, total	ng/L	8	1	75%	14.4	230	41.0	65.4	83.7
	Ni, dissolved	µg/L	106	7	57%	1.6	22	2.37	3.72	4.01
	Ni, total	µg/L	107	7	90%	2.08	51	5.48	7.86	7.68
	Pb, dissolved	µg/L	106	7	44%	1	23	0.74	1.64	2.99
	Pb, total	µg/L	107	7	98%	1	130	11.7	21.3	26.5
	Zn, dissolved	µg/L	107	7	98%	1	130	11.7	21.3	26.5
	Zn, total	µg/L	107	7	100%	26	1500	164.6	245.6	259.3
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	107	7	92%	0.12	8	0.41	0.74	1.13
	Ortho-P, dissolved	mg/L	105	7	55%	0.016	3.12	0.04	0.09	0.40
	P, total	mg/L	106	7	95%	0.031	1	0.16	0.23	0.20
	TKN	mg/L	105	7	92%	0.11	11.5	1.24	1.79	1.72
Pesticide & Herbicides	Chlorpyrifos	µg/L	23	3	0%	ND	ND	IDD	IDD	IDD
	Diazinon	µg/L	33	3	39%	0.016	1.4	0.02	0.12	0.30
	Diuron	µg/L	—		—	—	—	—	—	—
	Glyphosate	µg/L	—		—	—	—	—	—	—
	Oryzalin	µg/L	—		—	—	—	—	—	—
	Oxadiazon	µg/L	—		—	—	—	—	—	—
	Triclopyr	µg/L	—		—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—		—	—	—	—	—	—
	Acenaphthylene	µg/L	—		—	—	—	—	—	—
	Anthracene	µg/L	—		—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—		—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—		—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—		—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—		—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—		—	—	—	—	—	—
	Chrysene	µg/L	—		—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—		—	—	—	—	—	—
	Fluoranthene	µg/L	—		—	—	—	—	—	—
	Fluorene	µg/L	—		—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—		—	—	—	—	—	—
	Naphthalene	µg/L	—		—	—	—	—	—	—
	Phenanthrene	µg/L	—		—	—	—	—	—	—
	Pyrene	µg/L	—		—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-4 Summary Statistics for PARK-AND-RIDE FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	179	10	99%	1.03	278	10.8	18.0	28.6
	EC	µS/cm	179	10	100%	6	420	43.6	63.5	65.8
	Hardness as CaCO3	mg/L	179	10	97%	2	420	16.3	26.6	45.9
	pH	pH	179	10	100%	3.9	9.68	6.7	6.8	0.7
	TDS	mg/L	179	10	96%	6	720	38.1	61.7	78.3
	Temperature	˚C	50	7	100%	7.7	21.8	12.2	12.6	3.4
	TOC	mg/L	179	10	100%	1.3	150	12.2	18.6	20.6
	TSS	mg/L	179	10	99%	2	340	48.3	68.5	59.3
	Turbidity	NTU	2	2	100%	29	36	IDD	IDD	IDD
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	179	10	26%	0.53	3	0.5	0.7	0.6
	As, total	µg/L	179	10	47%	0.52	60	0.8	1.4	5.9
	Cd, dissolved	µg/L	179	10	21%	0.2	0.9	0.08	0.12	0.12
	Cd, total	µg/L	179	10	59%	0.2	2.3	0.21	0.30	0.30
	Cr, dissolved	µg/L	179	10	35%	1	5.1	0.7	1.0	0.9
	Cr, total	µg/L	179	10	90%	1	24	2.7	4.0	4.2
	Cu, dissolved	µg/L	179	10	99%	1.1	70	6.2	8.7	8.8
	Cu, total	µg/L	179	10	100%	1.3	120	12.9	17.1	15.2
	Hg, dissolved	ng/L	10	2	0%	ND	ND	IDD	IDD	IDD
	Hg, total	ng/L	11	2	45%	38.6	230	42.7	57.3	73.6
	Ni, dissolved	µg/L	179	10	57%	1	26	2.0	3.3	3.9
	Ni, total	µg/L	179	10	88%	1.9	28	4.8	6.2	4.8
	Pb, dissolved	µg/L	179	10	34%	1	25	0.5	1.3	2.7
	Pb, total	µg/L	179	10	96%	1	78	5.8	10.3	11.5
	Zn, dissolved	µg/L	179	10	96%	1	78	5.8	10.3	11.5
	Zn, total	µg/L	179	10	100%	8.2	960	103.3	154.3	157.1
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	179	10	93%	0.1	5.49	0.32	0.57	0.83
	Ortho-P, dissolved	mg/L	178	10	69%	0.03	1.01	0.07	0.15	0.19
	P, total	mg/L	179	10	98%	0.03	3.27	0.20	0.33	0.42
	TKN	mg/L	176	10	94%	0.13	13.6	1.52	2.28	2.20
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	20	2	15%	0.6	1.7	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Acenaphthylene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(a)Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(a)Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(b)Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(ghi)Perylene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(k)Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Chrysene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Dibenzo(a,h)Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Fluorene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Indeno(1,2,3-c,d)Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Naphthalene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Phenanthrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-5 Summary Statistics for REST AREAS: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	53	3	100%	2.1	239	13.0	19.9	39.6
	EC	µS/cm	53	3	100%	9	809	51.7	78.2	132.0
	Hardness as CaCO3	mg/L	53	3	98%	3	484	18.0	33.0	81.2
	pH	pH	53	3	100%	5.7	7.9	6.8	6.9	0.4
	TDS	mg/L	53	3	100%	4	778	38.0	61.2	130.0
	Temperature	˚C	12	3	100%	5.3	16.3	11.0	11.4	3.2
	TOC	mg/L	53	3	100%	2.5	247	15.0	22.2	40.5
	TSS	mg/L	53	3	98%	7	247	44.2	63.3	54.4
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	53	3	47%	1	20	0.6	1.4	3.3
	As, total	µg/L	53	3	57%	1	58	0.9	3.6	11.4
	Cd, dissolved	µg/L	53	3	17%	0.2	1.4	IDD	IDD	IDD
	Cd, total	µg/L	53	3	58%	0.2	2.8	0.17	0.32	0.53
	Cr, dissolved	µg/L	53	3	62%	1	13	1.2	1.9	2.5
	Cr, total	µg/L	53	3	100%	1	18	3.8	4.8	3.8
	Cu, dissolved	µg/L	53	3	100%	2.7	76	7.6	9.6	12.0
	Cu, total	µg/L	53	3	100%	4.6	89	13.1	16.0	14.2
	Hg, dissolved	ng/L	—	—	—	—	—	—	—	—
	Hg, total	ng/L	—	—	—	—	—	—	—	—
	Ni, dissolved	µg/L	53	3	55%	1.3	35	1.9	3.2	5.8
	Ni, total	µg/L	53	3	92%	1.7	42	4.8	7.3	8.3
	Pb, dissolved	µg/L	53	3	45%	1	8.3	0.7	1.2	1.7
	Pb, total	µg/L	53	3	98%	1.1	32	5.1	7.7	8.0
	Zn, dissolved	µg/L	53	3	100%	12	1500	46.2	82.5	263.7
	Zn, total	µg/L	53	3	100%	21	1800	91.1	142.4	298.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—		—	—	—	—	—	—
	NO3-N	mg/L	53	3	94%	0.2	3.83	0.69	0.96	0.88
	Ortho-P, dissolved	mg/L	52	3	83%	0.056	9.3	0.18	0.44	1.67
	P, total	mg/L	53	3	96%	0.08	2.36	0.32	0.47	0.53
	TKN	mg/L	53	3	98%	0.2	81.2	2.10	4.37	14.04
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	—	—	—	—	—	—	—	—
	Diuron	µg/L	3	1	33%	2.2	2.2	IDD	IDD	IDD
	Glyphosate	µg/L	3	1	33%	7.7	7.7	IDD	IDD	IDD
	Oryzalin	µg/L	3	1	33%	1.7	1.7	IDD	IDD	IDD
	Oxadiazon	µg/L	3	1	0%	ND	ND	IDD	IDD	IDD
	Triclopyr	µg/L	3	1	0%	ND	ND	IDD	IDD	IDD
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-6 Summary Statistics for TOLL PLAZAS: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	24	2	100%	3.8	73	18.9	25.6	19.8
	EC	µS/cm	24	2	100%	9	370	85.8	118.9	100.2
	Hardness as CaCO3	mg/L	24	2	100%	8	120	29.6	37.1	27.7
	pH	pH	24	2	100%	6.3	7.6	6.9	6.9	0.4
	TDS	mg/L	24	2	96%	6	280	51.9	81.5	74.2
	Temperature	˚C	18	2	100%	7.8	16.2	12.0	12.3	3.0
	TOC	mg/L	24	2	100%	4.4	76.7	24.7	31.0	20.3
	TSS	mg/L	24	2	100%	20	313	101.4	123.3	77.4
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	24	2	25%	1	1.8	0.7	0.8	0.4
	As, total	µg/L	24	2	79%	1	4.2	1.3	1.5	0.8
	Cd, dissolved	µg/L	24	2	100%	0.2	1.2	0.37	0.43	0.29
	Cd, total	µg/L	24	2	100%	0.5	2.5	1.04	1.15	0.56
	Cr, dissolved	µg/L	24	2	100%	1.2	11	4.4	5.1	2.5
	Cr, total	µg/L	24	2	100%	2.2	31	10.3	12.5	7.7
	Cu, dissolved	µg/L	24	2	100%	6.7	75	21.8	27.3	20.6
	Cu, total	µg/L	24	2	100%	26	110	55.5	59.6	23.0
	Hg, dissolved	ng/L	4	—	25%	63	63	IDD	IDD	IDD
	Hg, total	ng/L	4	—	25%	200	200	IDD	IDD	IDD
	Ni, dissolved	µg/L	24	2	100%	1	16	4.8	6.0	4.5
	Ni, total	µg/L	24	2	100%	4.8	31	12.3	13.7	6.8
	Pb, dissolved	µg/L	24	2	71%	1.4	19	3.1	5.2	5.2
	Pb, total	µg/L	24	2	100%	11	120	27.1	31.6	24.3
	Zn, dissolved	µg/L	24	2	100%	25	340	98.5	123.7	89.4
	Zn, total	µg/L	24	2	100%	140	650	268.3	292.9	131.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—		—	—	—	—	—	—
	NO3-N	mg/L	24	2	96%	0.16	2.78	0.55	0.84	0.81
	Ortho-P, dissolved	mg/L	23	2	39%	0.03	0.18	0.03	0.05	0.05
	P, total	mg/L	24	2	92%	0.077	0.52	0.23	0.25	0.11
	TKN	mg/L	24	2	100%	0.56	5.52	1.91	2.38	1.59
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	7	1	14%	0.1	0.1	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-7 Percentage of Total Metals Present in the Particulate Fraction

Metal	CVIF	Highway	Maintenance	Park-and-Ride	Rest Areas	Toll Plazas	Facility Average
Arsenic	69%	62%	25%	52%	59%	47%	53%
Cadmium	63%	67%	62%	60%	IDD	63%	63%
Chromium	78%	62%	74%	74%	61%	59%	68%
Copper	54%	55%	52%	49%	40%	54%	51%
Nickel	59%	56%	53%	46%	56%	56%	54%
Lead	88%	84%	92%	87%	84%	84%	86%
Zinc	64%	63%	91%	93%	42%	58%	69%

"IDD" indicates there were insufficient detected data to calculate percent particulate fraction.

EFFECTS OF VARIOUS FACTORS ON RUNOFF QUALITY

Effects of Rainfall Parameters, Antecedent Conditions, AADT and Other Site Characteristics

Multiple Linear Regression Results

The relationships between runoff quality and various environmental and site-specific factors were investigated using Multiple Linear Regression (MLR) analysis of the Statewide characterization studies data set. This analysis included the effects of precipitation factors (event rainfall and maximum rainfall intensity), antecedent conditions (cumulative seasonal precipitation and antecedent dry period), annual average daily traffic (AADT), contributing drainage area and percent impervious area on constituent concentrations in storm runoff from the Department's facilities.

The results of the MLR analyses are presented in Table 3-8 (all monitored facilities) and Table 3-9 (highways only), including relevant model statistics and the specific effects of precipitation factors, antecedent conditions, AADT, and drainage area on the Department's facility runoff quality. A summary of patterns in significant covariate effects is provided in Table 3-10 (all facilities) and Table 3-11 (highways).

Two sets of models were developed for 24 constituents: one set for all facilities combined and excluding AADT, and a second set for highway sites only. Statistically significant coefficients of determination (R^2-values with $p<0.05$) ranged from 0.076–0.524 for highways, and from 0.019–0.415 for all facilities combined. The results of these analyses indicate that all of these factors have statistically significant effects on pollutant concentrations in runoff, and that these effects are generally consistent for most pollutants. The interpretation of dominant (most frequently observed) statistically significant effects of precipitation factors, antecedent conditions, contributing drainage area, and annual average daily traffic (AADT) on runoff quality is summarized below as follows:

- A statistically significant negative coefficient for *Event Rainfall* was observed for nearly all pollutants modeled, indicating that concentrations tend to decrease as total rainfall increases for a specific event. This significant negative coefficient indicates that average pollutant concentrations tend to be higher for smaller rainfall events and lower for larger events; this implies that pollutants tend to become diluted in larger storms. This can only be true if, on average, concentrations tend to be higher in the earlier portion of runoff and lower in the latter portion of runoff. By inference, this result is consistent with the existence of an event first flush effect; i.e., the interpretation that concentrations tend to be highest in the initial portion of runoff events, and are diluted as the storm event continues (i.e., it is consistent with a storm event first flush effect).

- A statistically significant positive coefficient for *Maximum Rainfall Intensity* would indicate that higher rainfall intensities tend to result in greater pollutant concentrations in runoff. A significant negative slope would suggests that higher rainfall intensities tend to have a diluting effect. *Maximum Rainfall Intensity* tended to be highly correlated (R^2-value of approximately 0.3) with *Event Rainfall*, had a consistently smaller effect and was less often significant than *Event Rainfall*, and was therefore eliminated from MLR models to prevent collinearity problems.

- *Antecedent Dry Period* had a statistically significant effect in the MLR models for most constituents, and significant coefficients for this factor were all positive, with the exception of pH. The significant positive slope indicates that longer antecedent dry periods tend to result in higher pollutant concentrations in storm runoff, and is consistent with the "buildup" of pollutants during dry periods.

- The effect of the seasonal first flush (*e.g.* the first significant storm event(s) of a season) was assessed by evaluating the effect of *Cumulative Seasonal Precipitation* on runoff quality. The statistically significant negative slope of the coefficient for *Cumulative Seasonal Precipitation* indicates that pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. *Cumulative Seasonal Precipitation* had a statistically significant effect in the MLR models for every Statewide characterization studies constituent, and significant coefficients for this factor were negative in every case.

- A significant positive slope for *Drainage Area* indicates that sites with larger contributing drainage areas tend to have higher pollutant concentrations in runoff. A significant positive slope indicates that sites with larger contributing drainage areas tend to have lower pollutant concentrations in runoff. *Drainage Area* had a statistically significant effect in four of 24 MLR models for highway sites, and eleven of 24 models for all facilities combined. Significant coefficients for *Drainage Area* were negative for all of the highway models, but for only four of eleven combined facility models. There was no clear pattern for this factor and the most common result for this factor was *not significant*.

- A statistically significant positive slope for *Impervious Fraction* indicates that sites with a higher proportion of impervious area tend to have higher pollutant concentrations in runoff. *Impervious Fraction* had a statistically significant effect in four of 24 MLR models for highway sites, and nine of 24 models for all facilities combined. Significant coefficients were evenly divided between positive and negative for highway models, and were negative for six of nine combined facility models. The most common result for this factor was *not significant*.

- A statistically significant positive slope for *AADT* indicates that higher average annual daily traffic tends to result in higher pollutant concentrations in runoff. *AADT* had a statistically significant effect in the MLR models for nearly every constituent, and significant coefficients for *AADT* were predominantly positive. A significant negative slope was observed for only one constituent (dissolved orthophosphate), suggesting that higher *AADT* tends to result in lower concentrations of this constituent in runoff. This counter-intuitive result may indicate that vehicle traffic is not a significant source of this pollutant and that lower *AADT* may be associated with other sources or conditions responsible for orthophosphate in runoff (*e.g.* agricultural land uses or higher percentages of landscaped areas).

The effects of AADT, event rainfall, cumulative precipitation and antecedent dry period are also illustrated using total recoverable copper reported and MLR-predicted values in Figure 3-1 through Figure 3-4, and the cumulative model is illustrated in Figure 3-5. Total copper was selected for this example because it is one of the best (most accurate) MLR models and best illustrates these effects.

Table 3-8 Effects of Precipitation, Antecedent Conditions, and Drainage Area on Runoff Quality from all Department Facilities: Multiple Linear Regression (MLR) Model Statistics and Coefficients for Whole Storm (EMC) data.

			Model Statistics			*Model Coefficients* [(1)] *(intercept and independent variables)*							*Standardized Model Coefficients* [(2)]					
Pollutant Category	Dependent Variable, *X* (Runoff Quality Parameter)	Form of X in Model	df	Adjusted Model R-Squared	S.E of Model Estimate	constant (y-Int.)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]
Conventional	DOC	Ln(*X*)	944	0.415	0.654	4.377	(-0.452)	—	0.154	(-0.131)	—	(-0.0033)	(-0.459)	—	0.189	(-0.318)	—	(-0.0590)
	EC	Ln(*X*)	945	0.263	0.729	5.338	(-0.393)	—	0.137	(-0.077)	—	—	(-0.401)	—	0.169	(-0.188)	—	—
	Hardness as CaCO3	Ln(*X*)	987	0.158	0.779	4.490	(-0.267)	—	—	(-0.113)	—	—	(-0.274)	—	—	(-0.273)	—	—
	pH	*X*	1001	0.063	0.656	7.118	(-0.061)	—	—	(-0.056)	0.086	0.0052	(-0.079)	—	—	(-0.170)	0.128	0.1200
	TDS	Ln(*X*)	924	0.221	0.785	5.141	(-0.358)	—	0.146	(-0.073)	0.078	—	(-0.348)	—	0.172	(-0.170)	0.089	—
	Temperature	*X*	283	0.114	3.033	13.115	—	—	0.485	(-0.387)	—	—	—	—	0.133	(-0.275)	—	—
	TOC	Ln(*X*)	990	0.119	1.012	5.405	(-0.177)	—	—	(-0.163)	—	—	(-0.142)	—	—	(-0.308)	—	—
	TSS	Ln(*X*)	934	0.123	1.007	4.972	(-0.146)	—	0.118	(-0.142)	—	—	(-0.118)	—	0.115	(-0.272)	—	—
Trace Metals	As, total	Ln(*X*)	629	0.019	0.939	1.193	—	—	—	(-0.073)	—	—	—	—	—	(-0.143)	—	—
	Cd, total	Ln(*X*)	744	0.123	0.690	0.471	(-0.172)	—	—	(-0.100)	0.073	—	(-0.200)	—	—	(-0.262)	0.102	—
	Cr, dissolved	Ln(*X*)	695	0.068	0.660	1.513	(-0.119)	—	—	(-0.056)	(-0.100)	—	(-0.150)	—	—	(-0.166)	(-0.150)	—
	Cr, total	Ln(*X*)	911	0.088	0.818	1.742	(-0.125)	—	0.100	(-0.071)	—	0.0054	(-0.127)	—	0.123	(-0.171)	—	0.0980
	Cu, dissolved	Ln(*X*)	943	0.364	0.708	3.632	(-0.390)	—	0.193	(-0.129)	0.080	—	(-0.380)	—	0.227	(-0.301)	0.092	—
	Cu, total	Ln(*X*)	1003	0.217	0.892	4.732	(-0.326)	—	—	(-0.174)	—	—	(-0.281)	—	—	(-0.353)	—	—
	Ni, dissolved	Ln(*X*)	699	0.263	0.571	2.681	(-0.280)	—	0.069	(-0.100)	(-0.078)	(-0.0030)	(-0.359)	—	0.107	(-0.309)	(-0.117)	(-0.0730)
	Ni, total	Ln(*X*)	892	0.177	0.679	2.703	(-0.226)	—	0.122	(-0.078)	(-0.051)	—	(-0.260)	—	0.170	(-0.212)	(-0.069)	—
	Pb, dissolved	Ln(*X*)	535	0.057	1.076	1.790	(-0.204)	—	—	(-0.087)	—	0.0053	(-0.164)	—	—	(-0.157)	—	0.0780
	Pb, total	Ln(*X*)	904	0.141	1.289	3.940	(-0.189)	—	0.097	(-0.158)	0.310	—	(-0.118)	—	0.073	(-0.230)	0.230	—
	Zn, dissolved	Ln(*X*)	938	0.276	0.819	5.545	(-0.369)	—	0.162	(-0.135)	—	(-0.0047)	(-0.333)	—	0.176	(-0.289)	—	(-0.0750)
	Zn, total	Ln(*X*)	943	0.269	0.870	6.108	(-0.298)	—	0.181	(-0.139)	0.192	—	(-0.254)	—	0.187	(-0.281)	0.194	—
Nutrient	NO3-N	Ln(*X*)	870	0.289	0.791	1.409	(-0.424)	—	0.140	(-0.106)	0.146	(-0.0053)	(-0.393)	—	0.155	(-0.220)	0.161	(-0.0860)
	Ortho-P, dissolved	Ln(*X*)	619	0.165	0.732	(-1.466)	(-0.218)	—	0.091	(-0.089)	(-0.131)	—	(-0.237)	—	0.118	(-0.215)	(-0.175)	—
	P, total	Ln(*X*)	867	0.137	0.770	(-0.619)	(-0.188)	—	0.147	(-0.084)	—	(-0.0036)	(-0.195)	—	0.183	(-0.199)	—	(-0.0670)
	TKN	Ln(*X*)	871	0.366	0.676	2.330	(-0.397)	—	0.124	(-0.146)	—	(-0.0042)	(-0.408)	—	0.153	(-0.351)	—	(-0.0750)

Notes: "—" indicates variable is not significant or was excluded from model for collinearity problems. An example model equation is provided for dissolved copper:

$$Ln[Cu, dissolved, mg/L] = 3.632 - 0.390(LnEventRainfall) + 0.193(LnAntecedentDryPeriod) - 0.129\left(\sqrt[3]{CumulativePrecip}\right) + 0.060(LnDrainageArea)$$

(1) Unstandardized model coefficients: Positive coefficients indicate a tendency to cause an increase in the pollutant concentration or parameter in runoff. Negative coefficients indicate a tendency to cause decrease in the parameter concentration.

(2) Standardized coefficients allow comparison of the magnitude of the effects among independent variables with different measurement units

Table 3-9 Effects of Precipitation, Antecedent Conditions, Drainage Area, and AADT on Runoff Quality from Highways: Multiple Linear Regression (MLR) Model Statistics and Coefficients for Whole Storm (EMC) data.

		Model Statistics				Model Coefficients [(1)] (intercept and independent variables)								Standardized Model Coefficients [(2)]						
Pollutant Category	Dependent Variable, *X* (Runoff Quality Parameter)	Form of X in Model	df	Adjusted Model R-Squared	S.E of Model Estimate	constant (y-Int.)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	AADT*10-6 (vehicles/day)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	AADT*10-6 (vehicles/day)
Conventional	DOC	Ln(*X*)	590	0.410	0.614	4.113	(-0.404)	—	0.123	(-0.129)	—	—	—	(-0.435)	—	0.163	(-0.351)	—	—	—
	EC	Ln(*X*)	581	0.480	0.573	4.680	(-0.316)	—	0.110	(-0.032)	—	—	4.222	(-0.343)	—	0.145	(-0.088)	—	—	0.453
	Hardness as CaCO3	Ln(*X*)	579	0.339	0.656	3.841	(-0.220)	—	0.046	(-0.074)	—	—	3.502	(-0.235)	—	0.060	(-0.199)	—	—	0.370
	pH	*X*	582	0.313	0.587	6.585	—	—	(-0.091)	(-0.032)	—	0.0055	4.406	—	—	(-0.135)	(-0.098)	—	0.1330	0.531
	TDS	Ln(*X*)	572	0.292	0.725	4.731	(-0.309)	—	0.126	(-0.050)	—	—	2.582	(-0.310)	—	0.154	(-0.127)	—	—	0.255
	Temperature	*X*	174	0.096	3.174	14.569	—	—	—	(-0.431)	—	—	—	—	—	—	(-0.318)	—	—	—
	TOC	Ln(*X*)	583	0.144	1.086	5.233	(-0.209)	—	0.129	(-0.154)	—	—	—	(-0.153)	—	0.116	(-0.282)	—	—	—
	TSS	Ln(*X*)	575	0.254	1.015	4.275	(-0.124)	—	0.102	(-0.099)	—	—	4.934	(-0.091)	—	0.091	(-0.182)	—	—	0.358
Trace Metals	As, total	Ln(*X*)	389	0.041	0.777	1.210	—	—	—	(-0.087)	—	—	—	—	—	—	(-0.207)	—	—	—
	Cd, total	Ln(*X*)	472	0.205	0.647	0.084	(-0.149)	—	—	(-0.084)	—	—	2.458	(-0.172)	—	—	(-0.228)	—	—	0.268
	Cr, dissolved	Ln(*X*)	505	0.253	0.601	1.098	(-0.109)	—	—	(-0.046)	(-0.246)	—	3.070	(-0.135)	—	—	(-0.136)	(-0.362)	—	0.373
	Cr, total	Ln(*X*)	565	0.240	0.737	1.618	(-0.099)	—	0.106	(-0.055)	(-0.234)	—	3.508	(-0.101)	—	0.131	(-0.139)	(-0.282)	—	0.353
	Cu, dissolved	Ln(*X*)	581	0.508	0.615	2.919	(-0.290)	—	0.185	(-0.102)	—	—	3.679	(-0.286)	—	0.222	(-0.254)	—	—	0.357
	Cu, total	Ln(*X*)	582	0.524	0.722	2.900	(-0.161)	—	0.163	(-0.079)	—	—	6.823	(-0.133)	—	0.164	(-0.165)	—	—	0.555
	Ni, dissolved	Ln(*X*)	474	0.270	0.569	2.731	(-0.270)	—	0.068	(-0.107)	(-0.094)	(-0.0029)	—	(-0.342)	—	0.105	(-0.337)	(-0.142)	(-0.0790)	—
	Ni, total	Ln(*X*)	557	0.224	0.673	2.511	(-0.196)	—	0.141	(-0.075)	(-0.155)	—	1.013	(-0.219)	—	0.193	(-0.208)	(-0.207)	—	0.113
	Pb, dissolved	Ln(*X*)	376	0.076	1.148	2.042	(-0.248)	—	—	(-0.101)	—	0.0065	—	(-0.187)	—	—	(-0.173)	—	0.0950	—
	Pb, total	Ln(*X*)	586	0.364	1.183	2.272	—	—	—	(-0.102)	—	—	9.650	—	—	—	(-0.144)	—	—	0.545
	Zn, dissolved	Ln(*X*)	577	0.316	0.794	4.740	(-0.343)	—	0.164	(-0.112)	—	—	1.676	(-0.308)	—	0.180	(-0.253)	—	—	0.149
	Zn, total	Ln(*X*)	579	0.509	0.757	4.827	(-0.227)	—	0.143	(-0.084)	—	—	6.747	(-0.181)	—	0.139	(-0.169)	—	—	0.532
Nutrient	NO3-N	Ln(*X*)	529	0.371	0.735	1.299	(-0.417)	—	0.092	(-0.090)	—	(-0.0072)	2.870	(-0.387)	—	0.103	(-0.197)	—	(-0.1340)	0.260
	Ortho-P, dissolved	Ln(*X*)	382	0.149	0.694	(-1.160)	(-0.240)	—	0.084	(-0.077)	—	—	(-1.927)	(-0.269)	—	0.117	(-0.209)	—	—	(-0.214)
	P, total	Ln(*X*)	520	0.102	0.776	(-1.212)	(-0.143)	—	0.128	(-0.051)	—	—	0.900	(-0.148)	—	0.163	(-0.128)	—	—	0.094
	TKN	Ln(*X*)	537	0.385	0.656	1.689	(-0.343)	—	0.102	(-0.128)	—	—	1.535	(-0.355)	—	0.128	(-0.331)	—	—	0.155

Notes: "—" indicates variable is not significant or was excluded from model for collinearity problems. An example model equation is provided for dissolved copper:

$$Ln[Cu, dissolved, mg/L] = 2.919 - 0.290(LnEventRainfall) + 0.185(LnAntecedentDryPeriod) - 0.102\left(\sqrt[3]{CumulativePrecip}\right) + 3.679\left(AADT \cdot 10^{-6}\right)$$

(1) Unstandardized model coefficients: Positive coefficients indicate a tendency to cause an increase in the pollutant concentration or parameter in runoff. Negative coefficients indicate a tendency to cause decrease in the parameter concentration.

(2) Standardized coefficients allow comparison of the magnitude of the effects among independent variables with different measurement units

Table 3-10 Summary of Significant Covariate Effects for Multiple Linear Regression Models of Runoff Quality from all Department Facilities.

Covariate Factor (predictor variable form)	Dominant effect on pollutant concentrations(1)	Ratio of models exhibiting significant dominant effect(2)	Exceptions(3)	Comments
Event Rainfall (LnX)	Concentrations decrease with higher total event rainfall.	22 of 22 models had a significant negative coefficient	*Positive* : none; *Not significant* : As-tot, temperature	Very consistent predictor. Same pattern for all models.
Maximum Rainfall Intensity (LnX)	Not included in any models	Not included in any models	None (excluded for collinearity problems)	*Not significant* is the most common result. Although significant for some parameters, maximum intensity is highly correlated with event rainfall (R = 0.54). Generally appears not to be a good predictor variable due to collinearity problems.
Antecedent Dry Period (LnX)	Concentrations increase with longer antecedent dry period	16 of 16 models had a significant positive coefficient	*Negative* : none *Not significant* : hardness, pH, TOC, As-tot, Cd-tot, Cr-dis, Cu-tot, Pb-dis	Very consistent predictor. Same pattern for all models.
Seasonal Cumulative Precipitation (Cube Root of X)	Concentrations decrease as cumulative rainfall increases	24 of 24 models had a significant negative coefficient	*Positive* : none *Not significant* : none	Most consistent predictor. Significant for all paramters and same pattern for all models.
Drainage Area (LnX)	No consistent dominant effect	7 of 11 models had a significant negative coefficient	*Negative:* Cr-dis, Ni, dis, Ni-tot, Orthophosphate	Negative for Cr-dis, Cr-tot, Ni-dis, and Ni-tot, but *not significant* is the most common result. Appears to be a poor predictor overall.
Impervious Fraction (ArcSin-SquareRoot of X)	Concentrations decrease as imperviousness increases	6 of 9 models had a significant negative coefficient	*Positive:* pH, Cr-tot, Pb-dis	*Not significant* is the most common result. Effect is small compared to other factors. Appears to be a poor predictor.

(1) Summarized for MLR models including only Statewide characterization studies whole storm data. "Dominant Effect" is the most frequently observed sign of significant coefficients for the factor in MLR models. Concentrations are said to increase if most coefficients are positive, and to decrease if most coefficients are negative. In all cases, the relationship between covariate and dependent variables (after transforming to approximate normality) is approximately linear.

(2) Threshold of statistical significance is $p<0.05$.

(3) Constituents for which the predictor had a significant effect opposite to the dominant effect for the predictor.

Table 3-11 Summary of Significant Covariate Effects for Multiple Linear Regression Models of Highway Runoff Quality.

Covariate Factor (predictor variable form)	Dominant effect on pollutant concentrations[1]	Ratio of models exhibiting significant dominant effect[2]	Exceptions[3]	Comments
Event Rainfall (LnX)	Concentrations decrease with higher total event rainfall.	22 of 22 models had a significant negative coefficient	*Positive* : none; *Not significant* : pH, temperature, As-tot, Pb-tot	Very consistent predictor. Same pattern for all models.
Maximum Rainfall Intensity (LnX)	Not included in any models	Not included in any models	None (excluded for collinearity problems)	*Not significant* is the most common result. Although significant for some parameters, maximum intensity is highly correlated with event rainfal (R = 0.54). Generally appears not to be a good predictor variable due to collinearity problems.
Antecedent Dry Period (LnX)	Concentrations increase with longer antecedent dry period	17 of 18 models had a significant positive coefficient	*Negative* : pH *Not significant* : temperature, As-tot, Cd-tot, Cr-dis, Pb-dis, Pb-tot	Very consistent predictor. Same pattern for nearly all models.
Seasonal Cumulative Precipitation (cube root of X)	Concentrations decrease as cumulative rainfall increases	24 of 24 models had a significant negative coefficient	*Positive* : none *Not significant* : none	Most consistent predictor. Same pattern for all models.
Drainage Area (LnX)	Concentrations are lower for larger drainage areas	4 of 4 models had a significant negative coefficient	*Positive* : none	Negative for Cr-dis, Cr-tot, Ni-dis, and Ni-tot, but *not significant* is the most common result. Appears to be a poor predictor overall.
Impervious Fraction (ArcSin-SquareRoot of X)	No consistent dominant effect	2 of 4 models had a significant positive coefficient	No dominant pattern.	*Not significant* is the most common result. Effect is small compared to other factors. Appears to be a poor predictor.
AADT ($AADTx10^{-6}$)	Concentrations are higher for sites with higher traffic	17 of 18 models had a significant positive coefficient	*Negative* : Orthophosphate *Not significant* : DOC, TOC, temperature, As-tot, Ni-dis, Pb-dis.	Very consistent predictor. Same pattern for nearly all models.

(1) Summarized for MLR models including only Statewide characterization studies whole storm data for highways. "Dominant Effect" is the most frequently observed sign of significant coefficients for the factor in MLR models. Concentrations are said to increase if most coefficients are positive, and to decrease if most coefficients are negative. In all cases, the relationship between covariate and dependent variables (after transforming to approximate normality) is approximately linear.

(2) Threshold of statistical significance is $p<0.05$.

(3) Constituents for which the predictor had a significant effect opposite to the dominant effect for the predictor.

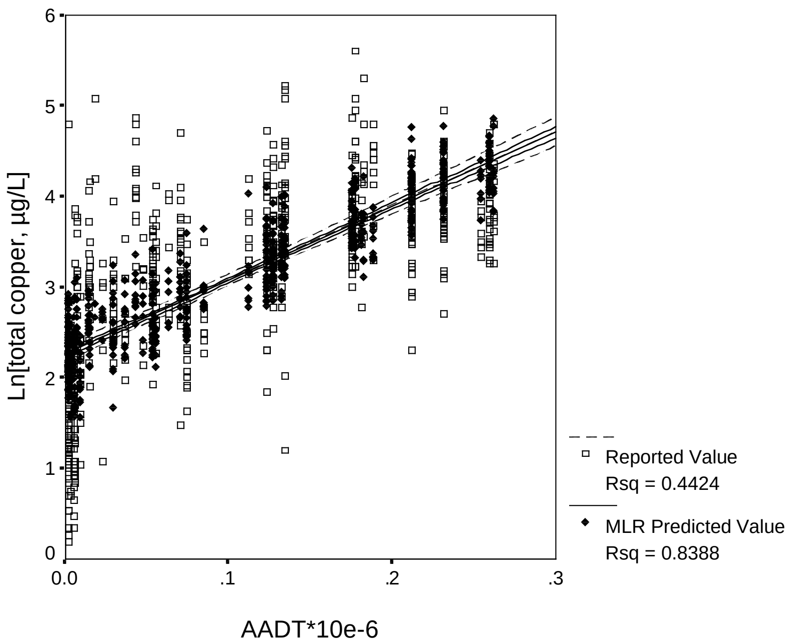


Figure 3-1 Effect of AADT on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified AADT.

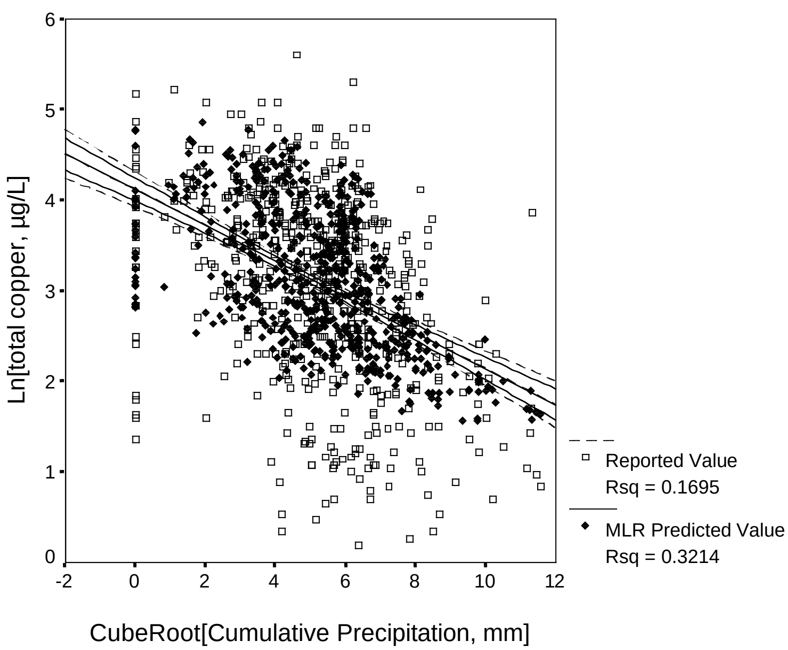


Figure 3-2 Effect of cumulative precipitation on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified cumulative seasonal precipitation.

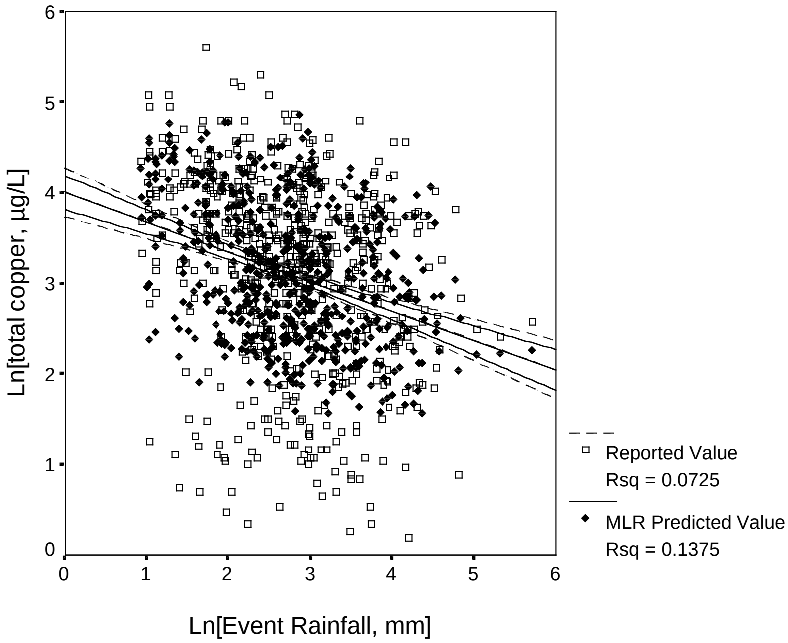


Figure 3-3 Effect of event rainfall on total copper concentrations.
Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified event rainfall.

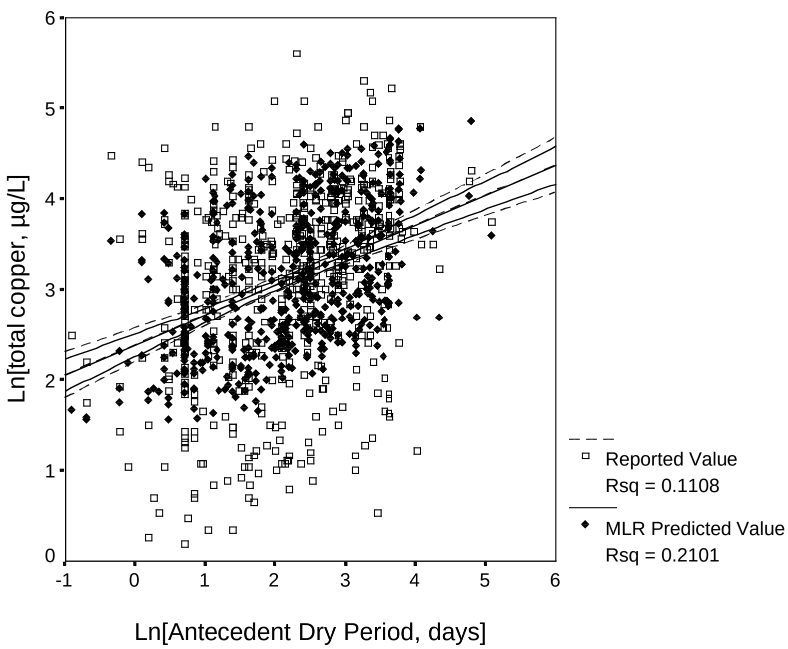


Figure 3-4 Effect of antecedent dry period on total copper concentrations.
Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified antecedent dry period.

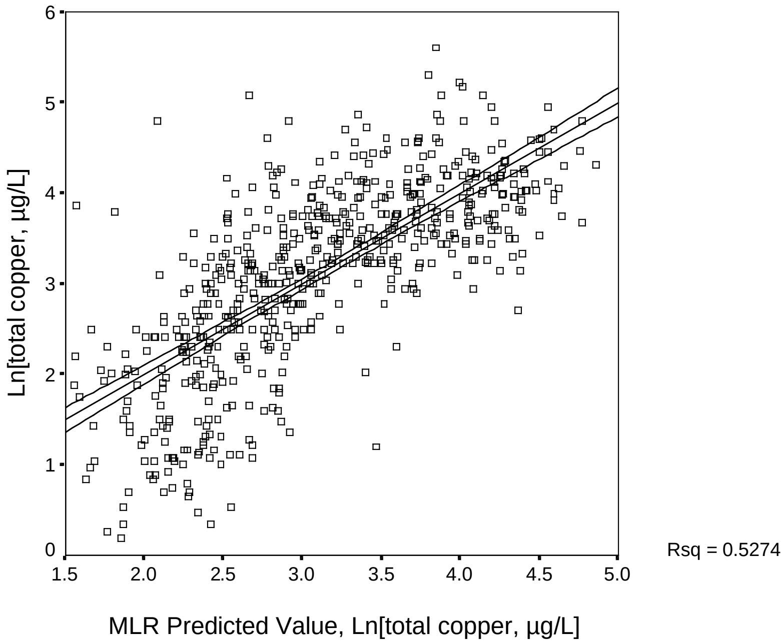


Figure 3-5 MLR model for total copper.
Regression fit lines illustrate mean and 95% confidence interval for mean reported Ln(total copper).

Model Validation

Although not a specific objective of this study, several of the best MLR models were validated using data not included in the dataset used to develop the MLR models. The MLR models for DOC, total copper, total zinc, and nitrate were used to predict concentrations of these pollutants for highway sites and storm events that were not part of the Statewide characterization studies dataset. These parameters were selected as representative models in each pollutant category. These predicted concentrations were compared to actual reported concentrations using standard linear regression analysis. The results of these comparisons are summarized in Table 3-12, and illustrated in Figure 3-6 through Figure 3-9.

The purpose of this validation exercise was to assess how well some of the best models were able to predict pollutant concentrations for new highway sites and storm events. Based on inspection of the regression plots, there was no apparent systematic bias in the predicted values and the range and distribution of the predicted values agreed well with the validation data. Note that the range of predicted values is expected to be smaller than that of the validation data set, because they are model predictions without the inherent variability of actual environmental data. The Coefficients of determination (R^2 values) for the MLR models developed with Statewide characterization studies data were compared with R^2 values for the regressions of validation data on MLR-predicted values for each parameter. The R^2 values for the regression of new data on MLR-predicted concentrations are similar to the R^2 values for the original MLR models, indicating that the overall fit of the validation data was similar to the original data used to develop the models. The slopes of the regressions were also evaluated for potential bias in MLR-predicted values. The slopes of the DOC and total zinc validation regressions were significantly different from one, indicating that models that included the validation data would differ slightly from the MLR models developed for this study. The slopes for the total copper and nitrate regressions were not significantly different from one at the 95% confidence level, indicating that models that included the validation data would not be significantly different from the current MLR models for these parameters. If the regressions of validation and predicted values were forced through zero (i.e., if the intercept was assumed to be zero), the slopes for all four validation regressions were not significantly different from one. Overall, these results indicate that the MLR-models for these parameters provide reasonable and realistic estimates of pollutant concentrations in runoff, and validates the process used to develop these models.

Table 3-12 Results of comparisons of MLR-predicted values to validation data

Model	Coefficients			95% Confidence Interval		Validation R^2	Original MLR R^2
	B	Std. Error	p-value	Lower Bound	Upper Bound		
Ln[DOC]							
Intercept	-.550	.148	.0002	.-.840	-.260		
MLR predicted Ln[DOC]	1.215	.059	<.0001	1.100	1.331	.504	.410
Ln[Total Copper]							
Intercept	.107	.127	.3995	-.142	.356		
MLR predicted Ln[total copper]	.944	.037	<.0001	.871	1.017	.480	.524
Ln[Total Zinc]							
Intercept	.722	.192	.0002	.344	1.099		
MLR predicted Ln[total zinc]	.829	.038	<.0001	.755	.904	.405	.509
Ln[NO_3-N]							
Intercept	.005	.029	.0789	-.006	.109		
MLR predicted Ln[total zinc]	.939	.046	<.0001	.849	1.029	.394	.371

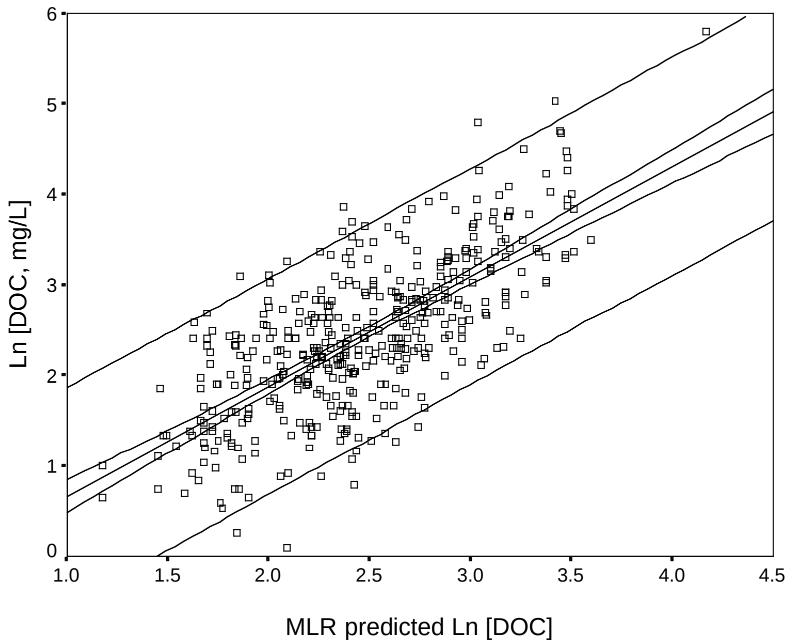


Figure 3-6 Validation data set for DOC vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(DOC) and individual predicted Ln(DOC).

Ln(Y) = 4.113 - .404 *Ln(*EventRain*) + .123*Ln(*AntDry*) - .129*CubeRoot(*CumPrecip*)
R^2 = .504

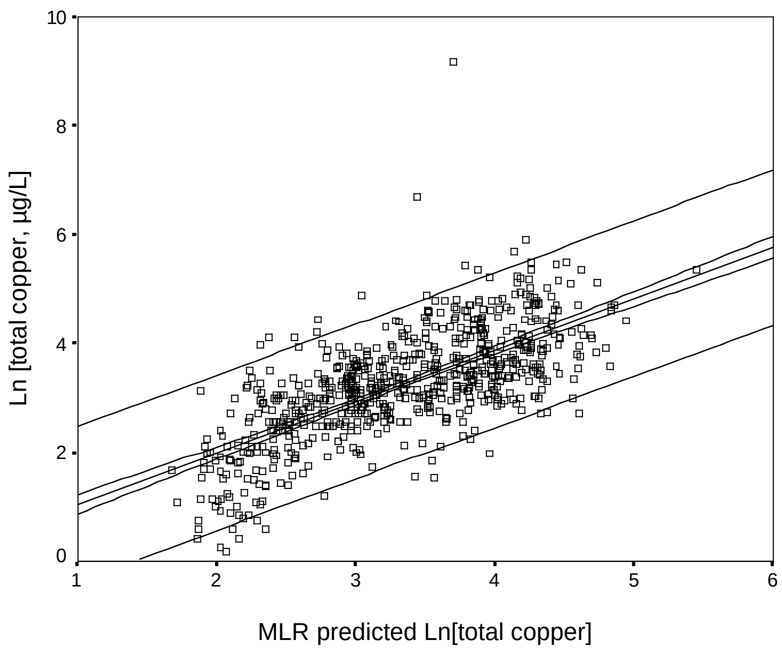


Figure 3-7 Validation data set for total copper vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(total copper) and individual predicted Ln(total copper).

Ln(y) = 2.9 - .161 *Ln(EventRain) + .163*Ln(AntDry) - .079*CubeRoot(CumPrecip) + 6.823*AADT*10-6
R^2 = .480

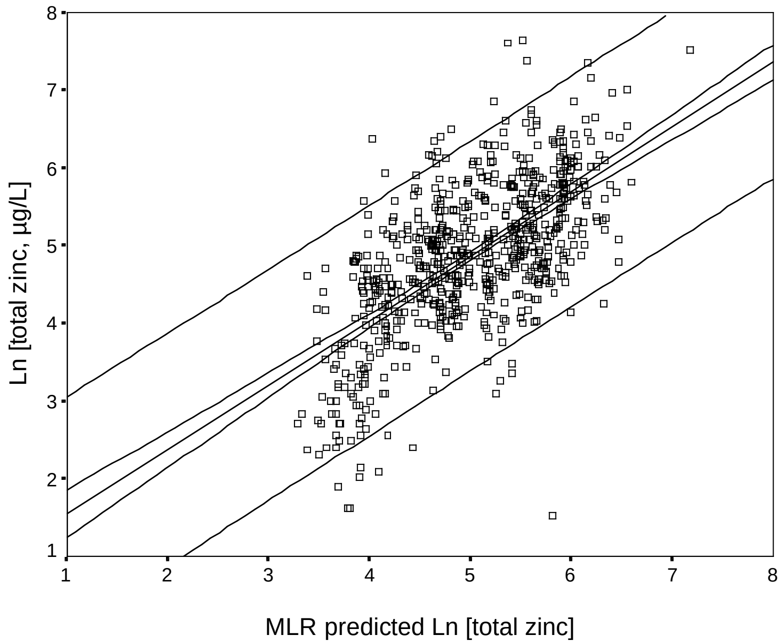


Figure 3-8 Validation data set for total zinc vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(total zinc) and individual predicted Ln(total zinc).

Ln(y) = 4.827 - .227 *Ln(EventRain) + .143*Ln(AntDry) - .084*CubeRoot(CumPrecip) + 6.747*AADT*10-6
R^2 = .405

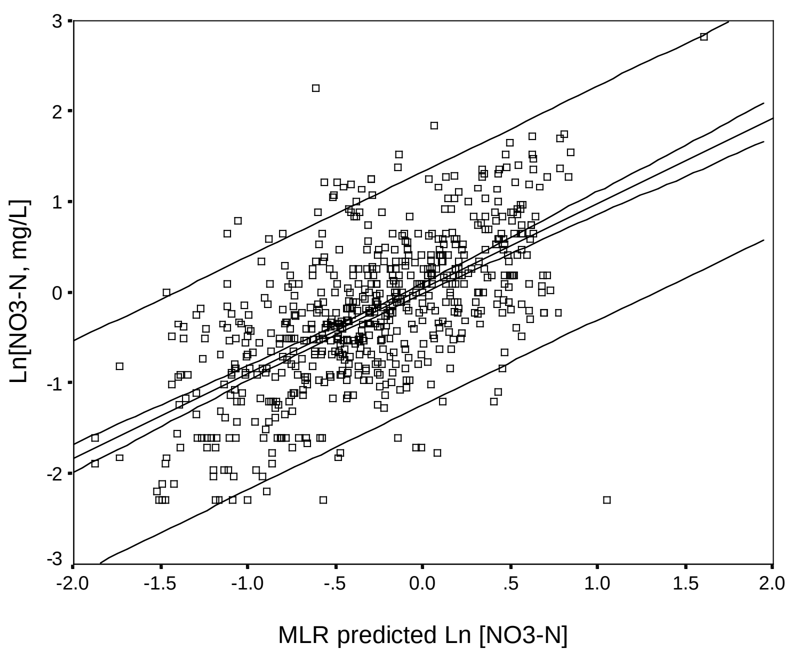


Figure 3-9 Validation data set for nitrate vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(NO_3-N) and individual predicted Ln(NO_3-N).

Ln(y) = 1.299 - .417 *Ln(EventRain) + .092*Ln(AntDry) - .090*CubeRoot(CumPrecip) - .0072*Ln(DrainageArea) + 2.870*AADT*10-6
R^2 = .405

Annual, Seasonal, and Intra-Event Variation

Annual Variation and Trends

Annual variability in runoff quality was assessed using ANOVA methods. Results of ANOVA analyses of the effects of annual variation on runoff quality are summarized in Table 3-13 for Department facilities monitored as part of the Statewide characterization studies. Annual variability in runoff quality was significant for a variety of constituents, but was generally small in most cases. Note that because the data cover only three monitoring years, these conclusions should not be extrapolated to longer-term patterns of annual variation. Patterns in annual variation for the three year period monitored are summarized below:

- Conventional parameters (organic carbon, EC, hardness, pH, TDS, temperature, and TSS) generally exhibited the highest annual variability, and annual variation was significant in 29 of 48 comparisons for conventional parameters. Annual variability tended to be higher for vehicle inspection facilities, park-and-ride facilities, rest areas, and toll plazas, with significant variation ranging from 5% - 42% in median runoff quality (depending on parameter and facility). Annual variation was typically lower for highway sites and maintenance stations, with significant variations in median runoff quality less than 10% for all conventional parameters.

- Trace metals generally exhibited low or insignificant annual variability. Annual variation was significant in 31 of 84 cases for trace metals (with each case consisting of the data for one parameter and one facility type). Annual variability in trace metals was generally not significant at Caltrans vehicle inspection facilities and toll plaza sites. Variation tended to be higher for rest areas and maintenance facilities, with significant variation ranging from 7% - 55% in median runoff quality (depending on parameter and facility). Annual variation was typically lowest for highway sites and maintenance stations, with significant variation in median runoff quality of less than 5% for all metals.

- Nutrients (nitrate, orthophosphate, total phosphorus, and TKN) generally exhibited the most frequently significant annual variation, with significant variation in 16 of 24 comparisons. However, the contribution of annual variability was typically low (not significant or less than or equal to 10%) for most parameters and facilities. Annual variation in median runoff quality for nutrients was highest for rest areas, with significant annual variation in median orthophosphate concentrations (30%), total phosphorus (17%), and TKN (19%) for this category of facility.

Seasonal Variation

The effect of the seasonal variation on runoff quality was assessed by evaluating the effect of cumulative seasonal precipitation on runoff quality in the MLR models. Cumulative seasonal precipitation exhibited a significant negative effect in every MLR model indicating that pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. Cumulative seasonal precipitation had a statistically significant effect in the MLR models for every Statewide characterization studies constituent evaluated, and significant coefficients for this factor were negative in every case. Preliminary results from the Department's First Flush

Characterization study (summarized in Appendix _) also reported a significant seasonal first flush effect for many pollutants in runoff.

Intra-Event Variation ("First Flush")

The effect of an intra-event first flush was evaluated using the MLR results for Event Rainfall (the total amount of rainfall recorded for a specific storm event). The results of these analyses indicated that increasing amounts of rainfall tended to result in a decrease in pollutant concentrations in runoff. This was interpreted to mean that the highest concentrations of pollutants occurred in runoff from the early part of the storm event, with concentrations becoming more dilute with increasing rainfall amounts. This indirect evidence of significant intra-event first flush effect was observed for nearly every conventional, trace metal, and nutrient parameter, and has been corroborated by the preliminary results from the Department's First Flush Characterization study, which was designed specifically to address this question.

Table 3-13 Annual Variation in Runoff Quality, Statewide Characterization Studies Data for Caltrans Facilities, 2000/01-2002/03

Pollutant Category	Parameter	Fraction	Proportion (%) of variation in runoff quality due to annual variation					
			CVIF	Highway	Maintenance	Parking	Rest Area	Toll Plaza
Conventional	DOC		26	6	ns	15	42	27
	EC		NS	4	ns	10	27	ns
	Hardness as $CaCO_3$		NS	6	9	14	ns	ns
	pH		NS	11	7	5	ns	ns
	TDS		NS	3	ns	9	24	ns
	Temperature		—	4	ns	ns	ns	—
	TOC		29	7	6	18	28	24
	TSS		11	2	8	4	ns	30
Trace Metals	As	Dissolved	NS	2	15	5	ns	ns
	As	Total	NS	1	18	4	ns	ns
	Cd	Dissolved	NS	2	ns	4	ns	ns
	Cd	Total	NS	2	8	ns	ns	ns
	Cr	Dissolved	NS	ns	ns	5	ns	ns
	Cr	Total	NS	ns	ns	12	28	ns
	Cu	Dissolved	NS	ns	13	4	40	ns
	Cu	Total	NS	ns	8	ns	55	ns
	Ni	Dissolved	NS	2	ns	ns	ns	ns
	Ni	Total	NS	2	ns	ns	18	ns
	Pb	Dissolved	NS	ns	ns	ns	ns	ns
	Pb	Total	NS	3	ns	4	31	28
	Zn	Dissolved	18	1	18	ns	26	ns
	Zn	Total	NS	3	15	ns	38	ns
Nutrient	NO_3-N		NS	2	7	10	ns	ns
	Ortho-P	Dissolved	NS	2	13	4	30	ns
	P	Total	NS	3	8	ns	17	ns
	TKN		21	5	10	10	19	18

Note:"—" indicates paramter wasnot monitored at this location.
"ns" indicates annual variation was not statistically significant at the 95% confidence level.

Runoff Quality from Different Facilities

Differences in runoff quality from different Caltrans facilities were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of ANCOVA analyses of differences in runoff quality for different Caltrans facilities are presented in Table 3-14. Summary statistics for the Statewide characterization studies data are also provided in Table 3-15. Caltrans facilities exhibited significant differences in runoff quality for all constituents except TKN. A significant result for the ANCOVA analysis indicates that at least one of the six facilities was significantly different from the overall average at the 95% confidence level. It does not indicate that every facility type is significantly different from every other facility type.

The results of these comparisons were as follows:

- **Conventional parameters:** Highway sites exhibited higher conventional pollutant concentrations in runoff than other facilities for DOC, EC, hardness, and TDS. Maintenance facilities, park-and-ride sites, and rest areas generally exhibited lower conventional pollutant concentrations in runoff. Toll plazas had higher than average concentrations of TOC and TSS in runoff, and lower pH. CVIF sites were generally not significantly different from overall average concentrations.

- **Trace metals:** Highway and toll plaza sites generally exhibited higher than average trace metal concentrations in runoff. Park-and-ride sites, and rest areas generally exhibited lower metals concentrations in runoff, and CVIF sites were typically not significantly different from average runoff quality. The exceptions to this pattern included arsenic and zinc, which were higher in maintenance facilities and CVIF runoff.

- **Nutrients:** Nutrient concentrations in highway runoff were not significantly different from the overall average, with the exception of NO_3-N. Maintenance facilities had consistently lower than average nutrient concentrations. There were no consistent patterns in nutrient concentrations for runoff from other facilities.

In general, these results indicate that higher pollutant concentrations in runoff are seen for facilities with generally higher vehicle traffic rates, as expected for highway and toll plaza sites. This pattern also corroborates the results of the MLR analyses, which established that higher AADT is associated with higher concentrations of most pollutant concentrations. Figure 3-10 and Figure 3-11 are provided to illustrate the interpretation of the pattern of differences in runoff quality from different facilities for TOC (Figure 3-10) and Nitrate (Figure 3-11).

Table 3-14 Significant Differences in Runoff Quality from Caltrans Facilities.

Pollutant Category	Parameter	Fraction	Significant Variation due to Facility Type?	Facilities with Significant Differences from Overall Facility Average Runoff Quality	
				Facilities Above Overall Average	**Facilities Below Overall Average**
Conventional	DOC		YES	HWY	PRK
	EC		YES	HWY	MAINT, PRK, REST
	Hardness as CaCO3		YES	HWY	MAINT, PRK, REST
	pH		YES	HWY	MAINT, PRK, REST, TOLL
	TDS		YES	HWY	MAINT, PRK, REST
	Temperature		NO	ns	ns
	TOC		YES	TOLL	PRK, REST
	TSS		YES	TOLL	PRK, REST
Trace Metals	As	Total	YES	MAINT	PRK, TOLL
	Cd	Total	YES	HWY, TOLL	PRK, REST
	Cr	Dissolved	YES	HWY, TOLL	CVIF, MAINT, PRK, REST
	Cr	Total	YES	HWY, TOLL	MAINT, PRK, REST
	Cu	Dissolved	YES	HWY, TOLL	PRK, REST
	Cu	Total	YES	HWY, TOLL	PRK, REST
	Ni	Dissolved	YES	HWY	PRK
	Ni	Total	YES	HWY, TOLL	PRK, REST
	Pb	Dissolved	YES	HWY	MAINT, PRK, REST
	Pb	Total	YES	HWY, TOLL	CVIF, PRK, REST
	Zn	Dissolved	YES	CVIF, MAINT, TOLL	HWY, PRK
	Zn	Total	YES	MAINT, TOLL	REST
Nutrient	NO3-N		YES	HWY	MAINT, PRK
	Ortho-P	Dissolved	YES	CVIF, REST	TOLL
	P	Total	YES	REST	MAINT
	TKN		NO	ns	ns

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Facility Type Designations: CVIF=Caltrans Vehicle Inspection Facility, HWY = Highway, MAINT = Maintenance, PRK = Park-and-Ride, REST = Rest Area, TOLL = Toll Plaza.

Table 3-15 Summary statistics for parameters monitored by the CALTRANS Statewide Characterization Study: Mean and Standard Deviation for Facilities.

Pollutant Category	Parameter	Units	Facility											
			CVIF		Hwy		Maintenance		Parking		Rest Area		Toll Plaza	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Conventional	DOC	mg/L	18.5	15.9	18.7	26.2	18.2	18.2	18.0	28.6	19.9	39.6	25.6	19.8
	EC	µS/cm	113.3	137.3	96.1	73.4	80.9	110.6	63.5	65.8	78.2	132.0	118.9	100.2
	Hardness as CaCO3	mg/L	33.5	22.1	36.5	34.2	26.7	28.7	26.6	45.9	33.0	81.2	37.1	27.7
	Chloride	mg/L	—	—	265.9	388.0	—	—	—	—	—	—	—	—
	pH	pH	7.1	0.4	7.1	0.7	6.8	0.6	6.8	0.7	6.9	0.4	6.9	0.4
	TDS	mg/L	84.8	92.1	87.3	103.7	68.9	78.1	61.7	78.3	61.2	130.0	81.5	74.2
	Temperature		12.5	3.3	12.5	3.4	12.5	2.8	12.6	3.4	11.4	3.2	12.3	3.0
	TOC	mg/L	20.0	16.9	21.8	29.2	20.6	23.0	18.6	20.6	22.2	40.5	31.0	20.3
	TSS	mg/L	83.4	53.0	112.7	188.8	96.4	95.0	68.5	59.3	63.3	54.4	123.3	77.4
	Turbidity	NTU	—	—	—	—	144.83	92.23	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	4.95	11.41	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	3.72	3.31	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	IDD	IDD	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	2.71	3.40	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	1.0	0.4	1.0	1.4	9.5	17.3	0.7	0.6	1.4	3.3	0.8	0.4
	As, total	µg/L	3.4	16.1	2.7	7.9	12.8	23.1	1.4	5.9	3.6	11.4	1.5	0.8
	Cd, dissolved	µg/L	0.20	0.16	0.24	0.54	0.27	0.22	0.12	0.12	IDD	IDD	0.43	0.29
	Cd, total	µg/L	0.56	0.40	0.73	1.61	0.69	0.63	0.30	0.30	0.32	0.53	1.15	0.56
	Cr, dissolved	µg/L	1.8	1.2	3.3	3.3	1.4	1.0	1.0	0.9	1.9	2.5	5.1	2.5
	Cr, total	µg/L	8.1	4.8	8.6	9.0	5.1	4.3	4.0	4.2	4.8	3.8	12.5	7.7
	Cu, dissolved	µg/L	15.6	13.3	14.9	14.4	14.3	17.6	8.7	8.8	9.6	12.0	27.3	20.6
	Cu, total	µg/L	33.6	24.1	33.5	31.6	29.5	37.6	17.1	15.2	16.0	14.2	59.6	23.0
	Hg, dissolved	ng/L	IDD	IDD	—	—	27.7	51.4	IDD	IDD	—	—	IDD	IDD
	Hg, total	ng/L	IDD	IDD	36.7	37.9	65.4	83.7	57.3	73.6	—	—	IDD	IDD
	Ni, dissolved	µg/L	3.5	2.4	4.9	5.0	3.7	4.0	3.3	3.9	3.2	5.8	6.0	4.5
	Ni, total	µg/L	8.4	4.7	11.2	13.2	7.9	7.7	6.2	4.8	7.3	8.3	13.7	6.8
	Pb, dissolved	µg/L	2.7	3.9	7.6	34.3	1.6	3.0	1.3	2.7	1.2	1.7	5.2	5.2
	Pb, total	µg/L	21.9	37.7	47.8	151.3	21.3	26.5	10.3	11.5	7.7	8.0	31.6	24.3
	Zn, dissolved	µg/L	88.2	79.1	68.8	96.6	21.3	26.5	10.3	11.5	82.5	263.7	123.7	89.4
	Zn, total	µg/L	244.5	151.6	187.1	199.8	245.6	259.3	154.3	157.1	142.4	298.9	292.9	131.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	1132	1621	—	—	—	IDD	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	13438	34299	—	—	—	IDD	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	1.08	1.46	—	—	—	IDD	—	—	—	—
	NO3-N	mg/L	0.89	0.81	1.07	2.44	0.74	1.13	0.57	IDD	0.96	0.88	0.84	0.81
	Ortho-P, dissolved	mg/L	0.13	0.12	0.11	0.18	0.09	0.40	0.15	IDD	0.44	1.67	0.05	0.05
	P, total	mg/L	0.28	0.16	0.29	0.39	0.23	0.20	0.33	0.42	0.47	0.53	0.25	0.11
	TKN	mg/L	2.16	2.72	2.06	1.90	1.79	1.72	2.28	2.20	4.37	14.04	2.38	1.59
Pesticide	Chlorpyrifos	µg/L	—	—	—	—	IDD	IDD	—	—	—	—	—	—
	Diazinon	µg/L	IDD	IDD	0.13	0.29	0.12	0.30	IDD	IDD	—	—	IDD	IDD
	Diuron	µg/L	—	—	4.60	18.24	—	—	—	—	IDD	IDD	—	—
	Glyphosate	µg/L	—	—	19.61	26.97	—	—	—	—	IDD	IDD	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Acenaphthylene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Chrysene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Fluorene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Naphthalene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Phenanthrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Pyrene	µg/L	—	—	0.05	0.03	—	—	IDD	IDD	—	—	—	—

Notes: "IDD" indicates that there were insufficient detected data to calculate statistic.
"—" indicates parameter was not monitored Statewide characterization studies for this facility.

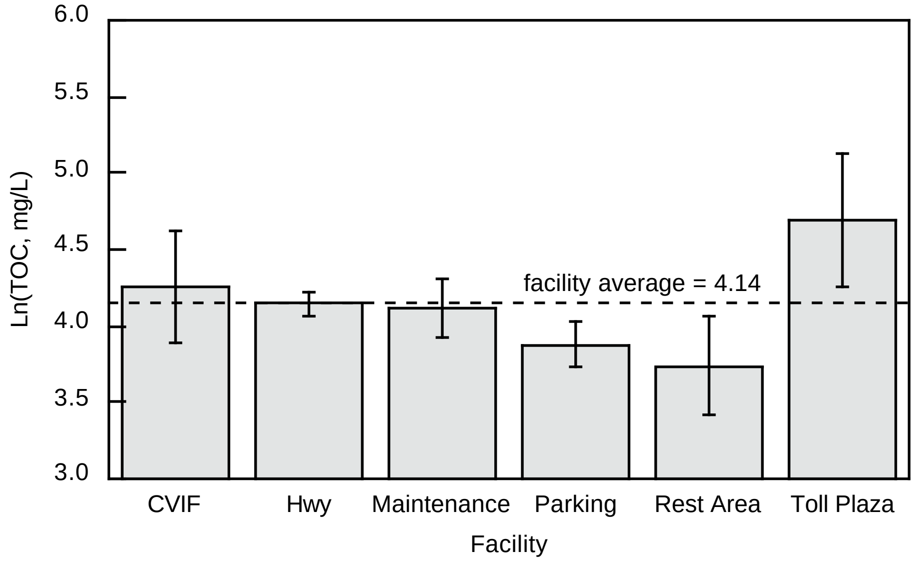


Figure 3-10 Estimated Marginal Means and 95% confidence limits for TOC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions.

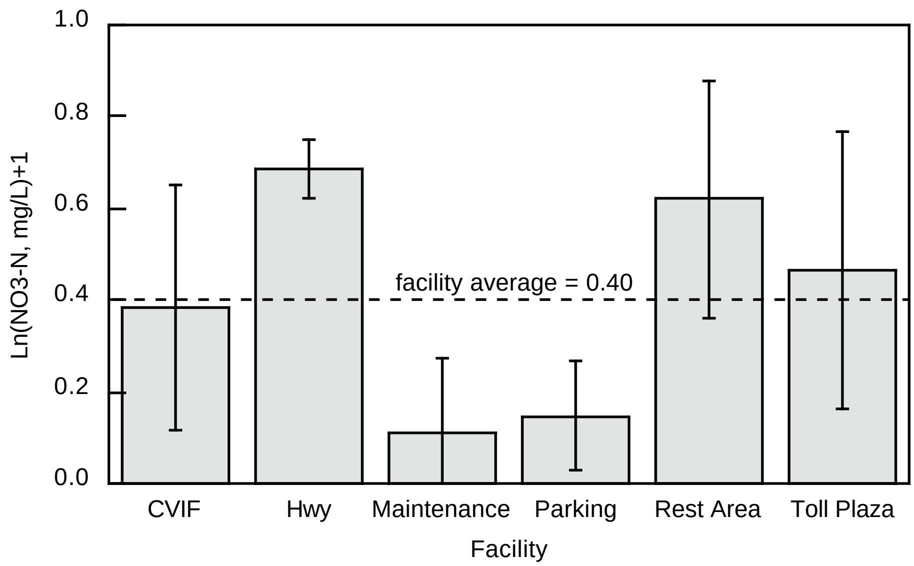


Figure 3-11 Estimated Marginal Means and 95% confidence limits for Nitrate

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions.

Geographic Variation Analysis Results

The effects of geographic region on stormwater runoff quality from highways were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of these analyses are summarized in Table 3-16. Geographic region exhibited significant effects on runoff quality for most constituents (exceptions were pH, temperature, and dissolved zinc). A few broadly defined patterns emerged for this factor:

- ***Conventional parameters:*** Highway sites in the Central and Southern Coast Ranges, the Klamath Mountains, and the Central Coast region generally exhibited higher conventional pollutant concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Temperate Desert region generally exhibited lower conventional pollutant concentrations in runoff.
- ***Trace metals:*** Highway sites in the Klamath Mountains, the Central Valley, and the Central Coast region generally exhibited higher trace metals concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Temperate Desert region generally exhibited lower metals concentrations in runoff.
- ***Nutrients:*** Highway sites in the Central Valley, the North Coast Interior Range, and the Central and Southern Coast Ranges generally exhibited higher nutrient concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Central Coast region generally exhibited lower nutrient concentrations in runoff.

Note that the numbers of sites monitored were limited for some regions (North Coast Range and Interior Range, Klamath Mountains, Temperate Desert), as these areas are characterized by relatively fewer highway miles; results of the geographical variation analysis for these regions therefore should be interpreted with a degree of caution. Figure 3-12 illustrates Caltrans monitoring locations and geographic regions. Figure 3-13 and Figure 3-14 are provided to illustrate the interpretation of the pattern of differences in runoff quality from different geographic regions for Total copper (Figure 3-13) and EC (Figure 3-14).

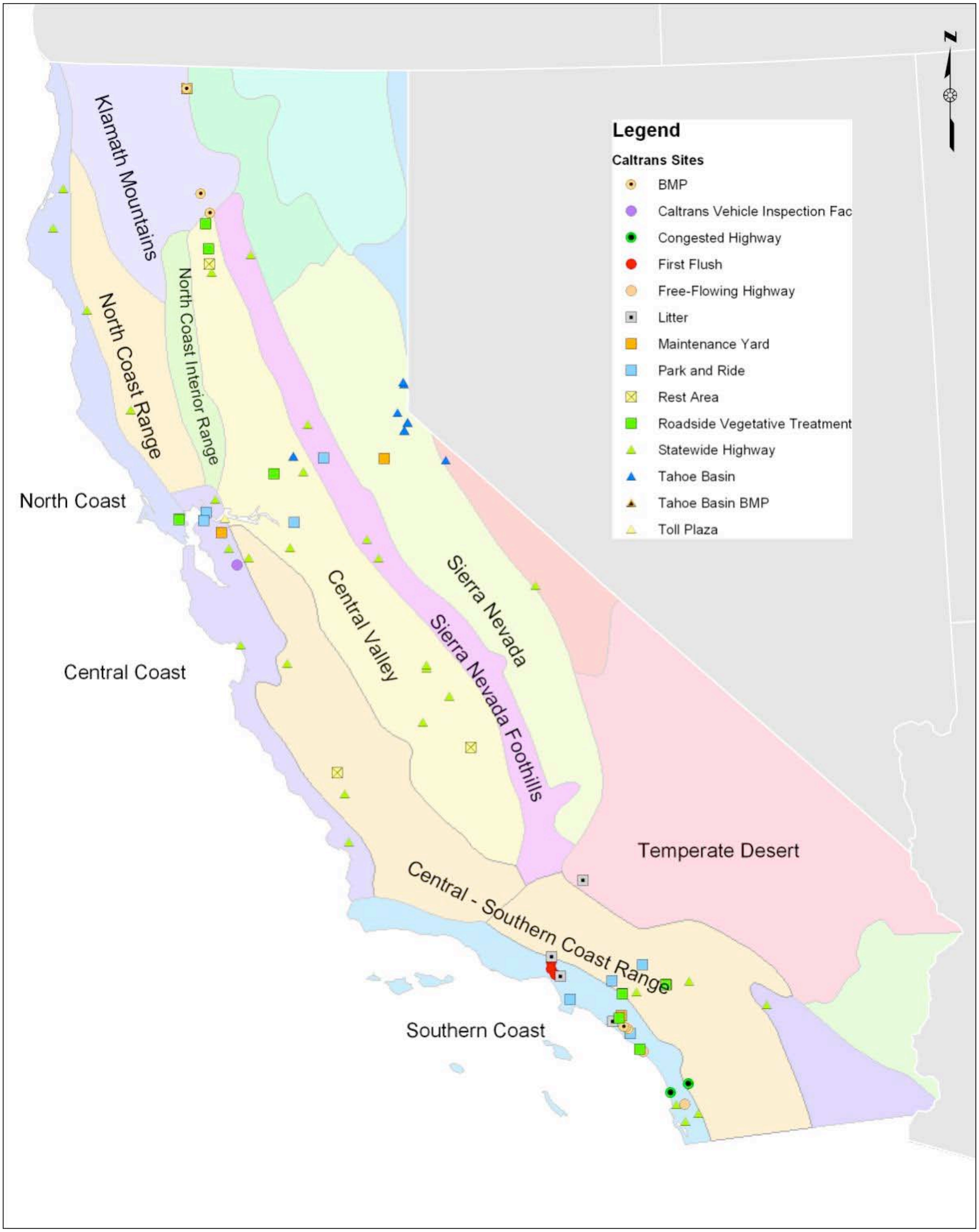


Figure 3-12 Geographic Regions and Caltrans Monitoring Sites

Table 3-16 Effect of Geographic Region on Highway Runoff Quality.

Pollutant Category	Parameter	Fraction	Significant Variation due to Geographic Region?	Regions with Significant Differences from Overall Average Runoff Quality for Geographic Regions: Regions Above Overall Average	Regions Below Overall Average
Conventional	DOC		YES	C/SCR	SNF
	EC		YES	CC, CV, C/SCR, NC, SC	SNF, TD
	Hardness as $CaCO_3$		YES	C/SCR	SNF, TD
	pH		NS	ns	ns
	TDS		YES	C/SCR	SNF
	Temperature		NS	ns	ns
	TOC		YES	CC, C/SCR, SC	SNF
	TSS		YES	CC, CV, C/SCR, KLM	ns
Trace Metals	As	Total	YES	ns	SNF
	Cd	Total	YES	CV, C/SCR	ns
	Cr	Dissolved	YES	CC, KLM, SC	C/SCR, SNF
	Cr	Total	YES	CC, CV, KLM	SNF
	Cu	Dissolved	YES	CC, CV	C/SCR, SNF
	Cu	Total	YES	CC, CV, SC	SNF
	Ni	Dissolved	YES	ns	SNF
	Ni	Total	YES	CC, KLM	SNF
	Pb	Dissolved	YES	ns	SNF
	Pb	Total	YES	CC, KLM	SNF
	Zn	Dissolved	NO	ns	ns
	Zn	Total	YES	CC, CV	NC, SNF
Nutrients	NO_3-N		YES	C/SCR, KLM	CC, SNF
	Ortho-P	Dissolved	YES	NCI	CC, SNF, SC
	P, total	Total	YES	CV, C/SCR, NCI	SNF
	TKN		YES	CV, C/SCR	SNF

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Abbreviations for Geographic Regions: CC=Central Coast, C/SCR=Central and Southern Coast Range, CV=Central Valley, NC=North Coast, NCR = North Coast Range, NCI = North Coast Interior Range, SC=Southern Coast, SNF= Sierra Nevada Foothills, TD =Temperate Desert, KLM=Klamath Mountains.

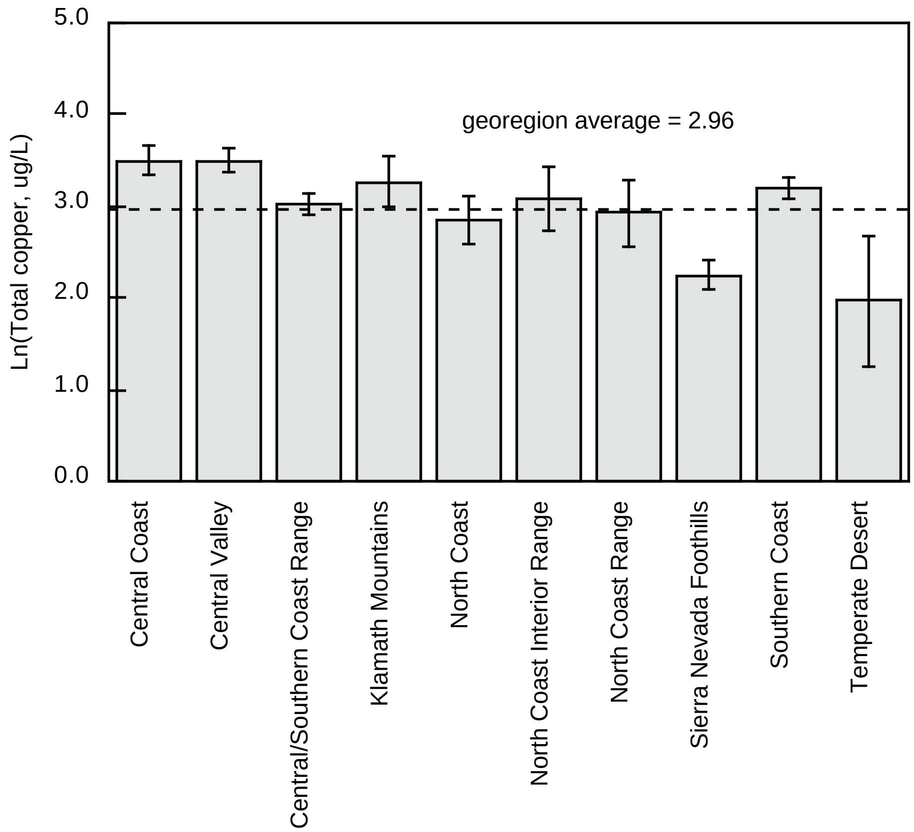


Figure 3-13
Estimated Marginal Means and 95% confidence limits for Total Copper

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average of georegions.

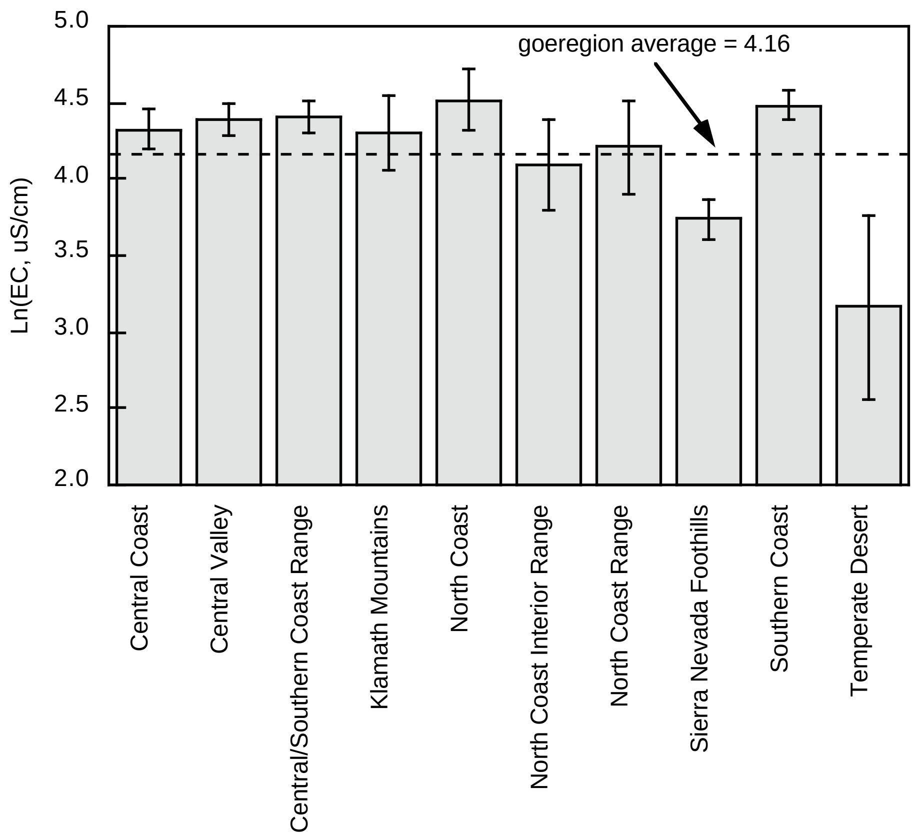


Figure 3-14
Estimated Marginal Means and 95% confidence limits for EC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average of georegions.

Effect of Predominant Surrounding Land Use

The effects of predominant surrounding land use on stormwater runoff quality from highways were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of these analyses are presented in Table 3-17. Surrounding land use contributed to significant differences in runoff quality from highway sites for all constituents except total chromium, dissolved lead, and NO_3-N. Patterns of significant differences in runoff quality from different predominating land uses are summarized as follows:

- **Conventional parameters**: Runoff from highway sites in agricultural and commercial areas exhibited higher concentrations of most conventional pollutants (EC, DOC, TDS, TOC, TSS) than the overall average and all other land uses. Highway sites in predominantly residential, transportation, and open land use areas generally exhibited lower than average conventional pollutant concentrations in runoff.
- **Trace metals:** Runoff from highway sites in agricultural and commercial areas also exhibited consistently higher concentrations of most trace metals than for other land uses. Predominantly residential, transportation, and open land use areas generally exhibited average or lower than average metals pollutant concentrations in runoff. Exceptions to this pattern were total and dissolved copper and total and dissolved zinc, which were significantly higher than average in transportation areas.
- **Nutrients:** Nutrient concentrations in highway runoff followed the same general pattern. Total phosphorus, and TKN were significantly higher in agricultural and commercial areas, and orthophosphate was also higher in agricultural area. Other land uses generally nutrient concentrations that were not significantly different from the overall average.

Figure 3-15 and Figure 3-16 are provided to illustrate the interpretation of the pattern of differences in runoff quality for different surrounding land uses for EC (Figure 3-15) and total copper (Figure 3-16).

Table 3-17 Significant Variation Due to Surrounding Land Use

Pollutant Category	Parameter	Fraction	Significant Variation due to Surrounding Land Use?	Land Uses with Significant Differences from Overall Average Runoff Quality for Land Uses	
				Land Uses Above Overall Average	**Land Uses Below Overall Average**
Conventional	DOC		YES	AG	TRANS
	EC		YES	AG, COMM	RES, TRANS
	Hardness as CaCO3		YES	AG, TRANS	RES
	pH		YES	COMM, OPEN	TRANS
	TDS		YES	AG, COMM	ns
	Temperature		YES	RES	OPEN
	TOC		YES	AG, COMM, MXD	OPEN, RES
	TSS		YES	AG, COMM	ns
Trace Metals	As	Total	YES	COMM	MXD
	Cd	Total	YES	COMM	ns
	Cr	Dissolved	YES	OPEN	TRANS
	Cr	Total	NO	ns	ns
	Cu	Dissolved	YES	AG, TRANS	OPEN, RES
	Cu	Total	YES	AG, COMM	OPEN, RES
	Ni	Dissolved	YES	AG	TRANS
	Ni	Total	YES	AG, COMM	TRANS
	Pb	Dissolved	NO	ns	ns
	Pb	Total	YES	AG, COMM	TRANS
	Zn	Dissolved	YES	TRANS	OPEN
	Zn	Total	YES	AG, COMM, TRANS	MXD, OPEN, RES
Nutrient	NO3-N		NO	ns	ns
	Ortho-P	Dissolved	YES	AG	TRANS
	P	Total	YES	AG, COMM	ns
	TKN		YES	AG, COMM, TRANS	OPEN

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Land Use designations: AG = Agriculture, COMM = Commercial, MXD = Mixed, no dominant land use determined, OPEN = Open, RES = Residential, TRANS=Transportation

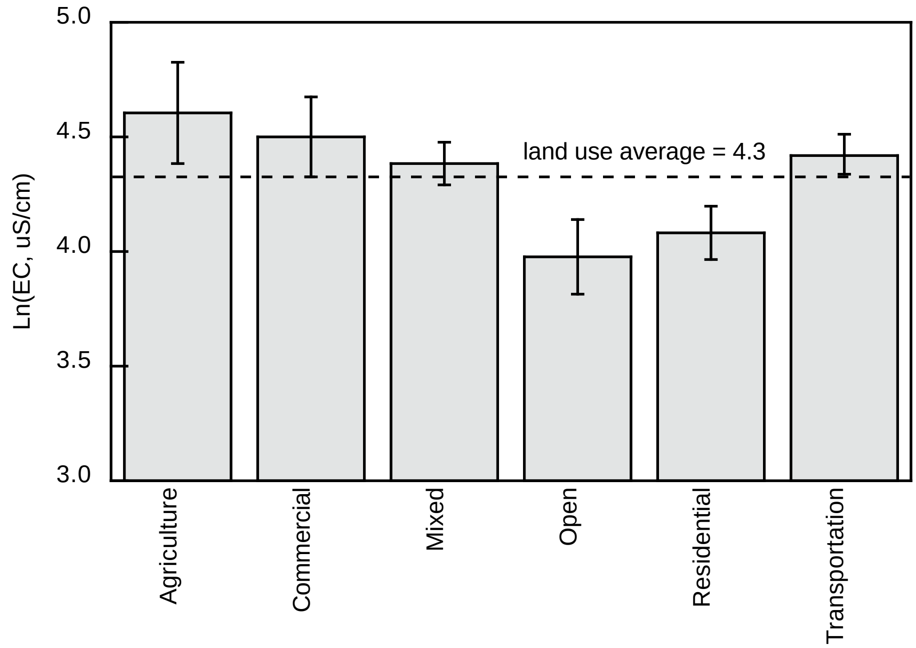


Figure 3-15 Estimated Marginal Means and 95% confidence limits for EC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average for land uses.

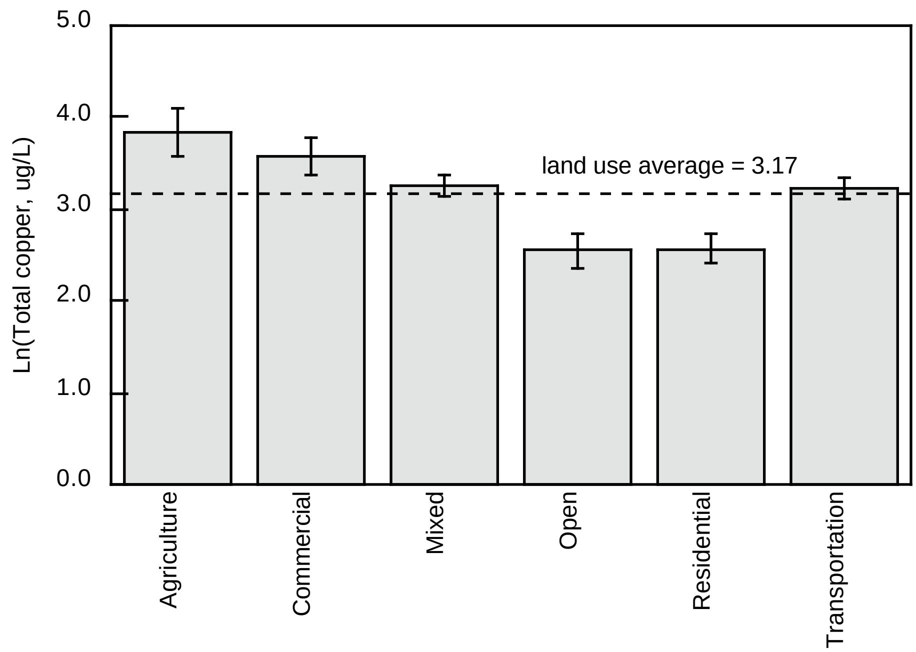


Figure 3-16 Estimated Marginal Means and 95% confidence limits for Total Copper

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average for land uses.

Comparisons with Water Quality Objectives

For the purpose of prioritizing constituents for future BMP implementation and study, runoff quality data were compared to California Toxics Rule (CTR) objectives (USEPA 2000) and to several other surface water quality objectives considered potentially relevant to stormwater runoff quality. The sources of other water quality objectives considered were National Primary Drinking Water Maximum Contaminant Levels (USEPA 2002), U.S. EPA Action Plan for Beaches and Recreational Waters (USEPA 1999a), U.S. EPA Aquatic Life Criteria (USEPA 1999b), California Department of Health Services Drinking Water MCLs (CDHS 2002), and California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos (Siepman and Finlayson 2000). In the case of CTR metals objectives that are adjusted for hardness, the objective was based on the lowest observed hardness for the data set for the most stringent assessment of percent exceedance.

These surface water quality objectives were considered relevant for comparison to stormwater quality because they apply to surface waters which may receive stormwater discharges from highways and other Caltrans facilities. Because these water quality objectives apply to receiving waters, and not directly to runoff, the comparisons are useful only as general guidelines for identifying pollutants with a higher priority for management, and do not reflect regulatory compliance status. Constituents were prioritized according to their estimated percent exceedance of the most stringent water quality objective, i.e. parameters with a higher percent exceedance received a higher monitoring priority, with greater 50% exceedance receiving *high* priority, 5–50% receiving a *medium* priority, and less than 5% receiving a *low* priority. Estimated percent exceedance was calculated based on the distributional parameters calculated for each constituent, using the statistical methods described previously for characterization of runoff quality (Section 2, page 17). Specifically, percent exceedance was estimated as the cumulative probability of exceeding the specific water quality objective, based on the normal or lognormal distribution statistics, as appropriate for the constituent of interest.

Runoff concentrations of most pollutants were observed to exceed the most stringent receiving water quality objectives, and a few parameters exceeded the objectives in a majority of runoff samples. It should be noted that the water quality objectives cited are not intended to apply specifically to stormwater discharges, and are used here only in the context of establishing priorities for continued monitoring. It should also be noted that many constituents monitored do not have relevant water quality objectives. The results of comparisons with the most stringent CTR and other relevant water quality objectives are provided in Table 3-18, and summarized below. Constituents that were monitored by Caltrans in stormwater runoff, but without relevant surface water quality objectives, are listed in Table 3-19.

- Copper, lead, and zinc were estimated to exceed their CTR surface water quality objectives for dissolved and total fractions in greater than 50% of samples.
- Dissolved fractions of cadmium and nickel were estimated to exceed CTR surface water quality objectives in less than 3% of runoff samples, while total fractions of cadmium and nickel were estimated to exceed CTR objectives in 22% and 15% of runoff samples,

respectively. Dissolved arsenic and chromium were estimated to exceed CTR objectives in fewer than 0.01% of runoff samples, while total fractions of arsenic and chromium were estimated to exceed objectives in approximately 5% and 2% of runoff samples, respectively.

- In all cases, trace metals exceeded objectives based on total fractions much more frequently than objectives for dissolved fractions.
- Of the trace organics (semi-volatile organic compounds), only benzo(b)fluoranthene was observed to exceed its CTR objective. Other trace organic compounds were not detected or not expected to exceed CTR objectives more frequently than in 0.01% of runoff samples. Note that because SVOCs were only monitored for highway facilities for a total of 32 samples, these results can not be generalized to other facilities.
- In comparisons with relevant non-CTR criteria, TDS, nitrate, and nitrite were estimated to exceed the drinking water MCLs for these parameters in less than 4% of samples.
- Total aluminum and iron were estimated to exceed their chronic U.S. EPA Aquatic Life Criteria in nearly 100% and 70% of runoff samples, respectively. It should be noted that these metals were monitored for a relatively few events and sites, and these results should not be generalized to all facility types. Chloride was estimated to exceed the chronic U.S. EPA Aquatic Life Criterion in 32% of samples.
- Diazinon was estimated to exceed the California Department of Fish and Game (CDFG) recommended chronic criterion in 79% of stormwater runoff samples, and chlorpyrifos was estimated to exceed the CDFG recommended chronic criterion in 73% of samples.
- Total and fecal coliforms were estimated to exceed the California Department of Health Services Action Level (for recreational beach use) in 21% and 43% of samples, respectively. These parameters were monitored only at selected highway and construction sites for a limited number of events.

Table 3-18 Comparisons of Caltrans runoff quality data with CTR and other relevant water quality objectives

Parameter	Units	Mean	Standard Deviation	Max Detected Value	CTR Objective	Other Objective	Source of non-CTR objective[1]	Estimated % exceedance	Rank[4]
Parameters with CTR Objectives									
Pb, total	µg/L	49	142	2600	0.66	15	—	97.2%	HIGH
Cu, total	µg/L	39	262	9500	3.2	1000	—	97.1%	HIGH
Cu, dissolved	µg/L	14	15	195	3.1	—	—	88.0%	HIGH
Zn, total	µg/L	207	286	4800	41	—	—	86.8%	HIGH
Pb, dissolved	µg/L	4.5	21.3	480	0.64	—	—	61.1%	HIGH
Zn, dissolved	µg/L	75	128	3320	40	—	—	51.7%	HIGH
Cd, total	µg/L	0.76	1.26	30	0.97	5	MCL	22.4%	MED
Ni, total	µg/L	13	67	2420	18	100	MCL	15.3%	MED
As, total	µg/L	3.3	8.9	91	150	10	MCL	4.7%	LOW
Cd, dissolved	µg/L	0.23	0.39	8.4	0.93	—	—	2.6%	LOW
Ni, dissolved	µg/L	4.2	5.3	98	18	—	—	1.9%	LOW
Cr, total	µg/L	10	21	620	76	50	CA DHS	1.8%	LOW
Benzo(b)fluoranthene (2)	µg/L	IDD	IDD	0.05	0.0044	—	—	(3)	LOW
Cr, dissolved	µg/L	2.9	4.9	141	65	—	—	0.01%	LOW
As, dissolved	µg/L	1.7	5.1	81	150	—	—	0.001%	LOW
Acenaphthene (2)	µg/L	IDD	IDD	0.25	1200	—	—	<0.01%	LOW
Fluoranthene (2)	µg/L	IDD	IDD	0.1	300	—	—	<0.01%	LOW
Fluorene (2)	µg/L	IDD	IDD	0.06	1300	—	—	<0.01%	LOW
Pyrene (2)	µg/L	0.05	0.03	0.13	960	—	—	<0.01%	LOW
Anthracene (2)	µg/L	IDD	IDD	ND	9.6	—	—	ND	LOW
Benzo(a)anthracene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Benzo(a)pyrene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Chrysene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Dibenzo(a,h)anthracene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Indeno(1,2,3-c,d)pyrene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Parameters with Other Relevant Objectives									
Al, total (2)	µg/L	8863	9746	31430	none	87	EPA AL	99.9%	HIGH
Diazinon (2)	µg/L	0.17	0.20	1.0914	none	0.05	CA DFG	78.8%	HIGH
Chlorpyrifos (2)	µg/L	0.044	0.08	0.97	none	0.014	CA DFG	72.6%	HIGH
Fe, total (2)	µg/L	6794	6794	43500	none	1000	EPA AL	69.2%	HIGH
Fecal Coliform Bacteria (2)	MPN/100 ml	1415	3029	16000	none	400	EPA AP	42.6%	MED
Chloride (2)	mg/L	280	407	1800	none	230	EPA AL	32.4%	MED
Total Coliform Bacteria (2)	MPN/100 ml	9169	25975	160000	none	10000	EPA AP	21.2%	MED
TDS	mg/L	139	466	11700	none	500	MCL	3.5%	LOW
NO_2-N (2)	mg/L	0.14	0.30	2.8	none	1	MCL	1.5%	LOW
NH_3-N (2)	mg/L	0.71	1.48	24.66	none	5.91	EPA AL	0.6%	LOW
NO_3-N	mg/L	0.93	1.50	48	none	10	MCL	0.3%	LOW

Table Notes: IDD indicates insufficient detected data to estimate statistic. ND indicates constituent was not detected.

(1) MCL = U.S. EPA Drinking Water Maximum Contaminant Level, DHS = California Department of Health Services, EPA AL = U.S. EPA Aquatic Life Criterion, CA DFG = California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos. (2) Parameter is not included on Caltrans Minimum Constituent List for Runoff Characterization. (3) Maximum observed value exceeded CTR objective, but there were insufficient detected data to estimate percent exceedance. (4) Rank is the assigned monitoring priority based on percent exceedance: HIGH—greater than 50% exceedance, MED–from 5-50% exceedance, LOW—less than 5% exceedance or infrequently detected in runoff.

Table 3-19 Statewide characterization studies constituents without CTR or other relevant water quality objectives

Conventional parameters	***Hydrocarbons***	***Metals***	***Pesticides***
BOD(1) COD(1) EC Hardness pH Temperature	Oil and Grease(1) TPH (Diesel) (1) TPH (Heavy Oil) (1) TPH (Gasoline) (1)	Aluminum, dissolved(1) Iron, dissolved(1) Mercury, total and dissolved(1)	Diuron Glyphosate Oryzalin Oxadiazon Triclopyr
Organic carbon, total and dissolved	***SVOCs***	***Nutrients***	
TSS Turbidity(1)	Acenaphthylene Benzo(g,h,I,)perylene Benzo(k)fluoranthene Napthalene Phenanthrene	Orthophosphate, dissolved Phosphorus, dissolved(1) Phosphorus, total TKN	

(1) Parameter is not included on Caltrans Minimum Constituent List for Runoff Characterization

Correlations Between Runoff Quality Parameters

Correlations between runoff quality parameters were screened using Spearman's non-parametric rank correlation procedure, and verified for significant linear relationship using Pearson's standard parametric procedure. Because of the large amount of data there were many correlations significant at the 95% confidence level. However, correlations with a Spearman's *rho*[1] value less than 0.8 were considered to be too weak for one parameter to serve as practical monitoring surrogate for the other parameter, even if correlations were significant. Significant correlations greater than 0.8 are summarized in Table 3-20, along with their corresponding Pearson's Product-Moment correlation coefficient, *R*. The complete Spearman's correlation matrix is presented in Appendix E.

Correlations were generally strongest within pollutant categories, with few correlations greater than 0.8 between constituents in different categories. Exceptions to this pattern included TSS with total aluminum and iron, and dissolved aluminum with ammonia nitrogen. Within the conventional parameters, the strongest correlations were observed among parameters associated with dissolved minerals (EC, TDS, and chloride), organic carbon (TOC and DOC), and suspended particulate materials (TSS and turbidity). Within the metals category, total concentrations of most metals were highly correlated, but correlations between total and dissolved concentrations were all less than 0.8, even between total and dissolved concentrations of the same metals. Total petroleum hydrocarbons were generally poorly correlated with all other parameters, but did exhibit a strong correlation between the diesel and heavy oil fractions of this category. Nutrients were generally not strongly correlated within the nutrient category or with other categories (with the odd exception of ammonia and dissolved aluminum). Total and fecal coliform bacteria exhibited no significant correlations greater than 0.8 within or outside the microbiological category.

These results suggest that for the purpose of assessing trends, the effectiveness of BMPs, and other pollutant management alternatives, some reductions in the parameters monitored would be practical:

- Organic carbon could be adequately monitored as either the total or dissolved fraction.
- Dissolved minerals could be adequately monitored as EC with estimates of TDS and chloride based on the relationship between these parameters.
- Suspended particulate matter could be adequately assessed by measurements of TSS, eliminating turbidity.
- TPH could be adequately monitored as either the diesel or the heavy oil fraction.
- Total aluminum and iron could be adequately monitored as TSS based on the relationship between these parameters.
- Correlations among total concentrations of the total fractions of several metals (cadmium, chromium, copper, lead, nickel, and zinc, as well as aluminum and iron) were consistently strong enough to monitor a select subset of these parameters to assess effectiveness of BMPs.

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[1] Spearman's *rho* is a non-parametric measure of association calculated from ranks. Spearmans's *rho* is analogous to the Pearson's Product-Moment correlation coefficient, *R*. In all cases, these values were nearly identical.

Table 3-20 Summary of correlations between runoff quality parameters. Spearman's *rho* > 0.8 and significant at the 95% confidence level.

Constituent Categories	Parameter Pairs	Spearman's *rho*	*n*	Pearson's R	*n*
Conventionals with Conventionals	TOC and DOC	0.962	1687	0.960	1677
	TSS and Turbidity	0.844	395	0.784	394
	EC and Chloride	0.976	27	0.970	27
	EC and TDS	0.794	1857	0.805	1799
	TDS and Chloride	0.891	27	0.876	27
Conventionals with Hydrocarbons	*None > 0.8*	—	—	—	—
Conventionals with Metals	TSS and Al, total	0.861	26	0.878	26
	TSS and Fe, total	0.891	59	0.898	59
Conventionals with Microbiologicals	*None > 0.8*	—	—	—	—
Conventionals with Nutrients	*None > 0.8*	—	—	—	—
Hydrocarbons with Hydrocarbons	TPH, Diesel and Heavy Oil	0.877	20	0.858	19
Hydrocarbons with other categories	*None > 0.8*	—	—	—	—
Metals with Metals	Al, total and Cd, total	0.814	28	0.823	25
	Al, total and Cr, total	0.893	28	0.951	28
	Al, total and Ni, total	0.822	28	0.879	26
	Cr, total and Fe, total	0.919	59	0.880	53
	Cu, total and Fe, total	0.863	59	0.872	59
	Cu, total and Pb, total	0.809	2231	0.792	2133
	Cu, total and Zn, total	0.857	2231	0.850	2224
	Fe, total and Ni, total	0.866	59	0.803	51
	Fe, total and Pb total	0.919	59	0.900	48
	Fe, total and Zn, total	0.822	59	0.842	59
Metals with Nutrients	Al, dissolved and NH_3-N	-0.901	14	-0.766	9
Metals with Microbiologicals	*None > 0.8*	—	—	—	—
Microbiologicals and other categories	*None > 0.8*	—	—	—	—
Nutrients and other categories	*None > 0.8*	—	—	—	—

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SECTION 4 DISCUSSION

The results of the runoff characterization monitoring performed by the Department, together with the analyses of the monitoring data presented in Section 3 of this report, provide adequate information to address the primary objectives of this report (listed in Section 1). Discussions of the results and interpretations of the analytical evaluations of stormwater runoff quality are presented below.

Effects of AADT and Other Factors on Runoff Quality, and Implications for Stormwater Management

Multiple Linear Regression (MLR) analyses of the Department's runoff quality data demonstrate a set of generally consistent relationships between runoff quality and precipitation factors, antecedent conditions, AADT, and drainage area. The results are generally consistent with—and provide qualitative validation of—models generated from previous analyses of the Department's stormwater runoff quality data (Kayhanian *et al*., 2003). However, the use of the more representative Statewide Characterization Study data for MLR analyses results in a more consistent picture of the effects of these factors than derived from the previous analysis.

The current results provide confirming evidence that traffic volumes and rainfall conditions – including antecedent conditions – are the most significant factors influencing runoff quality from the Department's facilities. Runoff quality is significantly correlated with traffic level; pollutant concentrations are higher for sites with higher AADT. Pollutant concentrations are also higher during events that occur at lower cumulative (seasonal) rainfall levels (i.e., those occurring earlier in the rainy season), and during storm events preceded by longer antecedent dry periods. Pollutant concentrations tend to decrease for storm events with higher event rainfall totals.

Larger drainage areas were also generally associated with lower pollutant concentrations for some parameters, but this effect was less consistent than the effects of AADT, event rainfall, cumulative precipitation, and antecedent dry period on runoff quality. Maximum rainfall intensity was not a statistically significant or consistent predictor of runoff quality for most constituents, due in part to correlation with event rainfall totals.

Seasonal and Event First Flush Effects

The MLR analyses indicate that pollutant concentrations decrease with increasing cumulative seasonal rainfall, and increase with antecedent dry period. California's climate is characterized by an extended summer dry season. The "first flush" rainfall event in the fall, with the longest annual antecedent dry period and the lowest cumulative seasonal rainfall total, is therefore expected to produce the highest runoff pollutant concentrations. The results of the current study are consistent with a significant seasonal "first flush effect," resulting in higher pollutant concentrations early in the wet season, with concentrations tending to decrease through the remainder of the wet season. The mechanism underlying these effects is generally understood to be the build-up of pollutants on exposed surfaces during dry weather, and wash-off during rainfall events.

A significant storm event first flush effect was also suggested for most pollutants by the statistically significant effect of storm event rainfall totals on pollutant concentrations. Although demonstration of a storm event first flush effect was not a specific goal of discharge characterization monitoring, this result suggests that concentrations of most pollutants monitored by the Department are significantly higher in the initial runoff of a storm event and tend to be diluted by additional rainfall and runoff. The Department is currently conducting studies designed specifically to address this question.

The findings of significant seasonal and storm event first flush effects confirm conclusions reached in other studies of these phenomena. The first year of results from a study conducted by UCLA and supported by the Department (Stenstrom *et al*. 2001) demonstrated a statistically significant storm event first flush effect for a number of pollutants. Analysis of stormwater runoff quality data from the City of Sacramento's Storm Water Monitoring Program have also demonstrated significant event and seasonal first flush effects for a variety of pollutants, as well as significant effects of precipitation factors and antecedent conditions (LWA 1996). The weight of evidence from these and other studies appear to provide compelling evidence of the relationships of these factors with stormwater runoff quality.

Effects of Categorical Factors on Runoff Quality

Several consistent differences were also found in the results of analyses of the effects of categorical factors (facility type, land use, and geographical region) on runoff quality. However, conclusions drawn from these results should be interpreted with caution. Although significant differences were found for most constituents for every category evaluated, the analyses and interpretation of the results are limited by some largely unavoidable imbalances in the sampling design. Specifically, most of the data for each categorical comparison was dominated by one district, geographical region, facility type, or land use, with few sites representing other levels of each category. Several land uses and geographic regions were represented by two sites with many sample events, resulting in pseudoreplication and artificial inflation of the significance of the effect of that categorical factor. This imbalance in design results in some uncertainty in interpreting the effects of specific land uses and geographic regions that must be acknowledged. Given this warning, the following patterns were noted in the Statewide characterizations studies data:

- The analysis of runoff quality from different facilities indicated that facilities expected to have the highest vehicle traffic, *e.g.* highways and toll plazas, exhibited elevated concentrations of most pollutants in runoff, compared to other facilities. Pollutant concentrations in runoff from lower traffic facilities (maintenance facilities, park-and-ride lots, Caltrans vehicle inspection facilities, and rest areas) were generally similar to each other and lower than highways and toll plazas. This pattern was consistent for the categories of conventional constituents and trace metals with few exceptions, and somewhat less consistent for nutrients. These results for facility types tend to confirm the importance of AADT as a predictor of pollutant concentrations in runoff and as an important factor in prioritizing the implementation of management alternatives.

- There were also significant differences in highway runoff quality for different geographic regions. However, the apparent effects of region may be due more to the actual effects of typical AADT and land use within those regions. Regions with pollutant concentrations that were significantly higher than average (Klamath Mountains, Central Coast, Central Valley, and North Coast and Interior Ranges) were represented by only a few sites with high AADT, or were in primarily urban areas (the Central Coast region is predominantly comprised of San Francisco Bay area sites). Lower than average regions (Sierra Nevada Foothills and Temperate Desert) were represented by only a few sites with low AADT and little urban influence. These results appear to be more supportive of the effects of AADT and urban influence on runoff quality than for consistent region-wide effects of other undefined factors.

- The results of analysis of surrounding land use effects indicated that most conventional pollutants, trace metals, and nutrients were higher in agricultural and commercial areas. Runoff quality from residential areas, transportation corridors, and open land use areas were generally similar to each other and lower than agricultural and commercial areas.

Relevance to Management of Runoff from Department Facilities

It should be noted that the large number of data in the Department's Stormwater Quality Database provides statistical power sufficient to detect relatively small effects on runoff quality (as small as 5% of total variation, as evidenced by the low R^2-values for significant MLR models for some constituents). Taking that into consideration, three results of these analyses have particular relevance to management or treatment of runoff from the Department's facilities:

- ***AADT*** - Pollutant concentrations increase in proportion to the annual average daily traffic for the contributing facility.

- ***Seasonal First Flush Effect and Antecedent Dry Period*** - Concentrations of most pollutants are higher when cumulative seasonal precipitation is lower — i.e., early in the wet season — and pollutant concentrations also tend to increase with longer antecedent dry periods.

- ***Storm Event First Flush Effect*** - This and other studies provide evidence that concentrations of most pollutants are significantly higher in the initial runoff from a storm event.

Value of MLR Models for Prediction and Runoff Management

MLR analysis of the Department's runoff quality data has been able to successfully identify environmental and site-specific factors that significantly effect runoff quality. Knowledge of these factors and their effects on runoff quality should be useful to the Department in evaluating future management alternatives, planning future monitoring efforts, and designing studies of management effectiveness. However, although MLR analyses have been valuable in identifying factors that have the greatest known influence on runoff quality, the MLR models developed for this study are still able to account for much less than 50% of the variability of most constituents in runoff. For this reason, there are significant limitations to the use of the models resulting from these analyses. Although the models developed herein may not be adequately accurate for prediction of concentrations or loads for specific sites and storm events, they can be used to provide improved estimates of long-term average concentrations or loads from Department facilities as a whole.

In a review of the statistical procedures used for this study, staff of the University of California, Davis Statistics Laboratory concluded that some marginal improvements in predictive value of the models would likely be gained and some potential biases moderated by expanding the statistical techniques used, particularly by introducing additional covariate terms. The additional methods recommended for consideration in this review included expanded exploration of transformations of predictor variables, multivariate ANCOVA, and principal components analysis. However, the review also concluded that improvements in the models would be incremental and would not change the overall conclusions drawn based on this study of the data.

Discharge Load Modeling and TMDLs

Developing MLR models for runoff quality has a number of practical applications. Modeling of runoff quality allows more accurate comparisons with relevant water quality regulatory limits than the simple statistical estimates of percent exceedance generated for this study. These models also provide tools relevant to BMP development and assessment and runoff management. Additionally, by combining runoff quality models of EMCs with runoff quantity models, pollutant loads can be better estimated. The relatively low coefficients of determination (R^2-values) for most of the significant MLR model parameters may limit appropriate uses of the MLR models to “big picture” management decisions. However, the current MLR models will still provide estimates of overall runoff quality and loads that are unbiased and with narrower confidence limits than simply using average annual estimates of mean runoff quality and rainfall or runoff.

The ability to estimate pollutant loads from the Department’s highway facilities as accurately as possible may be important in developing TMDLs for specific pollutants (depending on the form of the TMDLs) and subsequently in assessing the ability of the Department to comply with TMDL requirements included in their NPDES permit. If estimating pollutant loads is the ultimate use of MLR models, it may be possible to develop more accurate models of loads (i.e., models with higher R^2-values and lower residual mean squared values) directly from pollutant load data and additional site-specific or environmental independent factors. However, variability of pollutant loads (as measured by coefficient of variation) is typically much higher than for EMCs because storm event runoff volumes and loads typically vary by a couple of orders of magnitude for a specific drainage. The inherently higher variability of loads means models based directly on load data may be no more accurate or predictive than the current models.

Percentage of Metals in the Particulate Fraction

A large proportion of the concentrations of most metals are bound to particulate matter in runoff. Because most management practices and processes for treating stormwater target the particulate portion of runoff, metals with a higher percentages in the particulate fraction are presumed to be more efficiently removed or controlled. Based on data from Statewide discharge characterization studies for the metals with data available for both dissolved and total analyses, lead has the highest proportion present as particulates (86%). Cadmium, chromium, and zinc are between 60-70% in the particulate fraction, and arsenic, copper and nickel are between 50-55% in the particulate fraction. This indicates that at least 50% of these metals may be effectively managed or removed from runoff by targeting the particulate fraction, with the most effective removals expected for lead, cadmium, chromium, and zinc. Table 4-1 summarizes the particulate percentages for the several metals for which both dissolved and total concentration data were available.

Table 4-1 Particulate fraction of metals.

Metal	Percent Present as Particulates (Average for all facilities)
Arsenic	53%
Cadmium	63%
Chromium	68%
Copper	51%
Nickel	54%
Lead	86%
Zinc	69%

Use of Statewide Discharge Characterization Data

Summary statistics for highway runoff data from the three-year Statewide Discharge Characterization Study and from the overall Caltrans monitoring dataset were evaluated for patterns of differences between the two datasets. For these comparisons, the “overall” data set contains data from projects conducted generally before the Statewide Discharge Characterization Study, plus the data from the Statewide Characterization Study, while the “statewide characterization” data set contains only data from the Statewide Characterization Study. Ratios of the means, standard deviations, and coefficients of variation (COV) for highway runoff data were calculated as *Overall statistic ÷ Statewide characterization study statistic*, for core Department monitoring parameters. This analysis was performed to evaluate whether use of the representative Statewide Characterization Study monitoring design was able to moderate a bias of earlier monitoring efforts towards highly urbanized sites. The results of the evaluation are summarized in Table 4-2.

Averaged across monitoring parameters, the means, standard deviations, and COVs were all higher for the overall dataset. Means decreased by about 8% on average for the statewide characterization dataset when compared to the overall data set, with decreases of more than 10% for 27% of parameters, and decreases of 20% or more for 19% of parameters. This pattern indicates that earlier concerns about potential biases due to site selection in the pre-Statewide Characterization Study data set were warranted, and that the more rigorous process of selection of monitoring locations for the Statewide Characterization Study was important in providing a more representative estimate of runoff quality.

The difference in variation for the datasets (as measured by standard deviation and COV) was even more dramatic, with variability of the statewide characterization dataset lower than the overall data set by 10% for approximately 50% of the parameters, and lower than the overall data set by 20% for about 20% of the parameters. This suggests that implementation of more consistent sampling procedures as part of the Statewide Characterization Study was successful in decreasing data variability, even with an increase in the variety and range of sites and geographic regions monitored. The overall pattern of these results highlights the importance of using the Statewide Characterization Study data to characterize the Department's runoff quality and to evaluate the factors affecting stormwater runoff.

Table 4-2 Comparison of highway summary statistics from the Statewide Characterization Study (2000/01-2002/03) and overall dataset (1998/99-2002/03)

Ratios of Summary Statistics for SWCS Data to Overall Dataset

Parameter	Mean	SD	COV
DOC	0.96	0.83	0.86
EC	0.49	0.11	0.22
Hardness as CaCO3	0.81	0.53	0.65
pH	0.99	1.03	1.04
TDS	0.57	0.22	0.39
Temperature	0.99	1.02	1.03
TOC	1.03	0.91	0.89
TSS	0.79	0.65	0.83
As, dissolved	0.91	0.86	0.95
As, total	1.01	1.17	1.16
Cd, dissolved	0.99	1.21	1.22
Cd, total	0.92	1.28	1.40
Cr, dissolved	1.07	0.90	0.84
Cr, total	0.96	0.90	0.94
Cu, dissolved	0.99	0.92	0.92
Cu, total	0.76	0.09	0.12
Ni, dissolved	1.09	0.96	0.88
Ni, total	1.02	0.84	0.82
Pb, dissolved	1.31	1.31	1.01
Pb, total	0.82	0.94	1.16
Zn, dissolved	0.96	0.89	0.92
Zn, total	0.94	0.95	1.01
NO3-N	1.05	1.39	1.33
Ortho-P, dissolved	1.03	1.23	1.19
P, total	0.64	0.29	0.45
TKN	0.93	0.82	0.89
mean ratio	0.92	0.86	0.89
% decreases in statistic	69%	69%	62%
% of decreases > 10%	27%	46%	46%
% of decreases > 20%	19%	23%	19%

Annual Variability in Stormwater Runoff Quality

For highways, annual variation in statewide runoff quality was very low. Other types of facilities saw relatively higher degrees of annual variation.

Overall, annual variation was less than 10% or not significant for 75% of the facilities and parameters (116 of 154 separate comparisons). Notably, the overall trend observed in the results is that facility types with higher numbers of sites and broader geographic representation exhibited lower annual variability. Highways, which are represented by the most sites (46) and have the broadest geographic representation in the data set, exhibit annual variation that is less than 5% of the total variation for most parameters. Maintenance and park-and-ride facilities (with seven and ten sites, respectively) exhibit an intermediate level of annual variation (less than 15% for most parameters). Caltrans vehicle inspection facilities (two sites), rest areas (three sites), and toll plazas (two sites) exhibited the highest annual variation, with statistically significant annual variation in the range of 20-40% for many parameters, and greater than 40% annual variation for DOC and total copper from rest areas.

The most likely reason for this pattern in significant annual variation is that many of the factors expected to cause significant annual variation in runoff quality (e.g., changes in patterns of use, annual variations in weather and deposition patterns, or implementation of management practices) are site-specific or regional factors and would not affect all sites equally. Consequently, runoff quality for facility types represented by few sites is more likely to exhibit significant annual variation. However, based on the results for highways, annual variation for any facility type with broad geographic representation and sufficient numbers of sites is likely to be fairly low on a statewide basis—less than 5% of total variation for most parameters. Conversely, annual variability is expected to be much higher on a site-specific and regional level.

Based on the results for highways, it can be concluded that annual variation will have little impact on the characterization of the Department's average runoff quality *on a statewide basis.* However, annual variation becomes more important for characterization of runoff quality at smaller regional or site-specific scales. The conclusions drawn from these analyses also depend on the assumption that the period monitored is adequately representative of longer-term annual variability —an assumption that is probably not valid for the state as whole.

Comparisons with Water Quality Objectives

The Department's stormwater runoff quality data were compared to statewide water quality objectives found in the California Toxics Rule (CTR) and other surface water quality regulations as a means of identifying constituents with higher priority for future monitoring, or potentially greater need for BMP study and implementation (either structural or source controls). Because these water quality objectives apply to receiving waters, and not directly to runoff, the comparisons are useful as general guidelines for prioritizing pollutants, and do not reflect regulatory compliance status. After comparisons to CTR and other water quality objectives relevant to the discharge of stormwater, constituents were ranked according to their expected frequency of exceedance of the most stringent objective. Priority rankings of *high, medium*, and *low* were assigned based on exceedance rates of greater than 50%, 5%-50%, and less than 5%, respectively.

As result of these comparisons, it was determined that copper, lead, and zinc exceeded relevant objectives most frequently and therefore receive a *high* priority for future monitoring, and BMP study or implementation. The comparisons between CTR and other relevant surface water quality objectives and the Department's stormwater runoff quality data are discussed below:

- Based on comparisons with CTR and other relevant water quality objectives, copper, lead, and zinc are assigned high priorities, due to frequent exceedances of surface water quality objectives for both total and dissolved fractions of these metals. Expected frequencies of exceedance for these metals in stormwater runoff is greater than 85% for total fractions and greater than 50% for dissolved fractions of these metals.
- Based on comparisons with CTR and other relevant surface water quality objectives, arsenic, cadmium, chromium, and nickel receive lower priorities. As a group, the total fractions of these metals exceeded objectives in fewer than 25% of stormwater runoff samples, and the dissolved fractions are expected to exceed objectives in fewer than 5% of runoff samples. (Note: It is expected that these parameters would all benefit from the same BMPs as copper, lead, and zinc.)
- Based on comparisons with CTR and other relevant surface water quality objectives, semi-volatile organic compounds merit low priority rankings. In this category, only benzo(b)fluoranthene was observed to exceed any objective, and most constituents were not detected or were well below any relevant objectives.
- Based on comparisons with U.S. EPA drinking water MCLs for TDS, nitrate, and nitrite (the most stringent objectives), these parameters receive low priority rankings. These parameters were estimated to exceed their MCLs in less than 4% of samples. However, nitrate, TKN, total phosphorus, and dissolved orthophosphate are elevated to a higher priority in anticipation of the development of statewide nutrient objectives in the future.

Certain other constituents, such as chlorpyrifos and diazinon, were found at elevated concentrations, but were monitored for few events and at few sites. While these constituents were frequently observed at concentrations above California Department of Fish and Game recommended criteria for diazinon and chlorpyrifos, these criteria have not been officially adopted and do not currently have official regulatory status in California. Furthermore, these pesticides are not routinely used by the Department within highway right-of-ways. For these reasons, these constituents are not designated as high priority parameters for monitoring or management.

Many other parameters monitored by the Department do not have relevant statewide water quality objectives and were therefore not ranked based on comparisons to objectives.

Correlations Between Stormwater Runoff Quality Parameters

The purpose of evaluating correlations between stormwater runoff quality parameters was to determine whether monitoring of some specific parameters could be discontinued or reduced, based on strong correlations with other parameters. Based on the results of these analyses, there were a few cases for which relationships were strong enough to allow reduced monitoring for specific constituents of interest. The majority of these cases were conventional constituents: organic carbon, parameters related to dissolved minerals or dissolved solids (EC, TDS, and chloride), and suspended solids (TSS and turbidity). Additionally, total petroleum hydrocarbons could be adequately monitored by a single fraction in this category (diesel or heavy oil), because other fractions were below detection in the majority of samples. For the purpose of assessing BMP and management effectiveness, it would also be adequate to monitor only a few of the highly correlated metals in the total metals category.

The following priorities are identified for future monitoring and BMP studies based on strong correlations between runoff quality parameters:

- Continue monitoring TOC and discontinue DOC (based on a significant Pearson's correlation of 0.960).
- Continue monitoring TSS and discontinue turbidity (based on a significant Pearson's *R* of 0.784).
- Continue monitoring EC and discontinue chloride and TDS (based on significant Pearson's correlations of 0.970 and 0.805).
- Continue monitoring TPH (Heavy Oil) or TPH (Diesel), but not both (based on a significant Pearson's correlation of 0.858 between these parameters).
- For the purpose of assessing the effectiveness of management alternatives and BMPs in reducing total metals in runoff, only copper, lead, and zinc are high priorities for future monitoring. This is based on a high degree of intercorrelation among total concentrations of these metals with aluminum, cadmium, chromium, iron and nickel, as well as the fact that copper, lead, and zinc warrant a higher priority than other trace metals, based on comparisons with water quality objectives discussed previously.

Prioritization of parameters for future monitoring and BMP studies is summarized in Table 4-3.

Based on comparisons to objectives and evaluation of correlations between parameters, the constituents with high priority for future monitoring and BMP studies are as follows:

▪ pH	▪ Aluminum (total and dissolved)
▪ Temperature	▪ Iron (total and dissolved)
▪ Conductivity (EC)	▪ Copper (total and dissolved)
▪ Total Suspended Solids (TSS)	▪ Lead (total and dissolved)
▪ Total Organic Carbon (TOC)	▪ Zinc (total and dissolved)

Table 4-3 Summary of priority rankings for future monitoring and BMP studies, based on comparisons with water quality objectives and correlation analyses.

Parameter	Priority (Based on Comparison to Water Quality Objectives)	Comment
Conventional		
Conductivity (EC)	No relevant objective	Surrogate for TDS and chloride
Chloride	MEDIUM	Replace with EC
Hardness as CaCO3	No relevant objective	
pH	No relevant objective	
Temperature	No relevant objective	
Total Dissolved Solids (TDS)	LOW	Replace with EC
Total Suspended Solids (TSS)	No relevant objective	Replace with Turbidity
Turbidity	No relevant objective	Surrogate for TSS
Organic Carbon, Total (TOC)	No relevant objective	Surrogate for DOC
Organic Carbon, Dissolved (DOC)	No relevant objective	Replace with TOC
Metals		
Aluminum	HIGH	Assess effectiveness of BMPs for metals based only on highest priority metals: copper, lead and zinc
Arsenic	LOW	
Cadmium	MEDIUM	
Chromium	LOW	
Copper	HIGH	
Iron	HIGH	
Lead	HIGH	
Nickel	MEDIUM	
Zinc	HIGH	
Nutrients		
Ammonia	LOW	
Nitrate	LOW	
Nitrite	LOW	Infrequently detected (~25%)
Total Kjeldahl Nitrogen	No relevant objective	
Tota Phosphorus	No relevant objective	
Dissolved Orthophosphate	No relevant objective	
Herbicides		
Diuron	No relevant objective	
Glyphosate	No relevant objective	
Oryzalin	No relevant objective	
Oxadiazon	No relevant objective	
Triclopyr	No relevant objective	
Total Petroleum Hydrocarbons		
Oil and Grease	No relevant objective	
TPH (Gasoline)	No relevant objective	Rarely detected
TPH (Heavy Oil)	No relevant objective	Surrogate for TPH (Diesel)
TPH (Diesel)	No relevant objective	Replace with TPH (Heavy Oil)
Semi-Volatile Organic Compounds		
Acenaphthene	LOW	Rarely detected
Acenaphthylene	LOW	Rarely detected
Anthracene	LOW	Rarely detected
Benzo(a)Anthracene	LOW	Rarely detected
Benzo(a)Pyrene	LOW	Rarely detected
Benzo(b)Fluoranthene	LOW	Rarely detected
Benzo(ghi)Perylene	LOW	Rarely detected
Benzo(k)Fluoranthene	LOW	Rarely detected
Chrysene	LOW	Rarely detected
Dibenzo(a,h)Anthracene	LOW	Rarely detected
Fluoranthene	LOW	Rarely detected
Fluorene	LOW	Rarely detected
Indeno(1,2,3-c,d)Pyrene	LOW	Rarely detected
Naphthalene	LOW	Rarely detected
Phenanthrene	LOW	Rarely detected
Pyrene	LOW	Rarely detected

SECTION 5 SUMMARY AND CONCLUSIONS

SUMMARY

The Department conducted comprehensive monitoring of runoff from transportation facilities throughout the State of California during the period 1997-2003. The centerpiece of this effort was the three-year Statewide Characterization Study, conducted from 2000-2003. The Statewide Characterization Study was designed to provide data representative of runoff from the full range of transportation facility types, geographic locations, traffic levels, and land use characteristics for facilities under the Department's purview.

The monitoring was conducted using consistent protocols designed to ensure the scientific validity of the data. Several significant innovations were developed to assist the Department's staff and contractors in assuring quality control and consistency in monitoring and data management.

The Department's extensive monitoring has provided sufficient data with which to characterize the quality of runoff from the "edge of pavement" from the Department's highway facilities. This goal also has been achieved, though less intensively, for other types of transportation facilities that have been monitored by the Department. Based on these results, continued extensive monitoring of the type and scale performed under the Statewide Characterization Study is not necessary, as this study has provided sufficient information about the characteristics of edge-of-pavement runoff quality and its variability.

Factors Affecting Runoff Quality

Environmental factors affecting the quality of edge-of-pavement runoff have been identified and quantified in this report, and the major patterns of temporal variability (annual, seasonal, and intra-storm) have been evaluated. Analysis of the Statewide Characterization Study monitoring data has confirmed that AADT and storm event characteristics have statistically-significant effects on runoff quality from transportation facilities. Consideration of these factors can be included in planning and prioritizing efforts for future monitoring and for management of runoff quality from such facilities.

AADT is the most important site characteristic affecting runoff quality of those identified to date for highways. Precipitation characteristics, particularly antecedent dry period, cumulative seasonal rainfall, and event rainfall amount, are also statistically-significant factors affecting the quality of runoff from highways.

However, because the correlation coefficients were generally low ($R^2 < 0.5$), it is also clear that there are other unaccounted-for factors contributing to variability in runoff. These factors may include aerial deposition under both wet and dry conditions.

Although geographic region and contributing land use were determined to have some statistically-significant effects on runoff quality, these effects use are less consistent than AADT and the precipitation factors. Consequently, geographic region and land use characteristics are less valuable in predicting runoff quality and should be considered less important in planning and prioritizing stormwater monitoring and management activities. The results of this analysis may be applied to other transportation facility types within California.

Other factors that have not received such intensive attention may influence runoff quality from transportation facilities. Predominant among these are the effects of runoff from additional surfaces beyond the paved surfaces, within the transportation corridor right-of-way.

CONCLUSIONS

The following are the principal conclusions derived from this study:

- Transportation facilities with higher traffic levels (i.e., higher AADT), particularly highways and toll plazas, produce higher pollutant concentrations in runoff than lower AADT sites and other types of facilities.
- Concentrations of most pollutants are higher early in the wet season and after extended dry periods. These results support the idea that there is a build-up of pollutants during dry periods, with progressive wash-off during the rainy season, leading to what is commonly known as the seasonal “first flush effect.”
- Runoff pollutant concentrations decrease as storm size increases; smaller storms produce higher pollutant concentrations in runoff than those with larger rainfall amounts.
- The majority of the metals present in runoff are found in the particulate form.

SECTION 6 REFERENCES

Caltrans 2002. Storm Water Monitoring and Research Program: Characterization Monitoring Plan FY 2002-03. CTSW-RT-02-004. California Department of Transportation (Caltrans). Sacramento, CA. Jan., 2002.

Caltrans 2003a. Statewide Stormwater Runoff Characterization Study, Monitoring Season 2002-2003. CTSW-RT-03-052. California Department of Transportation (Caltrans). Sacramento, CA. June, 2003.

Caltrans. 2000. Guidance Manual: Stormwater Monitoring Protocols. CTSW-RT-00-005. California Department of Transportation (Caltrans). Sacramento, CA. July, 2000.

Caltrans. 2003b. The Electronic Toolbox. CTSW-OT-02-002. California Department of Transportation. Sacramento, CA. Nov., 2003.

Caltrans. 2003c. Comprehensive Guidance Manual for Stormwater Monitoring. CTSW-RT-03-055.36.19. California Department of Transportation. Sacramento, CA. Nov., 2003

CDHS. 2002. Primary Drinking Water MCLs. California Code of Regulations. California Department of Health Services, Sacramento, CA.

Helsel, D., and T. Cohn. 1988. Estimation of descriptive statistics for multiply censored water quality data. Water Resources Research, vol. 24, no. 12, pp. 1997- 2004.

Hurlbert, S. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54:187-211.

Kayhanian, M., A. Singh, and S. Meyer. 2002. Impact of non-detects in water quality data on estimation of constituent mass loading. Water Science and Technology. Vol. 45, No. 9, pp. 219-225.

Kayhanian, M., A. Singh, C. Suverkropp, and S. Borroum. 2003. Impact of Annual Average Daily Traffic on Highway Runoff Pollutant Concentrations. ASCE Journal of Environmental Engineering. Vol. 129, No. 9, pp. 975-990.

LWA. 1996. Sacramento NPDES Stormwater Discharge Characterization Program, 1996 DCP Update Report. Larry Walker Associates, Davis, CA. September, 1996.

Ruby, A. and M. Kayhanian. 2003. Advanced Stormwater Monitoring. Stormwater: the Journal for Surface Water Quality Professionals. September/October 2003.

Shumway, R., R. Azari, and M. Kayhanian. 2002. Statistical approaches to estimating mean water quality concentrations with detection limits. Environmental Science and Technology. Vol. 36, No. 15, pp. 3345-4453.

Siepmann, S., and B. Finlayson. 2000. Water Quality Criteria for Diazinon and Chlorpyrifos. Administrative Report 00-3. California Department of Fish and Game, Office of Spill Prevention and Response. 2000.

Sokal, R, and F. Rohlf. 1981. *Biometry*, *The Principles and Practice of Statistics in Biological Research*. 2nd Ed. W.H. Freeman and Company, New York, NY.

SPSS. 2001. *SPSS Base 11.0 User's Guide.* SPSS Inc. Prentice-Hall, Upper Saddle River, NJ.

Stenstrom, M., S-L. Lau, H-H. Lee, J. Ma, H. Ha, L-Y. Kim, S. Khan, and M. Kayhanian. First Flush Stormwater from Highway Runoff. *EWRI World Water and Environmental Resources Congress* , Orlando, FL, May 2001.

USEPA. 1999. Action Plan for Beaches and Recreational Waters. EPA/600/R-98/079. Office of Research and Development (USEPA), U.S. Environmental Protection Agency, Washington DC.

USEPA. 1999. National Recommended Water Quality Criteria, Correction. EPA 822-Z-99-01. U.S. Environmental Protection Agency, Office of Water, Washington DC.

USEPA. 2002. National Primary Drinking Water Regulations. Code of Federal Regulations, Title 40, Volume 19. 40CFR141.1, page 336. U.S. Environmental Protection Agency, Washington DC.

Zar, J. 1984. *Biostatistical Analysis*, 2nd Ed. Prentice-Hall. Englewood Cliffs, NJ.

BMP Retrofit Pilot Program

FINAL REPORT

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JANUARY 2004
California Department of Transportation
CALTRANS, DIVISION of ENVIRONMENTAL ANALYSIS
1120 N Street
Sacramento, CA 95814

Dedication

On August 27, 2001, Mr. Peter Van Riper, who coordinated the efforts of Caltrans District 7, passed away. Mr. Van Riper played an integral role in the completion of the BMP Retrofit Pilot program and made a significant contribution to the project. His dedication to the pursuit of an objective and practical study, and his relaxed and positive style was appreciated by all who worked with him. He will be sorely missed. This report is dedicated to his memory.

EXECUTIVE SUMMARY

Introduction

Litigation between the California Department of Transportation (Caltrans) and the Natural Resources Defense Council (NRDC), Santa Monica BayKeeper, the San Diego BayKeeper, and the United States Environmental Protection Agency (USEPA) resulted in a requirement that Caltrans develop a Best Management Practice (BMP) Retrofit Pilot Program in Caltrans Districts 7 (Los Angeles) and 11 (San Diego). The objective of this program was to acquire experience in the installation and operation of a wide range of structural BMPs for treating stormwater runoff from existing Caltrans facilities and to evaluate the performance and costs of these devices. A study team made up of representatives from the parties to the lawsuit, their attorneys, local vector control agencies, and outside technical experts provided oversight of the retrofit pilot program.

Technical feasibility and costs were assessed through detailed records kept on the process of designing, building, operating and maintaining each retrofit device. Technical feasibility considered siting, design, construction, operation, maintenance, safety, performance and public health issues. These elements are elaborated on in Section 1.10. In addition, by establishing the life-cycle costs and performance for each of the technologies, a basis for selecting one technology over another was developed. The benefit assessment used in this project was based primarily on the pollutant removal of each of the tested technologies.

Each BMP was designed, constructed, and maintained at what was "state-of-the-art" at the time the project began. The types of BMP pilot projects included in the study are shown in Table 1.

Table 1 BMP Types included in the Retrofit Study

Media Filters	**Biofiltration**
Austin sand filter (5)	Swale (6)
Delaware sand filter (1)	Strip (3)
Multi-Chambered Treatment Train (2)	**Infiltration Devices**
Storm-Filter™ (1)	Basin (2)
Extended Detention Basins (5)	Trench (2)
Drain Inlet Inserts	**Wet Basin (1)**
FossilFilter™ (3)	**Oil-water Separator (1)**
StreamGuard™ (3)	**Continuous Deflective Separation (1)**

Sites selected for retrofit with the piloted technologies were considered to be the most appropriate and feasible in terms of siting criteria established for each BMP. The potential sites for each type of technology were ranked using a weighted decision matrix; BMPs with the most restrictive siting criteria (such as infiltration) were sited prior to BMPs with less restrictive criteria. No right-of-way was purchased for the project; instead, all BMPs were retrofitted within existing State-owned areas.

Retrofit Pilot Program Accomplishments

The retrofit pilot program is thought to be the most comprehensive test of common stormwater management BMPs ever conducted, and the first significant evaluation in a climate of southern California's type. The program succeeded in demonstrating the effectiveness of several BMP types in reducing pollutant concentrations and mass loadings. The results generally are consistent with the performance of these devices measured in previous studies.

The program further yielded substantial information on the technical feasibility of the BMPs as retrofits in highway and support facility settings. The determination of the technical feasibility at any particular location requires site specific evaluation. The team conducting the program surmounted a number of challenges to constructability and operation.

The project also accounted for the costs of construction and operations and maintenance under pilot program circumstances. Potential cost reduction strategies were identified and are detailed in Chapter 14.

Technical Feasibility and Benefits

This study was designed to allow the parties to gain experience with the actual design, installation, operation, and maintenance of structural BMPs in the setting of the freeway system in southern California. Many BMPs have been used in other parts of the country, but cost, performance, and operation data were not generally available for retrofit implementation, especially in a semi-arid highway environment. In addition, the study included a number of proprietary BMPs. Many of these BMPs are relatively specialized for specific constituents, flow or physical conditions, limiting their applicability. Accordingly, the study was designed to confirm or determine the technical feasibility for potential retrofit of the selected BMPs into the Caltrans highway environment.

In several instances, siting of the BMPs presented technical challenges, among them the restrictive siting requirements related to the need for specific soil and subsurface conditions (infiltration devices), available space, or perennial baseflow (wet basin). At many of the sites a significant portion of the cost was associated with changes to the original storm drain system to direct more runoff to the test sites. These difficulties point out the need to include planning for BMP retrofit in the early stages of reconstruction projects to take advantage of possible drainage system reconstruction.

An unexpected element encountered at the beginning of the study was the importance of avoiding standing water in the BMPs. Standing water presents opportunities for vectors to establish themselves, and mosquito breeding was observed at all of the sites where standing water persisted for at least 72 hours. In addition to the technologies that incorporate a permanent pool (i.e., wet basin, MCTT, Storm-Filter™, Continuous Deflective Separation (CDS®) and Delaware sandfilter), standing water also occurred in stilling basins, around riprap used for energy dissipation, in flow spreaders, and in some outlet structures. Consequently, many of the BMPs were modified during the course of the study to eliminate standing water. To minimize vector concerns in future installations, the potential for standing water should be avoided during design.

A significant component of the overall reduction in constituent load of several of the BMPs was infiltration of runoff into the soil. This includes not only infiltration basins and trenches, where infiltration is the primary mechanism for mitigation of stormwater impacts, but also in unlined extended detention basins and biofiltration swales and strips. Although infiltration of runoff clearly reduces the potential impacts on surface water quality of highway runoff, there remains the possibility for groundwater contamination. The portion of the study concerned with identifying the impacts of infiltration devices on groundwater quality was not successful. Consequently, additional investigation of the potential for groundwater contamination from infiltrated runoff is warranted.

In general, the pollutant removal effectiveness of the tested BMPs was consistent with previously reported values. Analysis of the water quality data collected during the study indicated that in many cases the traditional method of reporting performance as a percent reduction in the influent concentration did not correctly convey the relative performance of the BMPs. The problem was primarily the result of differences in influent runoff quality among the various sites and was especially noticeable for the MCTTs. These devices were installed at park-and-rides, where the untreated runoff had relatively low constituent concentrations. These low influent concentrations resulted in a low calculated removal efficiency even though the quality of the effluent was equal to that achieved in the best of the other BMPs. Consequently, a methodology was developed using linear regression to predict the expected effluent quality for each of the BMPs as if they were subject to identical influent quality. The study found that a comparison on this basis resulted in a more valid assessment of the relative performance of the technologies. Table 2 presents the expected effluent quality for total suspended solids (TSS), total phosphorus, and total zinc that would be achieved if each of the BMPs were subject to runoff with influent concentrations equal to that observed on average for highway and maintenance stations during the study. Effective effluent concentrations of 0 are shown for the infiltration devices, since there is no discharge to surface waters. As experience with BMP selection, design and operational performance increases, it is expected that benefits measured in terms of pollutant removal and receiving water quality improvement will also increase.

Table 2 Effluent Expected Concentrations for BMP types

Device	TSS (Influent 114 mg/L)	Total Phosphorus (Influent 0.38 mg/L)	Total Zn (Influent 355 ug/L)
Austin Sand Filter	7.8	0.16	50
Delaware Sand Filter	16.2	0.34	24
EDB unlined	36.1	0.24	139
EDB lined	57.1	0.31	132
Wet Basin	11.8	0.54	37
Infiltration Basin	0	0	0
Infiltration Trench	0	0	0
Biofiltration Swale	58.9	0.62	96
Biofiltration Strip	27.6	0.86	79
Storm-Filter™	78.4	0.30	333
MCTT	9.8	0.24	33
CDS®	68.6	0.28	197

The retrofit pilot program findings provide a basis to develop a procedure for selecting the technically feasible BMP expected to provide the greatest and most consistent reduction of pollutants of interest in highway runoff. The procedure guides judgment of technical feasibility and utilizes graphs and equations developed from the program's database to estimate effectiveness in reducing pollutant mass loadings and when regulatory effluent limits exist.

All sediment and collected material that accumulated in the BMPs was tested for hazardous materials prior to disposal. The BMPs that required disposal of accumulated material were the three Austin sand filters in District 7, the one Delaware sand filter in District 11, the Storm-Filter™ and the material in the spreader ditch of one of the biofiltration strips in District 7. Title 22 testing was done and all locations were found to have non-hazardous material and therefore all material was disposed of at the landfill.

Media Filters

The Austin and Delaware sand filters and the MCTT provided substantial water quality improvement and produced a very consistent, relatively high quality effluent. Although the greatest concentration reduction occurred for constituents associated with particles, substantial reduction in dissolved metals concentrations was also observed when the influent concentrations were sufficiently high, contradicting expectations that little removal of the dissolved phase would occur in this type of device. Maintenance of the sand filter beds to alleviate clogging was not excessive at the test sites, and the siting requirements are compatible with the small, highly impervious watersheds characteristic of Caltrans facilities. Consequently, the piloted Austin and Delaware sand filters, and the MCTT sand filters are considered technically feasible.

The Delaware and MCTT designs both incorporate permanent pools in the sedimentation chamber, which can increase vector concerns and maintenance requirements. The Delaware filter could be applicable at certain sites where an underground vault system is desired or where a perimeter location is preferred, assuming the vector issues associated with the permanent pool are addressed. The MCTT was found to have a similar footprint and provide a water quality benefit comparable to the Austin sand filter; however, higher life-cycle cost, and the permanent pool and associated vector issues of the MCTT suggest that in general the Austin filter would be preferred.

The Storm-Filter™ did not perform on par with other media filters tested, showing little attenuation of the peak runoff rate and producing a reduction in most constituent concentrations that was not statistically significant. In addition, the standing water in the Storm-Filter™ has the potential to breed mosquitoes. Although technically feasible at the piloted location, the Storm-Filter™ pollutant removal was less and its life-cycle cost was more than the Austin filter. Therefore, the Storm-Filter™ will not be considered to be preferable for use at Caltrans facilities based on the media evaluated in this study, even if the vector problems were avoided.

Maintenance and operation of pumps at several sites was a recurring problem. Consequently, other technologies should be considered at sites with insufficient hydraulic head for operation of media filters by gravity flow.

Future research on construction methods and materials for sand filters is needed to improve the cost/benefit ratio for these devices. In addition, evaluation of alternative media may also allow the targeting of specific constituents or improvement in the performance for soluble constituents, such as nitrate, which are not effectively removed by a sand medium.

Extended Detention Basins

Extended detention basins have an especially extensive history of implementation in many areas and are recognized as one of the most flexible structural controls. The pollutant removal observed in the extended detention basins was similar to that reported in previous studies (Young, 1996) and appeared to be independent of length/width ratio, which is a commonly used design parameter. Resuspension of previously accumulated material was more of an issue in the concrete-lined basin, which exhibited less constituent concentration reduction than in-situ, earthen designs. Based on these findings, unlined extended basins are preferred except where potential groundwater contamination is an over-riding concern.

There are few constraints for siting extended detention basins, although larger tributary areas can reduce the unit cost and increase the size of the outlet orifices, making clogging less likely. The relatively small head requirement (as compared to Austin sand filters) associated with this technology is particularly useful in retrofit situations where the elevation of existing stormwater infrastructure is a design constraint. The unlined installations in southern California did not experience any problems associated with establishment of wetland vegetation, erosion or excessive maintenance (as compared to the lined basin). Except where groundwater quality may be impacted, unlined basins are preferred on a water quality basis because of the substantial infiltration and associated pollutant load reductions that were observed at these sites.

This study reaffirms the flexibility and performance of this conventional technology and confirms their technical feasibility, depending on site specific conditions. The effectiveness, small head requirement and few siting constraints suggest that these devices are one of the most applicable technologies for stormwater treatment at Caltrans facilities.

Wet Basin

One wet basin was successfully sited and operated for this study, and observed pollutant removal was substantial. An important finding of this study is that the discharge quality from a wet basin with a large permanent pool volume is largely a function of the quality of the baseflow used to maintain that pool and of the transformation of the quality of that flow during its residence time in the basin. It should be noted that for this specific pilot installation and receiving water (impaired by nutrients), an ancillary benefit was the treatment provided in the wet basin for the 'offsite' base flow and the substantial nutrient reduction observed during dry weather periods.

Depending on site specific information, wet basins are considered technically feasible for highway stormwater treatment; however, there are a number of concerns regarding the applicability of wet basins for retrofit of Caltrans facilities. The long-term maintenance requirements and costs of wet basins may not have been accurately estimated because some major maintenance activities did not occur during the study period. The potential for the basin to become a habitat for endangered species may result in required consultation with the USFWS and subsequent mitigation, should habitat 'take' occur during routine maintenance activities. The cost of these potential mitigation activities also is unknown. Consequently, wet basins warrant further study to understand the risk and cost of habitat mitigation and other potential impacts of endangered or threaten species issues.

Vector (mosquito) control required additional vegetation management that resulted in observed maintenance that was much higher than for other devices. Vector control experts were only marginally satisfied with the level of vector prevention provided by mosquito fish, although they were generally effective in reducing mosquitoes.

A primary siting constraint of this technology is the need for a perennial flow to sustain the permanent pool. The siting process showed that the vast majority of the pilot BMP locations constructed were in small, highly impervious watersheds with no dry weather flow.

Basin size also limited siting opportunities. With a permanent pool volume three times the water quality volume, the wet basin had as much as four times the volume of other technologies, such as detention basins. The larger size results in higher cost and land requirements higher than those of alternative technologies. Many other criteria for sizing the permanent pool have been recommended, which may reduce the facility size while providing only slightly less pollutant removal. (See *Composite Siting Study, District 11*, Appendix A)

A number of questions are left unanswered by this study and warrant further investigation. Additional work could help define the relationship between permanent pool volume, construction cost, and water quality benefit. An assessment of the feasibility of a seasonal wet basin, where the pool was allowed to go dry during the summer, would increase siting opportunities by potentially allowing siting of these devices where perennial flow is not present. Finally, additional work is needed to evaluate the impact of endangered and threatened species that would be attracted to the basin and affect the maintenance schedule or requirements.

Biofiltration

Biofiltration BMPs, including bioswales and biofiltration strips are considered technically feasible depending on site-specific considerations. Overall, the reduction of concentration and load of the constituents monitored was comparable to the results reported in other studies, except for nutrients. Nutrient removal was compromised by the natural leaching of phosphorus from the salt grass vegetation used in the pilot study. This condition was not known at the start of the project but was discovered later in the program (see Chapter 8 for details). While space limitations in highly urban areas may make siting these BMPs difficult, they are suitable for fitting into available space such as medians and shoulder areas. Their use should be considered where existing space and hydraulic conditions permit.

Although irrigation was used to establish vegetation for the pilot biofiltration swales and strips, natural moisture from rainfall was sufficient to maintain them once they were established. Complete vegetation coverage, especially on the sideslopes of swales, was difficult to maintain, even with repeated hydroseeding of these areas. Lower vegetation density and occasional bare spots are to be expected in an arid climate, but do not appear to seriously compromise pollutant removal. An important lesson of this study is that a mixture of drought-tolerant native grasses is preferred to the salt grass monoculture used at the pilot sites. In southern California, it is preferable to specify species that grow best during the winter and spring (the wet season) and to schedule vegetation establishment accordingly. Few erosion problems were noted in the operation of the sites; however, damage by burrowing gophers was a problem at several sites.

Biofiltration swales and strips were among the least expensive devices evaluated in this study and were among the best performers in reducing sediment and heavy metals in runoff. Removal of phosphorus was less than that reported by Young et al. (1996) but may be related to leaching of nutrients from the saltgrass during its dormant season. The swales are easily sited along highways and within portions of maintenance stations, and do not require specialized maintenance. In addition, the test sites were similar in many ways to the vegetated shoulders and conveyance channels common along highways in many areas of the state. Consequently, these areas, which were not designed as treatment devices, could be expected to offer water quality benefit comparable to these engineered sites. More research is needed to investigate this possibility.

The research needs involving biofiltration devices center on refinement of the design criteria and evaluation of the performance with vegetation other than salt grass. The current design criteria for strips are especially poor with little guidance on the relative size of the tributary area to the buffer strip, and almost no data on the effect of slope and length on removal efficiency. In southern California and other relatively dry climates, it is also important to establish the minimum vegetation coverage needed to provide effective pollutant removal.

Infiltration

Infiltration basins and trenches are considered be technically feasible depending on site specific conditions. However, there are three main constraints to widespread implementation of infiltration devices: locating sites with appropriate soils, the potential threat to groundwater quality, and the risk of site failure due to clogging. Further investigation of these constraints is recommended.

Infiltration basins and trenches can be an especially attractive option for BMP implementation, since they provide the highest level of surface water quality protection. In addition, they reduce the total amount of runoff, restoring some of the original hydrologic conditions of an undeveloped watershed. Although trenches and basins are similar in terms of their water quality benefits, the siting and maintenance requirements of the two devices are distinctly different. Infiltration basins generally treat runoff from relatively larger tributary areas and require more routine maintenance such as vegetation management, but they are easier to rehabilitate when clogged. Conversely, infiltration trenches generally treat runoff from smaller areas, and their smaller footprint allows them to be sited in more space-constrained areas. Observed routine maintenance was less; however, once clogged, partial or complete reconstruction may be required, resulting in uncertain long-term cost.

The original siting study did not identify sufficient suitable locations for the number of infiltration installations specified in the District 7 Stipulation within the time frame provided in the agreement. This study is being followed by assessments in both Districts to gauge the potential extent of infiltration opportunities. In Los Angeles, the assessment is being accomplished with field investigations in selected highway corridors and in San Diego by existing data, but more broadly based through the District. In addition, there is concern at the state and regional levels about the impact on groundwater quality from infiltrated runoff. The portion of this study that was implemented to assess the potential impact to groundwater quality from infiltrated stormwater runoff was largely unsuccessful and longer term, more comprehensive studies than were possible under this pilot program are warranted. Despite these uncertainties, the parties in this study worked cooperatively to develop interim guidelines for siting infiltration devices in response to requests by the State and Regional Water Quality Control Boards.

In summary, infiltration can be a more challenging technology in that site assessment, groundwater concerns, and long-term maintenance issues are important elements that are subject to some uncertainty. The experience in this study is that siting these devices under marginal soil and subsurface conditions entails a substantial risk of early failure. Analysis of this experience resulted in development of a detailed set of site assessment guidelines for locating infiltration devices in the future to ensure that soil and subsurface conditions are appropriate for their implementation. It is important that these guidelines be implemented to insure that infiltration is used with adequate separation from groundwater and in soils with a favorable infiltration rate. In addition, loss of soil structure, clogging, and other changes that may occur during the life of the facility may be difficult to ameliorate. Nevertheless, infiltration devices are considered technically feasible at suitable sites and they were among the most cost-effective BMPs tested in this study.

Continuous Deflective Separators

Two CDS® units were successfully sited, constructed and monitored during the study. The devices were developed in Australia with the primary objective of gross pollutant (trash and litter) removal from stormwater runoff. The devices are considered technically feasible depending on site specific conditions. They were highly successful at removing gross pollutants, capturing an average of 88 percent, with bypass of this material occurring mainly when the flow capacity of the units was exceeded. Even though these two units were sited on elevated sections of freeways, 94 percent of the captured material by weight was vegetation. Consequently, the maintenance requirements may be excessive if these units are located in an area with a significant number of trees or other sources of vegetative material.

A secondary objective of the CDS® units is the capture of sediment and associated pollutants, particularly the larger size fractions. The average sediment concentration in the influent to the two systems was relatively low and no significant reduction was observed. Reductions in the concentrations of other constituents were also not significant. It should be noted that the specific fiberglass CDS units tested in this study are no longer offered by the manufacturer. CDS does manufacture similar concrete units that were not evaluated as a part of this study.

These devices maintain a permanent pool in their sumps and mosquito breeding was observed repeatedly at the two sites. The frequency of breeding was reduced by sealing the lids of the units and installing mosquito netting over the outlet. Other non-proprietary devices developed by Caltrans for litter control, which do not maintain a permanent pool, may be preferred to this technology to minimize vector concerns.

Drain Inlet Inserts

Two models of proprietary drain inlet inserts were evaluated. The data collected during this study indicate that they cannot be operated unattended because of hydraulic limitations that resulted in flooding on a number of occasions and clogging that caused bypass of untreated runoff. Their pollutant removal was also minimal. The absolute number of maintenance hours was not large; however, the timing of maintenance was critical, right before and during storm events. Because of their frequent maintenance requirements and safety considerations (access along active freeways and highways), implementation on roadsides would not be appropriate. Installation at maintenance stations might be considered safer; however, timely maintenance is often infeasible due to other maintenance activities required during storm events. In addition, they were only marginally effective, with constituent removal generally less than 10 percent. Consequently, these particular models were judged to be not technically feasible at the piloted locations.

The two types of inserts monitored in this study were carefully selected from the many types that were available at the start of the study based on an evaluation of their water quality improvement potential. There are many other types of proprietary drain inlet inserts on the market that were not evaluated and may perform better than the two evaluated here; however, until there is better independent documentation of their pollutant removal effectiveness as well as operation and maintenance requirements, this technology should not be routinely considered for implementation. The variety of drain inlet inserts on the market has increased since the beginning of the pilot program, and one of the inserts evaluated during this study is no longer being manufactured. Some newer insert types are now available but the results of this study should not be used to assess the expected feasibility and/or performance of these recently available technologies. It should be noted trash removal was not monitored as part of this study and certain types of drain inlet inserts may be effective for this purpose.

Oil-Water Separator

Although an oil-water separator (OWS) was successfully sited, constructed and monitored, the results indicate that this is not an applicable technology for the piloted location. Twenty-two maintenance stations were originally considered for implementation of this technology and the ten with the potential for higher concentrations of petroleum hydrocarbons in runoff were subject to further evaluation. Four of these were subsequently selected for monitoring and of these, only one site appeared to have concentrations that were sufficiently high to warrant installation of an oil-water separator. However, concentrations of free oil in stormwater runoff observed during the course of the study from this site were too low for effective operation of this technology. Runoff quality from three other maintenance stations was monitored during the study and concentrations of petroleum hydrocarbons at these sites were also below the threshold required for effective operation of the oil-water separator. Improved source-control measures at Caltrans maintenance stations have generally been effective in reducing hydrocarbon pollutant levels below that which OWS are effective in removing. In conclusion, none of the 25 maintenance stations in Districts 7 and 11 that were evaluated had sufficiently high concentrations of free oil for successful implementation of this technology. At these low levels, other conventional stormwater controls can provide better treatment of hydrocarbons, as well as other pollutants of concern in runoff; however, they may be appropriate in certain non-stormwater situations (e.g., where source controls cannot ensure low oil and grease concentrations).

Cost

The incurred costs of constructing and operating the BMPs in this pilot study were documented in detail. These costs reflect the requirements of stormwater retrofit in the highway environment in the urban areas of southern California and may not be representative of those that might be incurred in other settings. There has been extensive discussion among the parties involved in this study regarding whether these numbers accurately represent the costs that would be incurred in a more extensive (widespread) retrofit program. Many reasons have been suggested for possible differences including, among others: costs specific to pilot projects, the bidding climate at the time the contracts were advertised, the lack of standard competitive bidding, and the dispersed nature of the construction activities. While the parties disagree to some extent about the degree of departure from a normal scenario, both parties agree that there were pilot-specific costs incurred in this project that would not be replicated in a larger scale retrofit implementation program. A separate study commissioned by the retrofit parties suggested ways to reduce costs. Additional cost information from elsewhere in the nation is provided in Appendix C.

The actual construction costs were reviewed on a site-by-site basis by a technical workgroup that included water quality specialists, construction managers and design engineers. The goal of the workgroup was to develop ‘generic’ retrofit costs that could reasonably be applied to other Caltrans BMP retrofit projects. The costs were developed by (1) reviewing the specific construction items for each site; (2) eliminating those that were atypical; and (3) adjusting the costs that were considered to be outside of what would ‘routinely’ be encountered in a retrofit situation. Specific construction items that were reduced or eliminated from the realized costs are discussed in the individual device chapters. The average adjusted construction costs for each of the technologies are presented in Table 3.

The construction costs for each of the BMPs have been normalized by the water quality volume rather than by tributary area to account for the significant differences in design storm depth used for sizing the controls in different parts of the study area and for the differences in the runoff coefficient at each site. For the flow-through devices, such as swales, the cost per unit volume calculations used the water quality volume for the tributary area that would be used for BMP sizing if a capture-and-treat type device, such as a detention basin, were implemented at the site. Where more than one facility of the same type was constructed, the mean cost per water quality volume is reported.

Life-cycle costs were developed by adding the present value of normalized expected operation and maintenance cost to the normalized adjusted construction cost. The expected maintenance requirements were developed based on the recommended Operation and Maintenance Plan (Appendix D) and are also presented in Table 3. The present value calculation used a 20 year life-cycle and a 4 percent discount rate. There was a substantial range of values for the life-cycle cost of biofiltration strips and drain inlet inserts among the individual sites because the size of the devices was fixed, while the tributary areas varied greatly. Nevertheless, the average value observed in the study was used for computations in this table as it was for other devices.

The pilot program construction cost figures represented throughout this report are directly applicable only to Caltrans and its operations. The unique environment and constraints associated with retrofitting BMPs into the California Highway system makes comparison to other possible applications of the same BMPs difficult. Furthermore, even within the Caltrans system, information on construction costs will undoubtedly increase greatly as BMPs continue to be developed and implemented, such that the construction cost information in this report will be of limited value over time. It should be recognized that the Operation and Maintenance cost information was based partly upon estimates and projections of future needs.

The parties engaged the assistance of outside experts to review the costs experienced in the retrofit pilot program and to make suggestions for cost reductions and improvements in efficiency. Eventually these consultants prepared a report, which is appended to this report in Appendix C.

Table 3 Cost of BMP Technologies (1999 dollars)

BMP Type (No. of installations)	Avg. Adjusted Construction Cost	Adjusted Construction Cost/m^3 of the Design Storm	Annual Adjusted O&M Cost	Present Value O&M Cost/m^3	Life-Cycle [a] Cost/m^3
Wet Basin (1)	$ 448,412	$ 1,731	$ 16,980	$ 452	$ 2,183
Multi-chambered Treatment Train (2)	$ 275,616	$ 1,875	$ 6,410	$ 171	$ 2,046
Oil-Water Separator (1)	$ 128,305	$ 1,970	$ 790	$ 21	$ 1,991
Delaware Sand Filter (1)	$ 230,145	$ 1,912	$ 2,910	$ 78	$ 1,990
Storm-Filter™ (1)	$ 305,355	$ 1,572	$ 7,620	$ 204	$ 1,776
Austin Sand Filter (5)	$ 242,799	$ 1,447	$ 2,910	$ 78	$ 1,525
Biofiltration Swale (6)	$ 57,818	$ 752	$2,750	$ 74	$ 826
Biofiltration Strip (3)	$ 63,037	$ 748	$2,750	$ 74	$ 822

BMP Type (No. of installations)	**Avg. Adjusted Construction Cost**	**Adjusted Construction Cost/m^3 of the Design Storm**	**Annual Adjusted O&M Cost**	**Present Value O&M Cost/m^3**	**Life-Cycle [a] Cost/m^3**
Infiltration Trench (2)	$ 146,154	$ 733	$ 2,660	$ 71	$ 804
Extended Detention Basin (5)	$172,737	$590	$ 3,120	$ 83	$ 673
Infiltration Basin (2)	$ 155,110	$ 369	$ 3,120	$ 81	$ 450
Drain Inlet Insert (6)	$ 370	$ 10	$1,100	$ 29	$ 39

[a] Present value of operation and maintenance unit cost (20 yr @ 4%) plus construction unit cost.

Despite the uncertainty in the projected costs of a wholesale BMP retrofit program, the cost data can be used to rank BMPs by life-cycle costs, which can serve as the first step in selecting the most cost-effective technology for a given site.

Recurring issues that strongly affected the capital cost of the devices were the discovery of unsuitable material in the subsurface and buried utilities at the sites selected for implementation of the devices. Unsuitable material included both natural and manmade objects that increased the cost of excavation. At several sites, large boulders had to be removed and the site over-excavated and backfilled. Other sites had been used as disposal areas, the extent of which was not realized until after construction began. Rarely did the as-built plans correctly identify the location of utilities, requiring their relocation or the repositioning of the BMP during construction. These types of conditions may be encountered fairly frequently in retrofit construction. Consequently, average published costs may be appropriate for planning purposes, but should not generally be used to estimate the cost for a particular site, unless supplemented with a detailed site assessment.

In addition to construction costs, it is also important to consider the operation and maintenance costs for each technology. An important element in selecting the most appropriate BMP for a site is an understanding of the amount and type of operation and maintenance required. BMPs that require less maintenance are preferred, other factors being equal.

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ACRONYMS AND ABBREVIATIONS

AC	Asphalt-concrete
ANOVA	Analysis of variance
AOS	Apparent opening size
BC	Brown and Caldwell
BMP	Best Management Practice
BSW	Biofiltration Swale
BSTRP	Biofiltration Strip
Caltrans	California Department of Transportation (Caltrans)
CDP	Coastal Development Permit
CDS®	Continuous Deflective Separator
cms	Cubic meters per second
DII	Drain inlet insert
EDB	Extended detention basin
EMC	Event mean concentration
FF™	FossilFilter™
GLACVDC	Greater Los Angeles County Vector Control District
GSRD	Gross Solids Removal Device
HDM	Highway Design Manual (Caltrans)
IB	Infiltration Basin
IT/STRP	Infiltration Trench/Biofiltration Strip
IVM	Integrated Vegetation Management
LAX	Los Angeles International Airport
MCTT	Multi-chambered treatment train
MFSA	Media Filter – Sand Austin Type
MFSD	Media Filter – Sand Deleware Type
MFSTF	Media Filter – Storm-Filter™
MID	Maintenance Indicator Document
MS	Maintenance station
MW	Montgomery Watson-Chaudhary
NRDC	Natural Resources Defense Council
O&M	Operation and maintenance
OWS	Oil-water separator
P&R	Park-and-ride

PS&E	Plans, specifications, and Estimate Package
QA/QC	Quality Assurance/Quality Control
ROW	Right-of-way
SDCOVC	San Diego County Vector Control District
SG™	StreamGuard™
SF™	Storm-Filter™
TKN	Total Kjeldahl Nitrogen
TPH	Total petroleum hydrocarbons
TSS	Total suspended solids
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VBDS	Vector Borne Disease Section, California Department of Health Services
VCD	Vector Control District
WB	Wet basin
WQV	Water quality volume

1 INTRODUCTION

The objectives of this document are to report on Caltrans' experiences in the retrofit pilot program, including cost, technical feasibility and benefits of a wide range of structural Best Management Practices (BMPs) for treating stormwater runoff from a variety of Caltrans facilities. Each BMP type evaluated during this study is discussed in a separate chapter describing siting, design, construction, operation, and maintenance. The results of the monitoring program, including the removal efficiencies determined, also are presented for each technology. Recommendations on design, operation and maintenance elements are made for each BMP type based on the lessons learned during this study. Appendices referenced provide a more detailed description of each element of this study.

The three concluding chapters present an overview of the study results; comparing relative cost and expected pollutant removal and presenting conclusions, recommendations and technical feasibility for Caltrans facilities. The findings reported here are the result of a collaborative effort between Caltrans and plaintiffs described below. A study team made up of representatives from the parties to the lawsuit, their attorneys, local vector control agencies, and outside technical experts provided oversight of the retrofit pilot program; however, it should be noted that there are elements about which there is some disagreement. This effort has resulted in an unparalleled, comprehensive study of the performance of many common, and a few uncommon, structural BMPs implemented along highways and at associated facilities.

1.1 The Program's Purpose and Goal

Experience in the stormwater management field over the past 20 years provided some basis to address BMP retrofit questions at the outset. A small set of BMP types has been fairly widely applied. A number of previous research projects measured their effectiveness in capturing and holding pollutants. The ability to construct, operate, and maintain these devices attests to their technical feasibility in the circumstances of their application.

Quantification of costs has not received as much attention as measurement of effectiveness. In recent years the relatively small set of available BMPs began to expand, especially through the introduction of a variety of commercial devices. Therefore, the goal of the retrofit pilot program was to produce and interpret data on the effectiveness, technical feasibility, costs, and benefits of the principal BMPs now available with respect to the southern California highway environment.

1.2 Study Background

Litigation between Caltrans and the Natural Resources Defense Council (NRDC) and Santa Monica BayKeeper resulted in a Stipulation requiring the development of a Best Management Practice (BMP) Retrofit Pilot Program in Caltrans District 7 (Los Angeles area). The goal of this program was to gain important experience in retrofitting existing

Caltrans facilities with structural BMPs to improve the quality of stormwater discharges. The Stipulation originally called for 38 individual pilot projects. The District 7 Stipulation permitted 10 pilot projects, involving six types of BMPs, to be located within Caltrans District 11, San Diego. After substitutions of specific BMP types, 36 pilots were required under the Stipulation. The types of devices constructed and monitored included drain inlet inserts, biofiltration strips, biofiltration swales, infiltration basins, infiltration trenches, media filters, extended detention basins, oil-water separators, and multi-chamber treatment trains.

Separate litigation in District 11 (San Diego area) between Caltrans and a consortium of plaintiffs, comprised of the San Diego BayKeeper, NRDC and USEPA, resulted in a Consent Decree that included an agreement to implement a BMP Retrofit Pilot Program in District 11. The types of BMP pilot projects within District 11 included biofiltration strips, biofiltration swales, an infiltration basin, infiltration trench, media filters, extended detention basins, and a wet basin. The construction cost for all pilot projects within District 11 was required to total at least $2.5 million. The entire BMP Retrofit Pilot Program included the design, construction, and monitoring of 39 discrete BMP pilot projects. The BMP types, site location numbers, and locations are listed in Table 1-1.

Table 1-1 BMP Types and Project Locations

BMP Type	District 7 Site Location/Site No.	District 11 Site Location/Site No.
Extended Detention Basin	I-5/I-605 (s) 74101	I-5/Manchester (sc) 111105
	I-605/SR-91 (s) 74102	I-5/SR-56 (c) 111101
		I-15/SR-78 (c) 111102
Wet Basin		I-5/La Costa (c) 111104
Austin Sand Filter	Eastern MS (s) 74202	La Costa PR (sc) 112203
	Foothill MS (s) 74203	SR-78/I-5 P&R (sc) 112204
	Termination P&R (s) 74204	
	Paxton P&R (s) 74103	
Delaware Sand Filter		Escondido MS (sc) 112202
Multi Chamber Treatment Train	Via Verde P&R (s) 74206	
	Metro MS (s) 74104	
	Lakewood P&R (s) 74208	
Storm-Filter™		Kearny Mesa MS (sc) 112201
Biofiltration Swale	I-605/SR-91 (s) 73222b	SR-78/Melrose Dr (sc) 112205
	Cerrito MS (s) 73223	I-5/Palomar Airport Rd (sc) 112206
	I-5/I-605 (s) 73224	
	I-605/Del Amo (s) 73225	
Biofiltration Strip	I-605/SR-91 (s) 73222a	Carlsbad MS (sc) 112207a

BMP Type	District 7 Site Location/Site No.	District 11 Site Location/Site No.
	Altadena MS (s) 73211b	
Infiltration Basin	I-605/SR-91 (s) 73101	I-5/La Costa (sc) 111103
Infiltration Trench	Altadena MS (s) 73211a	Carlsbad MS (sc) 112207b
Drain Inlet Insert – FossilFilter™	Foothill MS (s) 73216b	
	Las Flores MS (s) 73217b	
	Rosemead MS (s) 73218b	
Drain Inlet Insert – StreamGuard™	Foothill MS (s) 73216a	
	Las Flores MS (s) 73217a	
	Rosemead MS (s) 73218a	
Oil Water Separator	Alameda MS (s) 74201	
Continuous Deflective Separators (CDS®)	I-210 / Orcas (s) 73102	
	I-210 / Filmore (s) 73103	

c - Consent Decree
s – Stipulation

The study was conducted as a cooperative effort by the study team. The study team was comprised of the entities shown on the project organization chart. Key team members and their affiliation are listed in Table 1-2. Consultants hired by Caltrans were responsible for the majority of the day-to-day study operations. RBF Consulting provided overall study and consultant management under the direction of Caltrans and the Plaintiffs. RBF Consulting developed the project Scoping Study, Siting Studies and the Plans, Specifications, and Estimate Packages (PS&E) for the sites located in District 11. RBF Consulting also provided construction management for the District 11 sites with District oversight. Montgomery Watson (MW) and Brown and Caldwell (BC) Consultants provided PS&E, and construction management services (with District oversight) for sites located in District 7. MW and BC also provided construction services for some of the sites located in District 7. Operation and maintenance of the study sites was carried out by RBF Consulting in District 11 and MW and BC in District 7.

The responsibilities of Department of Health Services, University of California at Riverside, and Larry Walker and Associates regarding vector research are described in Section 1.7. The Glenrose Engineering and Holmes and Narver team efforts in reviewing cost are described in Section 1.9. Specific responsibilities of the study team by site location are shown in Table 1-3.

Communication within the study team was accomplished through several methods. First, biweekly reports were generated by Caltrans and the consultants to update the remainder of the study team. Biweekly conference calls were held with the Plaintiffs to respond to questions and receive input on the study. Second, quarterly reports were prepared which included the biweekly reports and to-date preliminary study results. The quarterly reports were reviewed during quarterly meetings, held with the entire study team (typically attended by about 30 persons). The study team ordered changes and modifications to the program as appropriate at these quarterly meetings. Minutes of the quarterly meetings were circulated after the meeting. These minutes were then included in an appendix of the subsequent quarterly report; all quarterly reports can be found in Appendix H of this report. About mid-August (2001), the parties agreed to end the regular biweekly conference calls and reports since monitoring of all BMPs, except the CDS® units, was complete. Subsequent working sessions and conference calls were held on an ad-hoc basis with the parties to go over the conclusions and findings of the study and to develop the final report.

The study team reviewed all monitoring data for conformance with the guidelines developed for the study. Once the study team determined that the monitoring data met the guidelines, information regarding device performance was released on an annual basis to the manufacturers of the proprietary devices (drain inlet inserts, Storm-Filter™) and to the designer of the MCTT (Dr. Robert Pitt).

BMP Retrofit Pilot Program

ORGANIZATION CHART

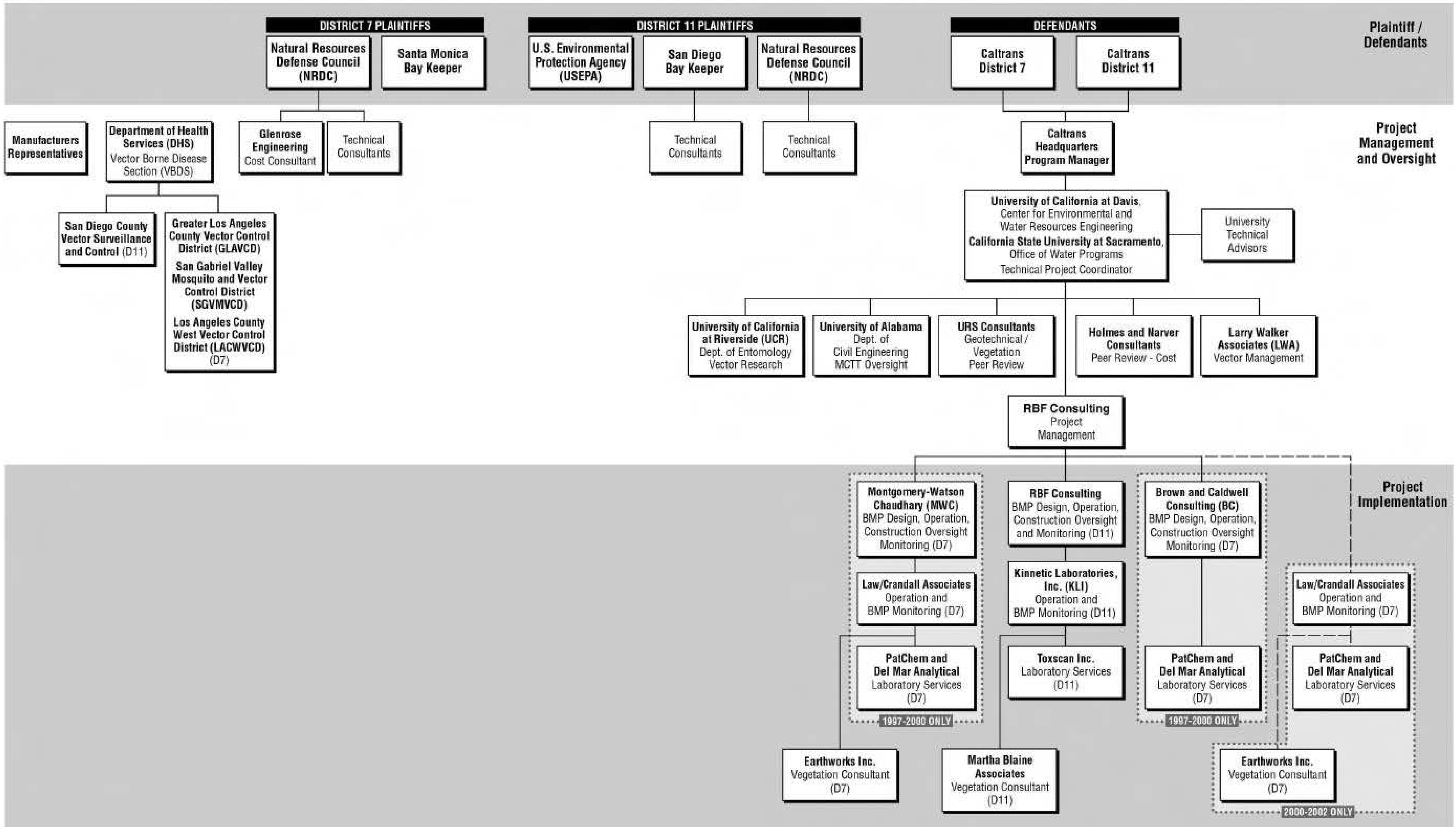

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Table 1-2 Key Team Members

Organization/Name	
Caltrans District 7	**University of California at Davis (UCD)/California State University Sacramento (CSUS) Technical Advisors**
Doug Failing, P.E.	Dr. John Johnston (CSUS)
Paul Thakur, P.E.	Dr. Ed Dammel (UCD)
Peter Van Riper, P.E.	Howard Yamaguchi, P.E. (UCD)
Richard Gordon	**University of California at Riverside**
James McCarthy, P.E.	Dr. Bill Walton
William A. Evans, Esq.	**University of Alabama**
Charles Belenky, Esq.	Dr. Robert Pitt, P.E., DEE
Bill Reagan, P.E.	**URS Consultants**
Caltrans District 11	Carol Forrest, P.E.
Cid Tesoro, P.E.	Ron Johnson, P.E.
Sayra Ramos, P.E.	**Holmes and Narver**
John Fredrick Smith, Esq.	David Sluga, P.E.
Lanny Chronert	Gary Sjelin, P.E.
Caltrans Headquarters	**Glenrose Engineering**
Steve Borroum, P.E.	Lauren Ross
Kim Noonan, P.E.	Matt Hollon
Dr. Kenneth Smarkel, P.E.	**RBF Consulting**
Bob Wu, P.E.	Scott Taylor, P.E.
Marcello Peinado, P.E.	Anna Lantin, P.E.
Mark Rayback, P.E.	Bill Whittenberg, P.E., DEE
Mike Flake, P.E.	Dr. Michael Barrett, P.E.
Natural Resources Defense Council	Richard Watson, AICP
David Beckman, Esq.	Laura Larsen, P.E.
Everett DeLano, Esq.	Ann Walker, P.E.
Alex Helperin	Tom Ryan, P.E.
Natural Resources Defense Council Technical Consultants	**Montgomery Watson-Chaudhary**
Dr. Richard Horner	Gary Friedman
Dr. Christopher May	William Weidenbacher, P.E.
Santa Monica BayKeeper	Chuck Paul, P.E.
Terry Tamminen	Glen Grant, P.E.
Steve Fleischli, Esq.	Ronald Wurz
San Diego BayKeeper	**Larry Walker Associates**
Ken Moser	Dr. Dean Messer
John Barth, Esq.	**Earthworks, Inc.**
Bruce Reznick	Margo Griswold
San Diego BayKeeper Technical Consultant	**Martha Blaine Associates**
Richard Graff, P.E.	Martha Blaine

Organization/Name	
U.S. Environmental Protection Agency	**Brown and Caldwell Consultants**
Jeremy Johnstone	Bob Finn, P.E.
Laurie Kermish, Esq.	Doug Robison, P.E.
Peter Jaffee, Esq.	Fred Burke, P.E.
UCD/CSUS Project Coordination	Mark Williams
Yulya Borroum, P.E. (UCD)	**Law/Crandall**
Brian Currier, P.E. (UCD)	Ed Othmer, P.E.
Glenn Moeller, P.E. (CSUS)	Byron Berger, P.E.
Cathy Beitia (CSUS)	Stephen Brinigar, P.E.
Kinnetic Laboratories, Inc.	Kurt Myers
Dr. Patrick Kinney	Bill O'Braitis
Robert Shelquist	Mike Eagen
Matt Zapala	**Department of Health Services**
Ken Kronschnabl	Dr. Vicki Kramer
Marty Stevenson	Charles Meyers
Chris Warn	Reuben Junkert, P.E.
Richard Mattison	Dr. Marco Metzger
PatChem Laboratory	Toby Roy, P.E.
Gary Goodwin	Dr. J. Wakoli Wekesa
Patricia Brueckner	**ToxScan Inc**
Del Mar Analytical Laboratory	Dr. Philip Carpenter
Patty Mata	**San Gabriel Valley Mosquito and Vector Control District**
Jeanne Shoulder	
Proprietary Device Manufactures	Sue Zuhlke
Bob Howard (CDS Technologies)	Kenn Fujioka
Bryan O'Wiggington, Stormwater Management Inc.	**Los Angeles County West Vector Control District**
Chuck McKinley, Kri-Star Enterprises	David Heft
Julie Osteen, Foss Environmental	**San Diego County Vector Surveillance and Control**
Patrick Gothro, Foss Environmental	
Greater Los Angeles County Vector Control District	Moise Mizrahi
	Mike Devine
Dr. Jack Hazelrigg	Lucky Ketcham
Susanne Kluh	Keith MacBarron
Minoo Madon	

Table 1-3 Consultant Responsibility by BMP Pilot Site

Location	BMP Type	Scoping/ Siting	Design	Construction Management	Maintenance and Monitoring	Laboratory
			DISTRICT 7			
I-605/SR-91	IB	RBF[a]	MW[b]	MW	MW	PatChem
I-210 E of Orcas	CDS®	RBF	MW	MW	MW	PatChem
I-210 E of Filmore	CDS®	RBF	MW	MW	MW	PatChem
I-5/I-605	EDB	RBF	BC[c]	BC	BC	PatChem
I-605/SR-91	EDB	RBF	BC	BC	BC	PatChem
Alameda MS	OWS	RBF	BC	BC	BC	PatChem
Eastern MS	MF	RBF	BC	BC	BC	PatChem
Foothill MS	MF	RBF	BC	BC	BC	PatChem
Termination P&R	MF	RBF	BC	BC	BC	PatChem
Via Verde P&R	MCTT	RBF	BC	BC	BC	PatChem
Lakewood P&R	MCTT	RBF	BC	BC	BC	PatChem
Altadena	Bio Strip/IT	RBF	MW	MW	MW	PatChem
Foothill MS	DII	RBF	MW	MW	MW	PatChem
Las Flores MS	DII	RBF	MW	MW	MW	PatChem
Rosemead MS	DII	RBF	MW	MW	MW	PatChem
I-605/SR-91	Bio strip/Swale	RBF	MW	MW	MW	PatChem
Cerritos MS	BioSwa le	RBF	MW	MW	MW	PatChem
I-5/I-605	BioSwale	RBF	BC	BC	BC	PatChem
I-605/ Del Amo	BioSwale	RBF	MW	MW	MW	PatChem
			DISTRICT 11			
I-5/SR-56	EDB	RBF	RBF	RBF	RBF	Toxscan
I-15/SR-78	EDB	RBF	RBF	RBF	RBF	Toxscan
I-5/La Costa (W)	IB	RBF	RBF	RBF	RBF	Toxscan
I-5/La Costa (E)	WB	RBF	RBF	RBF	RBF	Toxscan
I-5/Manchester (E)	EDB	RBF	RBF	RBF	RBF	Toxscan
Kearny Mesa MS	Storm-Filter™ (Perlite/Zeolite)	RBF	RBF	RBF	RBF	Toxscan
Escondido MS	MF	RBF	RBF	RBF	RBF	Toxscan
La Costa P&R	MF	RBF	RBF	RBF	RBF	Toxscan
SR-78/I-5 P&R	MF	RBF	RBF	RBF	RBF	Toxscan
Melrose Drive / SR-78	Bio Swale	RBF	RBF	RBF	RBF	Toxscan
I-5/Palomar Airport Road	Bio Swale	RBF	RBF	RBF	RBF	Toxscan
Carlsbad MS	Bio Strip/IT	RBF	RBF	RBF	RBF	Toxscan

[a] RBF Consulting
[b] Montgomery Watson
[c] Brown and Caldwell

Midway through the pilot study it was determined that the resultant interim reports and data were public records. At that time, other interested parties (most notably the State Water Resources Control Board Staff) were invited to attend the quarterly meetings, and they regularly received reports and information of findings and results.

Communication outside of the study team (verbal, written correspondence and professional papers) with other agencies or experts was reported to the study team during biweekly and quarterly meetings.

1.3 Research Objectives

The objectives of the BMP Retrofit Pilot Program included:

- Evaluation of the performance (constituent removal efficiency and effluent quality) of the device;
- Collection of information to assess the technical feasibility of design, construction, and maintenance in a retrofit environment;
- Evaluation of the operational aspects associated with maintenance of the structures and potential solutions to any identified problems;
- Assessment of costs for constructing and maintaining selected types of BMPs; and
- Evaluation of benefits to surrounding environment and to public health

This study documents the effectiveness of the various BMPs in removing selected constituents in highway runoff. Detailed records were kept of siting, design, construction, and operation and maintenance issues. Operational problems and procedures and resultant solutions were documented. Observations of the BMP operations were, for the most part, recorded in journal format due to the difficulty in characterizing these types of information. Costs were assessed through detailed records kept on the design, construction, operation and maintenance of each of the retrofit devices.

1.4 BMP Siting

The criteria used to select sites varied depending on the nature and specific requirements of the type of BMP to be evaluated. However, four general criteria controlled the selection of all retrofit pilot project sites:

- Each site had to be appropriate for the capabilities of the BMP being evaluated.
- Each site had to have a realistic opportunity to install, operate, and observe the devices being evaluated.

- All sites had to be owned and operated by Caltrans.

- All sites had to be operational and observed for two years under the District 7 Stipulation, and for at least one year under the District 11 Consent Decree.

Specific siting requirements for each BMP are included in the project *Scoping Studies* (RBF Consulting, 1998a, 1998b; included in Appendix A).

The retrofit pilot projects were sited to permit observations pertaining to technical feasibility, costs of retrofitting, and pollutant removal performance. Sites were originally selected because they were typical along Caltrans rights-of-way and at associated facilities, including interchanges, park-and-rides, and maintenance facilities. This was done to ensure that the program evaluated retrofit opportunities similar to those that would be encountered on a larger scale. Each site for a retrofit pilot project was selected to be appropriate, if not ideal, for the type of best management practice to be evaluated without pre-judgment about the outcome of the associated retrofit pilot study. A detailed discussion of the siting for each technology is contained in Appendix A.

Sites were selected using a weighted decision matrix process for each type of BMP in order to select the 'best' site from among candidate sites. Significant criteria in the selection of the retrofit project were assembled and then assigned a weighting factor to emphasize the more important selection criteria. All candidate sites were reviewed and ranked according to the weighted criteria established for the subject BMP. Among the primary criteria used in site selection (in no particular order) were:

- Maintenance access

- Presence of vehicles and heavy equipment (on maintenance station sites for obvious sources of pollutants)

- Space availability for BMP structure

- Proximity to structures for infiltration type devices

- Drainage pattern to available location

Several constraints were encountered in selecting appropriate sites for the BMPs. There was a limited amount of suitable, available surplus area within the right-of-way owned by Caltrans; consequently, relatively little area was available for the land-intensive BMPs. The second significant constraint was the lack of infiltration capacity of the soils at sites that would otherwise be appropriate for an infiltration basin or trench.

1.5 BMP Sizing and Design

Attempts were made to design each of the BMPs to fit the existing terrain while providing space for monitoring equipment or other features. The objectives were to locate, size, and shape the devices to best match site topography and provide extended flow paths to maximize their treatment potential. Designing in this way makes efficient use of space to provide the needed treatment volume. Due to the compressed study schedule, aesthetics were not always considered in the design of these devices; however, this element can be more prominent in future implementations. Detailed design information for each BMP is in the Basis of Design reports included in Appendix B. As-built plans for the BMPs can be found in Appendix G.

During the design of each BMP, an evaluation was made as to whether runoff from additional tributary areas could be captured and conveyed to the BMP for treatment in order to increase the pollutant removal and reduce the unit costs. There were two main impediments to increasing the area and runoff treated by each device. In many cases, the cost of bringing in additional runoff greatly increased the estimated cost of the BMP because of the extensive modifications to the existing storm drains that would be required, including jacking of pipe under active freeway lanes. Secondly, the existing piping downstream of the proposed BMP location was sized to handle the flow from only the original drainage area. Directing runoff from other watersheds to the device would require increasing the size of the storm drain system downstream to the point where sufficient capacity was available. Consequently, substantially increasing the tributary area to the BMPs was normally not cost-effective.

The BMPs were sized to treat the runoff generated by the 1 yr, 24 hr rainfall event. The runoff volume produced by this storm was used to size the storage type devices (detention basins, media filters, etc). In District 7, the *Caltrans Stormwater Facilities Retrofit Evaluation* (Brown and Caldwell, 1999) was used to estimate size of the water quality design storm by analyzing rain gauge stations within the study area. Rainfall values were determined using precipitation records from 1944 to 1995 (24 hr rainfall totals) from the Los Angeles International Airport (LAX) weather station. The data were analyzed using the log-Pearson type III method and by the annual series method. For comparison and to verify the data, second and third sets of rainfall records were analyzed from the Van Nuys and the downtown Los Angeles weather stations. Both methods indicated that a rainfall depth of 25.4 mm is approximately equal to the 1 yr, 24 hr storm. Runoff rates were calculated according to the methods specified by Los Angeles County (1989).

In District 11, the average rainfall depth for the design storm was calculated using the rainfall obtained from isohyetal maps and Averaged Mass Rainfall Plotting Sheets (*Basis of Design Reports*, RBF, 1999c, d, e; included in Appendix B). This procedure indicated that the rainfall depth for a 1 yr, 24 hr storm in District 11 varies between 33 and 48 mm. Rainfall depths and intensity for the design storms for both districts are summarized in Table 1-4. Areas contributing runoff to the BMPs were usually paved and a large percentage was impervious. To calculate volume of runoff, a runoff coefficient of 0.90 to 0.95 was assumed for impervious areas and 0.15 for pervious areas. Runoff rates in District 11 were calculated according to the methodology specified by the County of San Diego (1993).

For design of in-line devices, the 25 yr discharge was also calculated to ensure conveyance capacity. In-line devices were designed to pass the 25 yr storm runoff in addition to capturing the water quality volume (WQV). Off-line devices had upstream structures to divert runoff that exceeded the water quality design volume (peak flow).

The peak discharge rate was determined for those devices that were designed based on flow rates such as biofiltration swales. The peak discharge rate depends directly on the average intensity of the rainfall for the desired frequency, as well as the time of concentration. The time of concentration for each BMP Pilot was computed using topographic information and the local method to compute inlet time. Estimated flow rates for the water quality design storm and the 25 yr recurrence interval drainage design storm were computed using the Rational Method.

Table 1-4 Rainfall Design Characteristics for BMP Sites

Parameter Used for Design	District 7	District 11
1 yr rainfall intensity	6.1 – 35.6 mm/hr	32.0 – 48.2 mm/hr
25 yr rainfall intensity	73.7 – 82.6 mm/hr	78.7 – 121.9 mm/hr
1 yr rainfall depth	25.4 mm	33.0 – 48.3 mm

1.6 Operation and Maintenance

The devices evaluated by the pilot study were operated and maintained at state-of-the-art levels, i.e., the best technology and/or practice available at the time, which was consistent with the research aspect of this study. Operation, maintenance and monitoring plans (RBF Consulting, 1999a, 1999b) were developed for both districts to provide comprehensive guidance on the development of site-specific plans. Field guidance notebooks (Brown and Caldwell, et al., 1999; Kinnetic Laboratories Inc., 1999 were then prepared to facilitate record keeping, to document all maintenance activities and to ensure state-of-the-art operation and maintenance. These documents are included in Appendix D. In addition, a *Maintenance Indicator Document* (MID) (17 unpublished versions), which was modified and updated as the study progressed, described the maintenance protocols and identified the conditions under which maintenance would be required. The last version of the MID used during the study and the recommended final version is contained in Appendix D.

Since the BMPs were operated at state-of-the-art levels, they were inspected and maintained at more frequent intervals than is common for most municipal or highway operations. For instance, each BMP was inspected after every storm event to ensure that they were operating as designed. Based on operation and maintenance experience gained during the retrofit pilot program, the amount of maintenance specified in the earlier versions of the MID was frequently found to be overly intensive. The requirements were reduced in the later versions, which should result in lower maintenance costs than those incurred in this study. The actual maintenance hours reported for the study period are a product of these changing maintenance guidelines.

Maintenance was performed for aesthetic reasons and to ensure proper functioning of the BMP (RBF Consulting, 1999a, 1999b). Aesthetic maintenance generally included graffiti removal, grass trimming, weed control, and other miscellaneous details such as tree pruning and painting. Functional maintenance included both preventive and corrective maintenance. Preventive maintenance was performed regularly and included such activities as vegetation management at BMP sites and removal of trash and debris from outlet structures of the extended detention basins and sand filters. Vegetation control also served as a vector prevention function. Corrective maintenance was required on an ad-hoc basis to address intermittent operational problems.

1.7 Monitoring Overview

The monitoring program included a comprehensive effort to document not only the chemical pollutant removal, but also to make and record visual observations of the operation of the devices; these observations were termed “empirical observations.” Detailed stormwater monitoring protocols were developed for each device and a series of field data sheets were developed to record the empirical observations as described below (Brown and Caldwell, et al., 1999; Kinnetic Laboratories Inc., 1999).

1.7.1 Chemical Monitoring

The BMPs were monitored to determine their effectiveness at removing a number of conventional constituents commonly observed in highway runoff. With the exception of the drain inlet insert, oil-water separator and infiltration BMPs, all the sites were outfitted with automatic samplers (Sigma 900 Max Series) and flow meters (Sigma 950 Series) to collect flow weighted composite samples of the influent and effluent of the devices. In drain inlet inserts samples were collected from the effluent only and at the oil-water separator samples were collected as grab samples. Automatic samplers consist of a peristaltic pump, pump control electronics, a sample distribution system, a power supply, and a housing that contains the composite bottle(s). Rain gauges (Sigma 2149) were installed at all sites. In addition to the monitoring related construction costs shown in the following chapters, an additional $30,000 to $40,000 is required to equip and calibrate a site with paired samplers.

Flow measurements were taken at the BMP sites to allow the calculation of constituent loads. For extended detention basins, media filters, MCTTs, and the wet basin, the influent was measured using a Parshall flume or H-flume. The effluent flows were measured using a V-notch weir. The influent and effluent of the biofiltration strips and swales were measured using flumes. The oil-water separator did not have equipment to measure flow; flow was determined using rainfall amount and impervious area. At the drain inlet inserts only effluent flow was measured using flumes. The infiltration basins had a bubbler type flow meter to determine basin depth and calculate the infiltration rates. The flow monitoring equipment was calibrated according to the manufacturer's specifications.

Sampling teams mobilized to capture storms that were predicted to produce at least 6.4 mm of rain with 75 percent or greater probability. An antecedent dry period of at least 48 hours was required, with a preferred separation of 72 hours; however, if the first event of two consecutive storms was not captured and the rainfall total was less than 6.4 mm, and the second event was forecast to be at least as large as the first event, then sampling was attempted for the second event.

Twelve aliquots, 75 percent capture and 2.5 mm of rain were the general minimum criteria for a successfully monitored event. However, if a sample represented between 50–75 percent of the runoff, and had 20 or more aliquots, then the data were analyzed. If a composite sample had less than 12 aliquots, percent capture was greater than 85 percent, and sample volume captured was sufficient for full analysis, the data were also analyzed. In some cases as few as eight aliquots and 50 percent capture was considered sufficient. Data not meeting the general criteria were flagged and acceptance was based on review by members of the study team. Samples were refrigerated at sites where it was possible to connect to an existing power source. At sites where connection to an existing power source was not possible marine batteries were used and samples were placed on ice. Additional detail and results from the monitoring effort is contained in Appendix F.

In general, all sites were monitored for solids, nutrients, total and dissolved heavy metals, organics, and fecal coliform. Groundwater samples from infiltration trenches and infiltration basins were only analyzed for metals to assess the potential impact on groundwater quality. At the drain inlet insert sites only suspended solids, metals, and petroleum hydrocarbons were analyzed. Since many constituents can impair beneficial uses of receiving waters at extremely low concentrations, only analytical methods that have appropriate detection limits were selected. Table 1-5 summarizes the constituents selected for analysis along with the required analytical procedure.

Grab samples of runoff were collected at the oil-water separator and analyzed for organics, fecal coliform, and TSS. Suspended solids, nutrients, and metals were collected as composite samples, where a number of individual sample aliquots were mixed together over the duration of the storm. Total nitrogen concentrations are calculated as the sum of nitrate and Total Kjeldahl Nitrogen (TKN), which assumes that the concentration of nitrite is small compared to the other components. This is generally a safe assumption.

Detailed QA/QC plans were developed for each type of the BMPs monitored (Kinnetic Laboratories Inc., 1999; Brown and Caldwell, 1999). These plans required the collection and analysis of duplicate samples, field and laboratory blanks, equipment blanks, matrix spike and matrix duplicate spikes, and laboratory replicate/splits. Water quality analyses not achieving the required accuracy are qualified in the study database.

Two different methodologies were used to describe the constituent removal of the devices. The first methodology, required under the Scoping Study (RBF Consulting, 1998a and 1999b), uses an assumed log-normal distribution of influent and effluent concentrations to estimate load reduction. The performance calculated using these values is strongly affected by the average influent concentration at a particular site and can make devices evaluated at locations with low influent concentrations appear to perform less effectively in comparison to those located at sites with higher influent concentrations. Consequently, a second, innovative methodology was developed based on a regression analysis of influent and effluent concentrations to predict performance at all the devices based on a common influent concentration typical of highway and associated land uses.

Table 1-5 Selected Constituents and Analytical Methods

Parameter	Reporting Detection Limit mg/L	Analytical Method (USEPA, 1979; 1994)
Total suspended solids (TSS)	1	160.2
Zinc (Zn)	0.001	200.8
Lead (Pb)	0.001	200.8
Copper (Cu)	0.001	200.8
Nitrate Nitrogen (NO_3-N)	0.01	300.00
Total Kjeldahl Nitrogen (TKN)	0.1	351.3
Total Phosphorus (TP)	0.002	365.3
Ortho-phosphate (OP)	0.001	365.3
Fecal Coliform (FC)	2 – 200 MPN/100 ml	SM 9221E[a]
Total Petroleum Hydrocarbons – gasoline (TPH-G)	0.05	8015 mod/ext.
Total Petroleum Hydrocarbons – diesel (TPH-D)	0.1	8015 mod/ext.
Total Petroleum Hydrocarbons – motor oil (TPH-MO)	0.2	8015 mod/ext.
Total Recoverable Petroleum Hydrocarbons (TRPH)	5	1664

[a] Standard Methods

1. Italicized constituents limited to maintenance stations.
2. Fecal coliform originally run at 200 but dropped to 2 MPN/100 ml later

In the first method, the data were assumed to be log-normally distributed and the mean *(m)* and variance (s^2) of the log transformed event mean concentrations (EMCs) were calculated as:

$$m = \frac{\sum x}{n}$$

$$s^2 = \frac{\left(n\sum x^2 - \left(\sum x\right)^2\right)}{n(n-1)}$$

where: x is the natural log of EMCs.

Sx represents the summation of data points (x).

n is the number of data points (x).

The mean of the EMCs (a) was calculated as:

$$a = e^{(m + s^2/2)}$$

An analysis of variance (ANOVA) was then performed to determine whether the mean influent and effluent concentrations were significantly different. The probability (P) that the two means are not different is reported for all measured constituents for each BMP type.

The annual constituent loads were obtained by multiplying the season total runoff volume by the mean concentration. The efficiency was determined by comparing the influent and effluent loadings over the entire wet season using the following equation:

Efficiency (%) = [(Loading in – Loading out)/Loading in] * 100

These efficiencies represent the average pollutant removal for the water treated and do not take into account untreated bypasses that occur when the storm runoff exceeds the design WQV. The water quality of the bypassed fraction would need to be known to accurately assess the total pollutant reduction for all runoff from the watershed, but this was not measured during this study.

For the devices with flow-weighted influent and effluent samples, a second methodology was used to assess water quality improvement. A linear regression analysis was performed on the paired samples from each type of device to predict effluent quality based on any influent quality of interest. The regression line was tested for statistical significance at the 90 percent confidence level. For some constituents at certain sites, there was no statistical relationship between influent and effluent quality. This means that the effluent quality can be expressed as a constant value, which is the irreducible minimum effluent concentration. As suggested by Gilbert (1987), the mean and uncertainty (used to calculate the 90 percent confidence interval of the estimate of the mean) for these constituents were calculated using non-transformed values because of the relatively low coefficient of variation.

Where a significant linear relationship exists, the effluent concentration for any influent concentration of interest can be calculated as:

$$C_{eff} = aC_{\inf} + b$$

where:

C_{eff}	=	Predicted effluent EMC
C_{inf}	=	Influent EMC
a	=	slope of the regression line
b	=	y intercept

When expressed in this way, *b* can often be interpreted in a physical sense as the irreducible minimum effluent concentration.

The uncertainty for constituents that exhibit a statistically significant relationship was calculated according to the methodology specified by Wonnacott and Wonnacott (1990):

$$t_{0.05}s\sqrt{\frac{1}{n}+\frac{\left(X-\overline{X}\right)^2}{\sum_{i=1}^{n}\left(X_i-\overline{X}\right)^2}}$$

where:

t = value of the t statistic for the appropriate degrees of freedom (n-2)

s = standard error of the estimate

n = number of paired data points

X = Influent value of interest

X_i = Observed influent concentrations from monitoring data

Note that the size of the confidence interval is a function of the value at which the mean is calculated. The confidence interval is smallest when the influent concentration of interest equals the average observed influent concentration.

1.7.2 Empirical Observations

Significant effort during this study was directed to recording and analyzing the operation and maintenance experience. Forms were developed so that engineers and support staff could record their observations to facilitate compilation of this information. During each visit to the site, a site visit log was filled out to record observations. The types of observations varied with the type of BMP being evaluated. Some of the general types of observations recorded on applicable forms in the Field Guidance Notebooks (Brown and Caldwell et al., 1999; Kinnetic Laboratories Inc., 1999; see Appendix D) included:

- Water level
- Visual evidence of flow short circuiting (for wet weather visits)
- Description of amount and locations of sediment accumulation
- Evidence of scouring and of resuspension of settled particles
- Amount of litter and predominant type
- Change in litter accumulation and location since previous visit
- Conditions/clogging of outlet structure

- Evidence of erosion
- Condition of BMP
- Degree and type of vegetation establishment (if present)
- Stability of basin slopes / evidence of erosion
- Evidence of vandalism of equipment or basin structures
- Presence of unpleasant odors

Information collected on these forms was entered into a database. Separate forms for Site Inspections, Maintenance Activities, and Empirical Observations were used. Also included in the database were results from sampling activities. The database was updated monthly with the previous month's inspections and sampling data. Reports were generated and displayed on the project's website on a monthly basis.

1.8 Vector Issues

A special study team was created to investigate the presence and development of vectors in the pilot BMPs. Because of their ability to transmit human diseases, the vectors of greatest concern and the primary focus of this study effort were mosquitoes. Caltrans, the Vector-Borne Disease Section of the California Department of Health Services (VBDS), the University of California at Riverside, local vector control agencies, and consultants worked together to monitor vector populations associated with BMPs, determine proper strategies for vector suppression at the various study sites, and present findings. A comprehensive final report summarizing all vector-related activities during the study, *Final Vector Report, Caltrans BMP Retrofit Project sites Districts 7 and 11*, September 2001, is available in Appendix E.

In 1998, the University of California at Riverside, developed a monitoring program to compare the populations of adult mosquito and midges at selected BMP sites, pre- and post-construction. Three different traps were used to sample populations; carbon dioxide-baited traps were used to capture host-seeking adult female mosquitoes, gravid traps were used to capture gravid female mosquitoes, and light traps were used to capture midges. Two documents summarize the monitoring plan for Caltrans District 7 and 11, and the final report gives a detailed discussion of the methodology and results. The three documents are listed below and are available in Appendix E.

- *Vector Control Background Monitoring Plan for Caltrans Retrofit BMP Pilot Project, District 7,* September 2001.
- *Vector Control Background Monitoring Plan for Caltrans Retrofit BMP Pilot Project, District 11*, July 1, 1998.

- *Monitoring Program for Pathogen-Transmitting and Nuisance Adult Diptera Associated with the Stormwater BMP Retrofit Pilot Program in Caltrans District 7 and District 11,* September 1, 2000.

In 1999, VBDS developed a separate monitoring and abatement program for immature stages of mosquitoes and other vectors associated with BMPs. Any source of standing water has the potential to create the habitat necessary for vectors to reproduce. Inspections were conducted weekly at all BMP sites by local vector control agencies and VBDS to determine if standing water and subsequent mosquito larvae were present. When necessary, abatement of larvae was performed by the local districts by using altisoid liquid or pellets and a few occasions at the start of the study Golden Bear oil was used. Golden Bear oil use was discontinued because of potential interference with water quality monitoring. VBDS prepared a document outlining the immature mosquito monitoring and abatement plan for Caltrans District 7 and 11. The final report gives a detailed summary of mosquito production during the two-year study. The two documents are listed below and are available in Appendix E.

- *BMP Mosquito Production Study,* September 1999.

- *An Initial Assessment of Vector Production in Structural Best Management Practices in Southern California,* June 2001.

In addition to monitoring for mosquito larvae, the study team modified BMPs that held standing water for over 72 hours to suppress mosquito production to the greatest extent possible, without impairing their intended function. Caltrans, VBDS, the local southern California vector control agencies, and stormwater consultants recommended and implemented appropriate changes to BMP designs to eliminate vector-breeding habitats. A report prepared by VBDS, *A Preliminary Assessment of Design Criteria for Vector Prevention in Structural Best Management Practices in Southern California,* June 2001 includes recommendations for preventing vector habitat in BMP structures; it is available in Appendix E.

To further clarify their position on BMPs that hold water longer than 72 hours, the VBDS prepared a memorandum on this subject. The memorandum summarizes the legal authority and requirement of the Department of Health Services to protect public health, including the ability to assess civil penalties. The memorandum, "Standing Water in Structural Best Management Practices for Stormwater Runoff," September 4, 2001, is provided in Appendix E

Finally, to better understand the relationship between stormwater management structures, such as treatment BMPs, and vectors, VBDS undertook an extensive, independent study to obtain information from different agencies across the United States. Through the use of detailed surveys as well as email and telephone communication, VBDS contacted several hundred agencies. In addition, VBDS was invited to participate in tours of treatment BMPs in Portland, Oregon and in Austin, Texas to witness potential vector habitats first hand. Two reports were prepared by VBDS that provide details of these out-of-state investigations. The two document titles are listed below and are available in Appendix E.

- *A Preliminary Assessment of Vectors Associated with Storm Water Management Structures in the United States: A Nationwide Vector Control Perspective*, June 2001.

- *A Preliminary Assessment of Vectors Associated with Storm Water Management Structures in the United States: Addendum*, June 2001.

The health code statutes, as written, give vector control district managers wide latitude in determining what constitutes a public health threat and under what conditions abatement will occur. The vector control districts in Los Angeles County have established an abatement threshold of one larva for the BMPs. With this threshold, these districts can abate when a single larva is collected from a site. The San Diego County Vector Surveillance and Control Division generally does not rely on thresholds in determining abatement needs. San Diego County prefers an approach where factors such as BMP location, larval density, and proximity to residential areas are considered.

1.9 Biological Issues

Biological issues were an important concern for BMP operation and maintenance. The presence of endangered species, threatened species and species of special concern in a BMP could affect scheduled maintenance and other activities. Early and effective coordination with the U.S. Fish and Wildlife Service (USFWS) and the California Department of Fish and Game could avert some of the problems associated with the presence of biological resources; however, the potential presence of protected species may result in siting, construction, operation, and maintenance restrictions.

In District 11 there were several species of concern. The nesting period of the least tern was a concern at the La Costa Austin filter and construction had to be delayed until the end of the nesting period. Nets were installed over the Austin sand filters and infiltration basin during the dry season to prevent the nesting of the least tern and Snowy Plover in the sand filter bed. Mylar strips were used at the La Costa wet basin to discourage the nesting of sensitive species in the wet pond vegetation. Salt grass used in biofilters is also a habitat for the salt marsh skipper (butterfly). The sites in District 11 were monitored for the presence of the skipper. In District 7, the primary concern was the opportunity for burrowing owls, an endangered species, to use the gopher mounds and ground squirrel burrows. There was abundant gopher activity at many of the swales and detention basins in District 7, but no owls were observed.

The trees located adjacent to the biofiltration swale for the I-5/Palomar Airport Road offramp had to be protected in accordance with the Coastal Development Permit (CDP) in effect for the Cannon Road improvements. The CDP required that any existing trees that would be removed by construction activities be replaced at a 5:1 ratio. The BMP was redesigned to eliminate the need for mitigation by confining flow in concrete channels around the two areas of concern. To further protect the trees, excavation activities were restricted to the area beyond the tree dripline. Consequently, the BMP facility incorporates three biofiltration swales and two intermediate concrete swales.

1.10 Maintenance Effort and Construction Cost

One of the research objectives of the BMP Retrofit Pilot Program was to develop reliable information relative to the effort required for operation and maintenance of the BMPs under study. This included more detailed record keeping of maintenance activities than would normally be necessary in a routine operational setting. The scope of work included routine and as-needed maintenance functions as specified in the *Maintenance Indicator Document* (see Appendix D), as well as stormwater runoff sampling and empirical observation (RBF Consulting, 1999a, 1999b). Routine and as-needed maintenance and operation efforts (maintenance hours) were accounted for separately from stormwater runoff sampling, empirical observation and maintenance or related services for sampling equipment. Two categories for each BMP (not by site) were developed over the course of the study: 1) maintenance and operation, and 2) sampling and empirical observation.

The operation and maintenance hours presented are limited to those spent on actual field activities and required equipment. These activities include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Equipment time included the time equipment was allocated to the BMP for maintenance.

Construction cost items included the original bid schedule, additional items of work authorized following contract award, and State-furnished materials. Since this was a pilot program, most sites were equipped with water quality sampling and flow measurement equipment. Therefore, the costs that were unique to the monitoring of the pilot program were separated from the total construction costs.

There has been extensive discussion among the parties involved in this study as to whether the construction cost numbers accurately represent the costs that would be incurred in a more extensive (widespread) retrofit program. Many reasons have been suggested for possible differences, including, among others: the compressed nature of the study schedule, the bidding climate at the time the contracts were advertised, the lack of standard competitive bidding, and the dispersed nature of the construction activities. The parties in the study subsequently agreed upon adjusted costs and these are presented in addition to the incurred costs. Adjusted construction costs include allowances for site-specific costs and ancillary costs of construction that may be encountered during future BMP retrofits (Adjusted Retrofit Construction Cost Tables, Appendix C).

The adjusted construction cost is the actual cost minus all pilot-unique cost and minus adjustments to site-specific cost. Certain site-specific costs were adjusted when the original cost could potentially be avoided in future BMP retrofits. For example, buried concrete rubble was found at one EDB location that doubled the construction cost. This was a site-specific cost that was adjusted by using the average buried materials cost of similar basin-type BMPs. For each BMP, the subtracted costs were expressed as a percentage of the adjusted construction cost. These percentages are reported in the individual BMP chapters in bulleted statements explaining the cost adjustments. These percentages represent what additional cost could be expected above the adjusted cost if the conditions in which the subtracted cost occurred were replicated.

1.11 Technical Feasibility

Technical feasibility is defined as the acceptability of a BMP for use at any suitable site according to the criteria in the list below. Whether a technically feasible BMP should or should not be used depends on a number of site-specific factors that are spelled out in subsequent chapters.

1. The BMP should operate passively during storm events. No personnel are required to be on site prior to or during a storm event to initiate operation of the BMP or perform routine maintenance to keep the device operational. This does not imply that routine inspections, periodic maintenance, and/or emergency maintenance will not be required to ensure the proper operation of the BMP.

2. Maintenance requirements for a BMP should be well understood and defined with respect to scope and periodicity (see MID). In addition, regular maintenance personnel should be able to perform routine inspections and maintenance tasks using available equipment and without special training.

3. Maintenance personnel must be able to perform operational and maintenance (O&M) inspections and tasks without significant safety risks. Also, safe access to BMPs should be provided.

4. Estimates of the long-term maintenance requirements for the device should be identified.

5. The BMP device should be designed and operated so that it does not create a public nuisance or health hazard. Specifically, this is a concern with regard to potential disease vectors such as mosquitoes. Structural BMP design and prescribed O&M should be adequate to ensure BMP operation with respect to water quality, while at the same time reducing potential vector concerns to an acceptable level.

6. The BMP device should be appropriate for the local climatic conditions. Except for initial installation and vegetation establishment periods, irrigation should not be required. An artificial source of water should not be required except in the case where specific BMP design requirements call for sufficient supplementary water to support wetland plants (i.e., wet pond or constructed wetland).

7. The BMP device should be appropriate for the local geological and topographical conditions. Local soil characteristics, underlying geology, and groundwater

should support the use of a particular BMP type. Furthermore, stormwater runoff drainage patterns (i.e., sheet flow or channelized flow) and topography (i.e., gradient and elevation differential) should support the use of a particular BMP type at a specific location.

8. The BMP device should be able to be sited within the highway right-of-way (ROW) clear recovery zone or within a highway-related facility (i.e., maintenance station or park-and-ride lot) so that it is in compliance with the safety requirements of the Highway Design Manual (HDM).

9. The BMP device must meet the drainage design criteria of the HDM. The device should accommodate flow up to and including the design flow rate without flooding.

10. The BMP device should be designed and sited such that stormwater flows greater than the design flows for the BMP will be routed around or through the device in a way that avoids damage (e.g., erosion) and/or flushing of pollutants already trapped within the device. This may be accomplished through an off-line design or by other structural design features incorporated into the BMP.

11. The BMP device should provide for the significant removal of target constituents of concern based on the influent concentrations typically encountered in runoff from highway ROW areas or highway-related facilities and pollutant mass loading reductions and concentration decreases as given in this report.

12. The siting, design, and operation of a BMP device should not produce any significant adverse environmental impacts.

1.12 Retrofit Pilot Program Accomplishments

The retrofit pilot program is thought to be the most comprehensive test of common stormwater management BMPs ever conducted, and the first significant evaluation in a climate of southern California's type. The program succeeded in demonstrating the effectiveness of several BMP types in controlling effluent pollutant concentrations and mass loadings. The results generally are consistent with the performance of these devices measured in previous studies. The knowledge produced on the relative effectiveness and cost of the BMP options in southern California furnishes a basis for applying the Permanent Injunction's provision on BMP selection.

The program further yielded substantial information on the technical feasibility of the BMPs as retrofits in highway and support facility settings. The team conducting the program surmounted a number of challenges to constructability and operability, particularly in reducing mosquito vector risks, by revisions in design and operations.

While the retrofit pilot program was designed to meet the terms of a court order to a California transportation agency, its findings have much broader application. They showed that performance expectations derived elsewhere are similar in this differing climate, The experience gained here in the linear, relatively constrained highway environment as well as in related support facilities, can also be utilized by other transportation agencies at state and local levels, as well as other jurisdictions dealing with stormwater runoff and non-point source (NPS) pollution.

2 SAND FILTERS

2.1 Siting

Seven sand filters were sited and constructed for this study, four in District 7 and three in District 11. Of these, six were "Austin" style sand filters and one was a "Delaware" sand filter (located in District 11). One of the Austin-style sand filters was constructed at the Paxton Park-and-Ride, but was not monitored and that site is excluded from the following discussion.

Several siting criteria that are similar for both types of filters were considered in order to maximize the effectiveness of these devices. The most important consideration was the extent to which runoff from bare soil would be able to enter the filter. The biggest threat to the long-term successful operation of filtration BMPs is the introduction of excessive amounts of sediment that cause premature clogging of the filter media. For this reason, site selection was limited to relatively small, highly impervious watersheds such as park-and-ride (P&R) lots and maintenance stations (MS). It was also verified that there were no construction activities up-gradient from the selected filter sites. The characteristics of the contributing watersheds for the selected sites are shown in Table 2-1.

These facilities need enough head to operate hydraulically – a minimum of about 1 m. The available head between the inlet and outlet must exceed the depth of the sedimentation basin, depth of water over the filter, the filter media, and the underdrain system. All of the sites in District 7 lacked sufficient head, and pumps were installed to return the treated discharge to the existing drainage system. All the systems in District 11 were successfully designed to use gravity flow.

Table 2-1 Summary of Contributing Watershed Characteristics for Sand Filters

Site Location	Filter Type	Watershed Area Hectare	Impervious Cover %
Eastern Regional MS	Austin	0.6	90
Foothill MS	Austin	0.7	100
Termination P&R	Austin	1.1	90
La Costa P&R	Austin	1.1	56
SR-78/I-5 P&R	Austin	0.3	80
Escondido MS	Delaware	0.3	85

2.2 Design

The Austin design (Figure 2-1 and Figure 2-2) has an open-air filter and a separate sedimentation basin. A concrete wall separates the sedimentation basin and the filter chamber. This is one of two designs approved by the City of Austin and is known there as “full sedimentation.” Runoff from the sedimentation basin enters a perforated riser that transfers the runoff to the filter chamber. An orifice plate on the outlet of the riser was sized so that the sedimentation basin would completely drain from basin-full condition in 24 hours. A level spreader was provided in the filter basins to distribute runoff evenly over the 450 mm deep sandbed. Guidelines developed by the City of Austin (1988) for filter configuration were used in the facility designs.

The Delaware unit (Figure 2-3 and Figure 2-4) operates along the curbside edge of paved areas and parking lots and requires the least area for installation among the various sand filter types. The device consists of separate sedimentation and filter chambers, but differs from the Austin design in that a permanent pool is maintained in the sedimentation chamber. Ideally, runoff enters the sedimentation chamber as surface flow. However, to increase the amount of area treated by the device at the Escondido MS, a storm drain system was used to collect the runoff, which was then introduced at one end of the sedimentation chamber.

As runoff enters the sedimentation chamber, water remaining in the device from previous storms is displaced and flows over a weir into the sand filter chamber. The Delaware unit was designed and installed according to the guidelines described by Young et al. (1996), except the depth of sand was 300 mm rather than 450 mm. It should be noted that according to these guidelines, there is only storage in the unit for 5 mm of runoff; consequently, if a larger water quality volume is to be treated using this design, the unit must act as a flow-through device. Design characteristics for all of the sand filters are shown in Table 2-2.

2.3 Construction

The lessons learned during the construction of sand filters centered on material availability for the filter, excavation during filter construction, unknown field conditions, and interface with existing activities at the sites. The filters were all constructed in maintenance stations or park-and-ride facilities that provided a limited work area and the requirement to coordinate with normal facility operations.

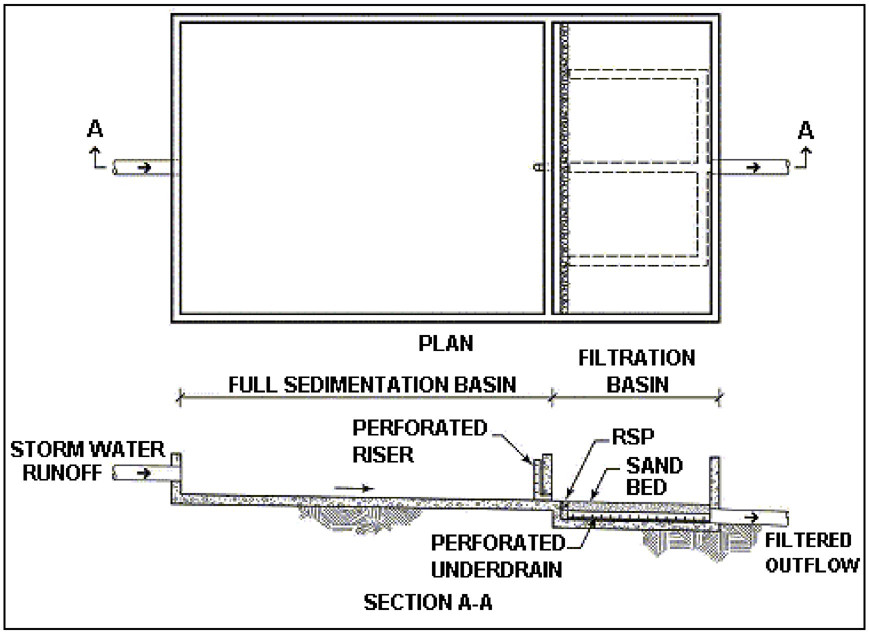


Figure 2-1 Schematic of an Austin Sand Filter

Figure 2-2 I-5/SR-78 Austin Sand Filter

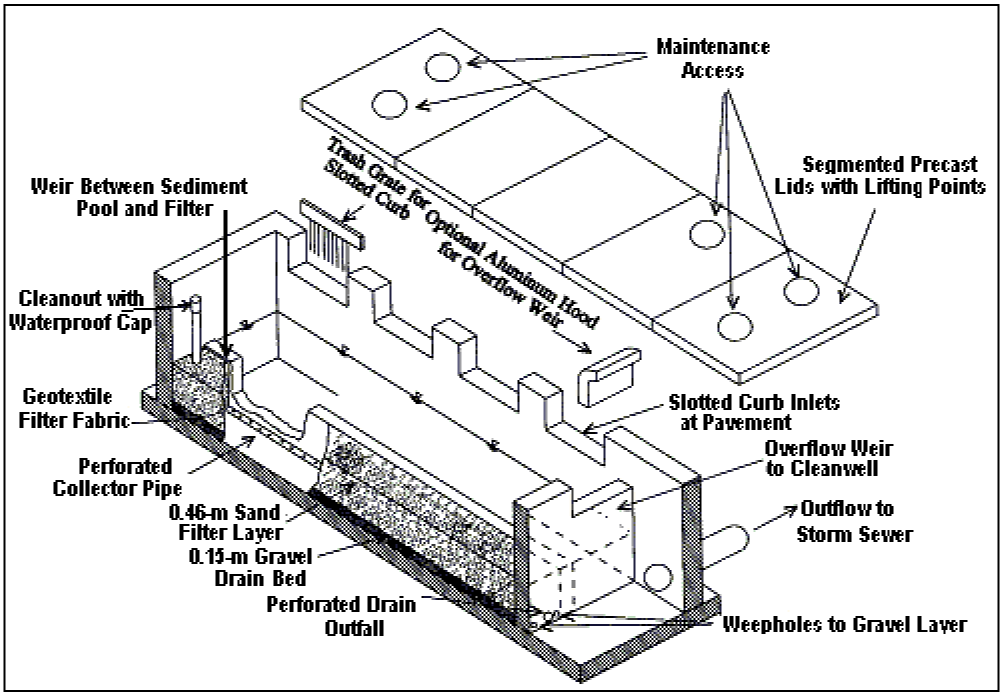


Figure 2-3 Schematic of a Delaware Sand Filter (Young et al., 1996)

Figure 2-4 Escondido MS Delaware Sand Filter

Table 2-2 Design Characteristics of the Sand Filters

Site Location	Design Storm mm	WQV m^3	Sedimentation Basin Area m^2	Filter Basin Area m^2
Eastern Regional MS	25	115	54	27
Foothill MS	25	217	102	40
Termination P&R	25	222	114	57
La Costa P&R	36	286	180	72
78/I-5 P&R	38	106	56	32
Escondido MS	48	12.2 (120)[a]	27	27

[a] The volume of water treated at Escondido MS is 120 m^3 during the design storm. The Delaware design specifications require the filter design volume to be 38 m^3/ha of tributary area. Therefore, the sedimentation basin at Escondido is designed to capture 12.2 m^3 of water; but during the design storm, 120 m^3 of water flows through the device.

2.3.1 Material Availability

There was some confusion among the design and construction personnel regarding the sand specifications for the filters. The engineers and contractors initially interpreted the Austin guidelines incorrectly as requiring a special gradation that was not available locally. The intent of the Austin guidelines is to require an aggregate appropriate for making concrete as specified in ASTM C-33. The project engineers substituted a standard locally available sand mix that was in keeping with the intent of the Austin guidelines.

2.3.2 Excavation and Unknown Field Conditions

Problems with excavation for the sand filters included structurally unsuitable soils, buried manmade objects and interference with existing utilities. Structurally unsuitable soils require over-excavation to provide a suitable subgrade for construction. Detailed geotechnical investigation prior to construction (soil borings) can usually identify this condition. Buried manmade objects (broken concrete) were also encountered; the presence of these also can be detected through comprehensive subsurface investigation. Unknown utilities were encountered during excavation at four of the seven sand filter pilot sites. At two locations, the existing storm drain system location did not match that shown on the as-built drawings. Some of the problems encountered during excavation were magnified due to the large, deep design of the sedimentation basin and sand filter necessitated by the required water quality volume, the need to intercept pre-existing storm drains, and the desire to minimize the footprint of the device.

2.3.3 Interface with Existing Activities

Retrofit of sand filters at maintenance stations and park-and-ride lots impacts the operation of the facility during construction operations. The contractor has a limited lay-down area, and must coordinate with the activities at the maintenance station or in the case of the park-and-ride lots, must temporarily restrict use to portions of the lot. Environmental factors may influence construction start time. For example, a least tern nesting site delayed by several weeks the construction start up at one retrofit location.

2.4 Maintenance

At the beginning of the study, sand filters were generally assumed to have greater maintenance requirements than many other types of stormwater treatment facilities. Major maintenance items include removal of sediment from the sedimentation basin when the accumulation exceeds 300 mm and removal of the uppermost layer (50 mm) of the sand bed when the drain time exceeds 48 hours. Sediment removal was not required during the course of the study. After three wet seasons total accumulated sediment depth was less than 25 mm. This indicates that sediment removal may not be required for as many as 10 years or more at these sand filters. Maintenance of the sand bed may be required every 3 to 5 years as described below.

Removal of the top 50 mm of sand was required in the third year at the Delaware filter and the three Austin filters in District 7. According to the maintenance plan, after successive removal of 50 mm of sand lowers the thickness to 300 mm, new sand is installed to restore the depth to 450 mm. Because the Delaware was initially constructed with a sand depth of 300 mm, the removed sand is immediately replaced to maintain a thickness of 300 mm.

The condition of the sand bed varied strikingly between sites. For instance, at the Foothill, Eastern, Termination and Escondido Maintenance Stations, a stiff crust formed on the surface of the sand after about 2 years of operation, while runoff never completely covered the sand at the La Costa Park-and-Ride after 3 years of operation. The Delaware filter had the smallest filter area relative to the tributary area of any of the sand filters, so it is not surprising that this facility experienced clogging; however, the filter areas at the other three District 7 sites were roughly similar to those in District 11.

One potentially significant difference is that all of the Austin filters that clogged incorporated pumps in their design. Repeated problems with pump operation resulted in standing water on the filter bed for extended periods that may have contributed to the clogging by allowing sufficient time for biological growth on the surface of the filter. In all filters, clogging appeared to be due to cementing of the top layer of sand rather than to a distinct accumulation of sediment on the surface. These data indicate that the interval between sand rejuvenation may be site-specific and a function of the runoff quality (loading rate) or operational characteristics of the filter, so that no general guidance for appropriate interval can be developed. Regular inspections are needed to indicate when filter rejuvenation should occur.

Weekly inspections for trash accumulation and the presence of endangered or threatened species were conducted during the wet season. Because of the proximity of the La Costa sand filter to endangered species nesting areas, plastic netting was placed over the filtration chamber to prevent entrance by these species. Monthly inspections were also conducted to identify damage to inlet and outlet structures, emergence of woody vegetation, and evidence of graffiti or vandalism.

An average of only about 51 hr/yr were required for field activities based on data from 2000 and 2001, not including vector control activities. The Austin and Delaware designs did not have significantly different maintenance needs during the period of record and the hours from the two types of devices have been combined for this analysis. The incorporation of a permanent pool in the Delaware design increased the amount of vector control required at the site, compared to other sand filters that drained fully.

As shown in Figure 2-5, pump replacement and maintenance account for the largest field activity, followed by inspections, media maintenance, and structural repair. The large proportion of operation and maintenance time spent on pump-related problems indicates that designs utilizing gravity flow are preferred.

The number of inspections and time spent reflect the requirements of the MID, which specified weekly inspections during the wet season. Minor structural repairs are commonly required to repair defects such as cracks that form in the structure; however, the majority of hours assigned to this category were associated with filling a subsiding area near the perimeter of the Eastern MS site. Dewatering was required to eliminate standing water that collected in the level spreader (Austin type) in the filtration chamber and which provided a breeding site for mosquitoes.

Maintenance at all of the Austin sand filter sites was hampered by the lack of adequate access. Although each basin was fitted with a rung-type ladder to allow maintenance personnel access, these were not sufficient for equipment access for major maintenance activities. Access ramps could be included in the design of the filters where sufficient space is available. Limiting the depth of the basins would also provide better access.

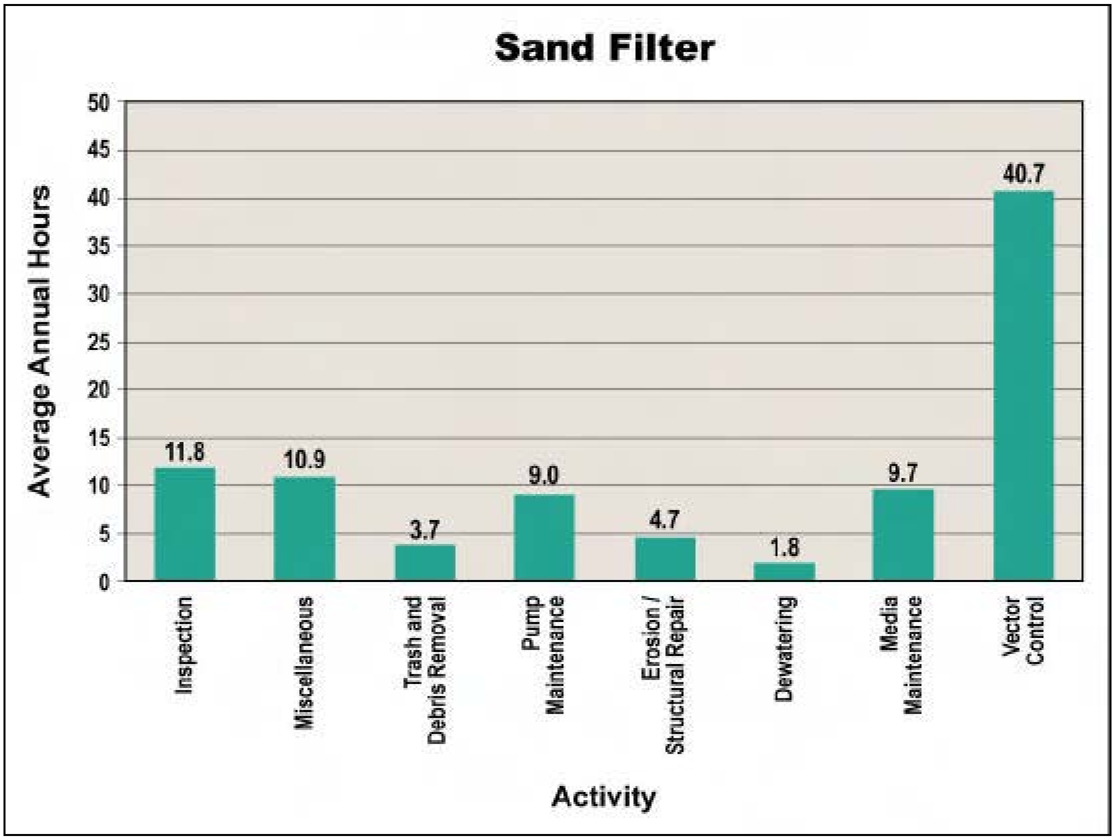


Figure 2-5 Field Maintenance Activities at Sand Filter Sites (1999-2001)

2.5 Performance

2.5.1 Chemical Monitoring

Since all of the Austin filters were designed using the same guidelines, the data for all sites have been treated as if it came from a single site. It should be noted, however, that there are statistically significant differences in the mean TSS concentration in the effluent of the Austin sand filters. These differences were not large, ranging from about 4 mg/L to 11 mg/L, and the ability to detect the differences is mainly a result of the extremely consistent TSS concentration in the effluent. For most constituents, the differences among the sites were not significant; so grouping the data together is an appropriate way to estimate the average performance that might be expected from a large number of facilities.

There were substantial differences in the measured influent and effluent volumes, especially at sites that incorporated pumps in their design, such as the Termination Park-and-Ride location. This was due at least in part to the lack of a check valve in the effluent piping, allowing some of the treated runoff to flow back into the sump. For the purpose of calculating performance, it was assumed that the effluent volume equals the influent volume, since all of the sand filters are constructed of concrete (i.e., there are no significant infiltration or evaporation losses). Therefore, all constituent mass reduction is the result of reduction in concentration between the treated and untreated runoff.

The data collected during the first year of monitoring at the Delaware sand filter site was not used in the calculations, since the facility was a net exporter of many constituents during that time. It appeared that the sand used at that site was not as well washed as at the Austin sites, and by the second year, performance had improved dramatically. Consequently, it is recommended that the specifications in Caltrans standard specification for fine aggregate (90-2.02 and 90-3), which limits the amount of fine materials in the sand be followed. It is similar to the ASTM C-33 specification, with the addition of a washing requirement, which further limits fines.

The average influent and effluent concentrations and the percent reduction shown in Tables 2-3 and 2-4 were calculated using the methodology described in the introductory chapter for constituents with a log-normal distribution. The column titled "Significance" is the probability that the influent and effluent concentrations are not significantly different, based on a one-way ANOVA. Constituent removal was generally very good, except for nutrients, particularly nitrate. The concentrations of this constituent increased in both types of sand filters. Nevertheless, the data indicate that modest removal of total nitrogen does occur. The results for nitrate and other constituents are similar to those reported in studies from the Austin area (Glick et al., 1998). A comparison of removal efficiencies of selected constituents for the two types of filters indicates that despite the overall similarity there are some substantial differences in performance.

The estimate of a percent reduction to characterize the pollutant removal of a device implies a functional relationship between influent and effluent quality and assumes that the effluent quality from a site with different runoff characteristics can be estimated from the percent reduction observed at these sites. This is not the case for TSS and most other particle-associated constituents. This can be demonstrated by plotting the influent versus effluent concentration for TSS and dissolved copper for the Austin sand filters as shown in Figure 2-6 and Figure 2-7.

The data in Figure 2-6 indicate that rather than being a fraction of the influent concentration, the effluent concentration of TSS is constant with an average value of about 7 mg/L. This is an important distinction if these data will be used to estimate effluent quality from sand filters installed at other sites or for estimating compliance with water quality standards for storms with high concentrations of TSS.

Table 2-3 Concentration Reduction of Austin Sand Filters

Constituent	Mean EMC		Removal %	Significance P	Concentration Reduction Previous Work (Glick et al., 1998)
	Influent mg/L	Effluent mg/L			
TSS	88	8.6	90	<0.000	89
NO_3-N	0.660	1.10	-67	0.009	-76
TKN	3.120	1.48	53	0.002	50
Total N[a]	3.780	2.58	32	-	17
Ortho-phosphate	0.180	0.14	24	0.376	NA
Phosphorus	0.410	0.25	39	0.003	59
Total Cu	0.021	0.010	50	<0.000	72
Total Pb	0.020	0.003	87	<0.000	86
Total Zn	0.236	0.047	80	<0.000	76
Dissolved Cu	0.009	0.008	7	0.645	NA
Dissolved Pb	0.002	0.001[b]	40	0.001	NA
Dissolved Zn	0.094	0.036	61	<0.000	NA
TPH-Oil[c]	1.300	0.9	31	0.271	NA
TPH-Gasoline[c]	0.100[b]	0.1[b]	-	-	NA
TPH-Diesel[c]	0.900	0.7	22	0.171	NA
Fecal Coliform[c]	5,800 MPN/100mL	1,600 MPN/100mL	72	0.190	NA

[a] Sum of NO_3-N and TKN
[b] Equals value of reporting limit
[c] TPH and Coliform are collected by grab method and may not accurately reflect removal

Table 2-4 Concentration Reduction of the Delaware Sand Filter

Constituent	Mean EMC		Removal, %	Significance P
	Influent mg/L	Effluent mg/L		
TSS	102	19	81	<0.000
NO_3-N	0.35	0.84	-142	0.016
TKN	1.91	1.22	36	0.059
Total N[a]	2.26	2.06	9	-
Ortho-Phosphate	0.08	0.07	11	0.780
Phosphorus	0.37	0.21	44	0.049
Total Cu	0.021	0.007	66	0.003
Total Pb	0.015	0.002	85	0.062
Total Zn	0.429	0.033	92	<0.000
Dissolved Cu	0.007	0.004	40	0.124
Dissolved Pb	0.002	0.001[b]	31	0.099
Dissolved Zn	0.215	0.012	94	<0.000
TPH-Oil[c]	2.20	1.00	55	0.186
TPH-Gasoline[c]	0.05 [b]	0.05 [b]	-	-
TPH-Diesel[c]	1.5	0.8	47	0.399
Fecal Coliform[c]	5,800 MPN/100mL	1,200 MPN/100mL	79	0.435

[a] Sum of NO_3-N and TKN
[b] Equals value of reporting limit
[c] TPH and Coliform are collected by grab method and may not accurately reflect removal

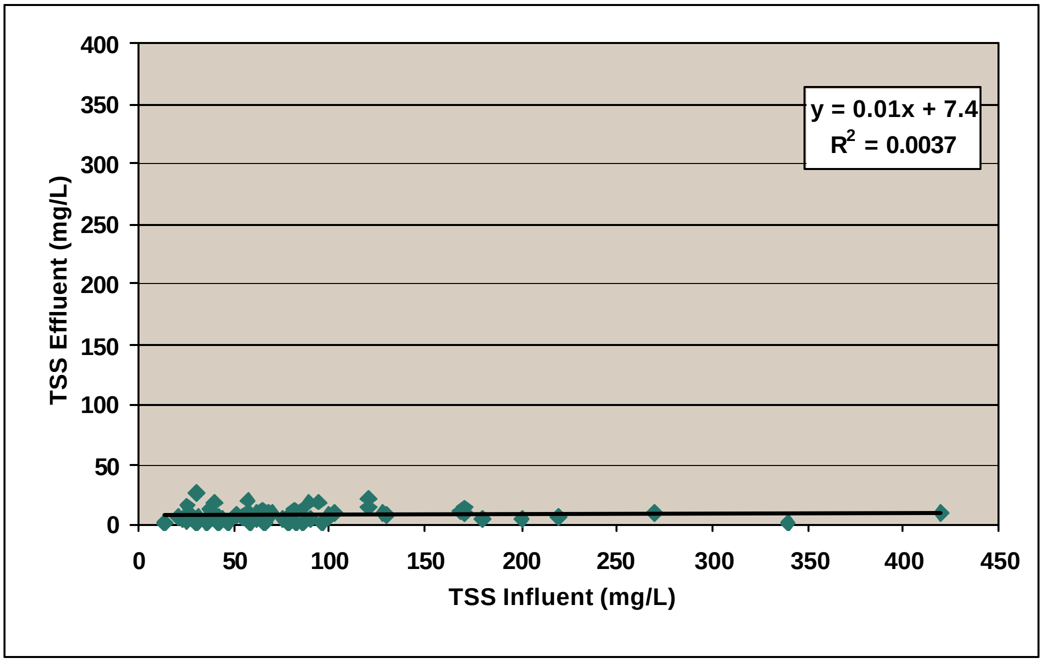


Figure 2-6 Influent and Effluent Concentration Relationship of TSS for all Austin Sand Filters

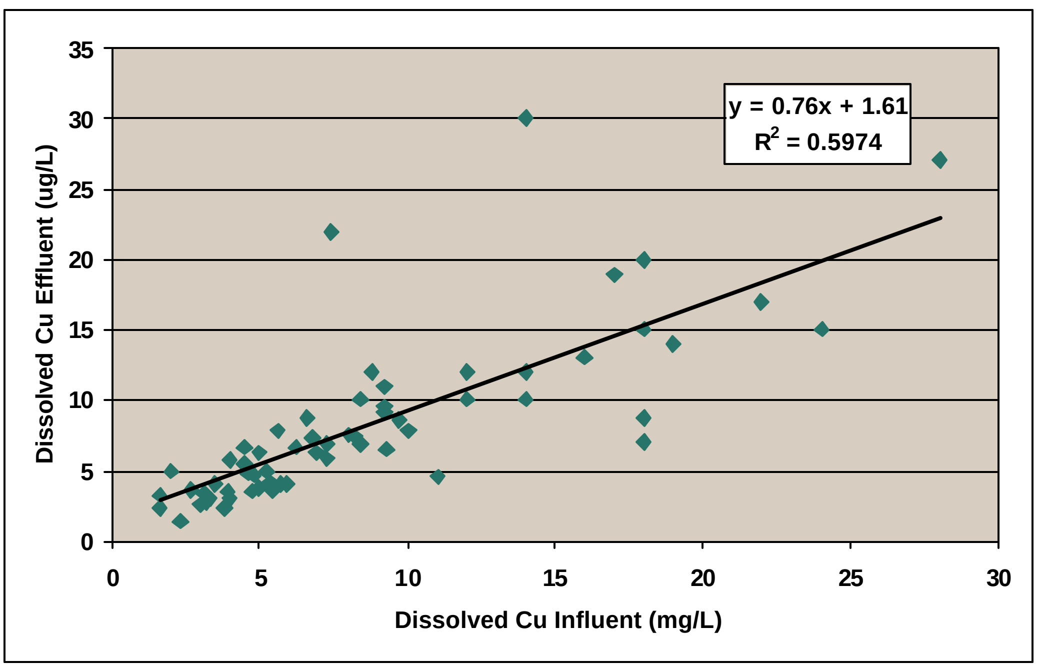


Figure 2-7 Influent and Effluent Concentration Relationship of Dissolved Copper for all Austin Sand Filters

Conversely, dissolved copper does exhibit a linear relationship between influent and effluent quality as shown in Figure 2-7, so it is appropriate to represent performance as a function of influent quality. Based on previous studies, sand filters were not expected to produce substantial reductions in dissolved constituents; however, a significant reduction was observed when the influent concentration exceeded about 15 µg/L. The observed behavior for dissolved copper and other metals indicates that adsorption on the sand grains or accumulated sediment may be occurring. Alternatively, the dissolved and particulate phases may not be in equilibrium when the runoff enters the facility as a result of rapid changes in runoff pH (very low pH in rainfall, which is rapidly neutralized during the runoff process). Therefore, some of the dissolved phase may become associated with particles during the residence time within the sedimentation basin, facilitating removal by physical processes (i.e., settling and straining).

Tables 2-5 and 2-6 present the results of the regression analysis for the constituents in this study. Where a constant is shown, the effluent concentration is statistically independent of the influent concentration. If the effluent concentration is correlated with the influent concentration, that functional relationship is shown as the "Expected Concentration." The last column in Tables 2-5 and 2-6 indicates the uncertainty of the estimate at the 90 percent confidence level. As suggested by Gilbert (1987), the mean and uncertainty for the constituents that are not a function of influent quality are calculated using non-transformed values because of the relatively low coefficient of variation. The uncertainty for constituents that exhibit a linear relationship is calculated according to the methodology specified by Wonnacott and Wonnacott (1990). Note that rather than predicting values for constituents measured as total and dissolved, these tables differentiate between dissolved and particulate (total minus dissolved) phases. This was done to clearly distinguish between the different relationships that might exist for dissolved and particulate constituents.

The top 50 mm of sand was replaced in the third year at the Delaware filter and the three Austin filters in District 7. All sand and collected material that accumulated in the sand bed was tested for hazardous materials prior to disposal. Testing found the sand material to be nonhazardous and therefore all material was disposed of at the landfill. Testing results can be found in Appendix F.

2.5.2 Empirical Observations

Empirical observations were recorded during and after storm events. The most striking observation for the Austin design was that very little of the filter bed was actually used during most events and at some sites even after 3 years of use, parts of the filter bed remained in their initial, pristine condition. Because of slight irregularities in the sand surface elevation, the discharge from the sedimentation basin would collect in the lower areas of the filter bed and infiltrate quickly enough that the water level would never rise high enough to cover the entire filter surface. This observation indicates that the permeability assumed in the City of Austin guidelines is very conservative and smaller filter areas may be adequate. Reducing the size of the filter area may, however, increase maintenance frequency because the same amount of sediment will be deposited on a smaller filter area, possibly causing more rapid clogging of the media. Further investigation would be required to determine the impact of filter area on maintenance requirements.

Table 2-5 Predicted Effluent Concentrations - Austin Filter

Constituent	Expected Concentration [a]	Uncertainty, ±
TSS	7.8	1.2
NO_3-N	0.93x + 0.37	$0.86\left(\frac{1}{64}+\frac{(x-0.67)^2}{24.01}\right)^{0.5}$
TKN	0.60x – 0.11	$0.99\left(\frac{1}{60}+\frac{(x-2.71)^2}{362}\right)^{0.5}$
Particulate P	0.07	0.02
Ortho-Phosphate	0.62x + 0.02	$0.14\left(\frac{1}{33}+\frac{(x-0.18)^2}{1.74}\right)^{0.5}$
Particulate Cu	2.0	0.6
Particulate Pb	0.057x + 0.49	$4.82\left(\frac{1}{63}+\frac{(x-17)^2}{9460}\right)^{0.5}$
Particulate Zn	11	3.1
Dissolved Cu	0.76x + 1.62	$6.27\left(\frac{1}{63}+\frac{(x-8.8)^2}{2195}\right)^{0.5}$
Dissolved Pb	0.22x + 0.81	$1.27\left(\frac{1}{63}+\frac{(x-2.1)^2}{195}\right)^{0.5}$
Dissolved Zn	0.23x + 10.6	$42.1\left(\frac{1}{63}+\frac{(x-92)^2}{296,910}\right)^{0.5}$

[a] Concentrations in mg/L, except metals which are in µg/L.
x = influent concentration of interest

Table 2-6 Predicted Effluent Concentrations - Delaware Filter

Constituent	Expected Concentration [a]	Uncertainty, ±
TSS	16.2	5.6
NO_3-N	0.96x + 0.47	$0.96\left(\frac{1}{13}+\frac{(x-0.34)^2}{0.93}\right)^{0.5}$
TKN	0.35x + 055	$1.38\left(\frac{1}{13}+\frac{(x-1.86)^2}{9.69}\right)^{0.5}$
Particulate P	0.25	0.09
Ortho-Phosphate	0.5x + 0.03	$0.048\left(\frac{1}{8}+\frac{(x-0.08)^2}{0.042}\right)^{0.5}$
Particulate Cu	3.0	1.1
Particulate Pb	0.14x – 0.35	$1.97\left(\frac{1}{12}+\frac{(x-11.7)^2}{308}\right)^{0.5}$
Particulate Zn	16.5	6.3
Dissolved Cu	0.52x + 0.53	$3.09\left(\frac{1}{13}+\frac{(x-6.81)^2}{340}\right)^{0.5}$
Dissolved Pb	1.0[b]	0.05
Dissolved Zn	0.054x + 1.0	$7.62\left(\frac{1}{10}+\frac{(x-213)^2}{67096}\right)^{0.5}$

[a] Concentrations in mg/L, except metals which are in µg/L
[b] Equals value of reporting limit
x = influent concentration of interest

A second observation was that the level spreader incorporated in the Austin filter designs does not perform any real function. Despite the presence of the spreader, runoff still tends to collect in the lowest part of the filter bed. In addition, the level spreaders retained water between storm events, raising concerns about potential mosquito breeding and increasing maintenance related to vector control at all of the sites. A better design would incorporate energy dissipation in front of the riser outlet to prevent scouring of the sand bed in lieu of the spreader.

One advantage of sand filters is the attenuation in peak runoff rates and the potential for mitigation of channel erosion downstream. Figure 2-8 compares the influent and effluent flow rates for the La Costa sand filter for a single event. The peak flow rate entering the facility is nearly 18 times larger that the peak discharge rate.

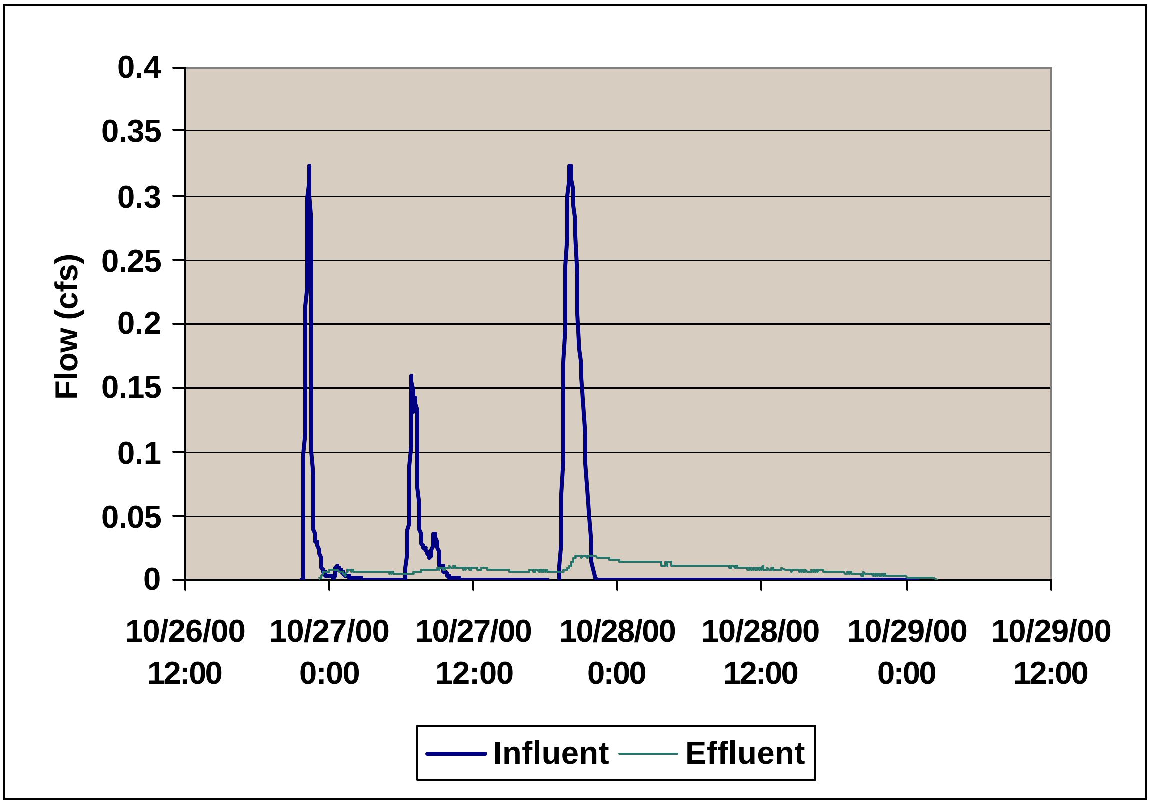


Figure 2-8 Comparison of Influent and Effluent Flow Rates at the La Costa Sand Filter

Table 2-7 shows the number of occurrences of mosquito breeding and number of abatement actions that were taken. This table highlights the disparity between the Los Angeles and San Diego areas in regard to abatement actions. In the Los Angeles area, breeding was observed a total of 16 times and abatement actions were carried out 14 times, while in the San Diego area, 66 breeding observations resulted in only one abatement action, reflecting the different policies in the two areas.

Different riser designs were used to transfer runoff from the sedimentation basin to the filter basin in Districts 7 and 11. In District 7, rate control was provided by limiting the number of perforations in the riser pipe and installing bags of gravel around the openings. This method did not seem to provide consistent flow control and periodically replacing the gravel bags, which deteriorated in the sun, increased maintenance. In District 11, the rate control was provided by affixing an orifice plate to the outlet of the riser. The riser itself incorporated many regularly spaced perforations surrounded by a trash screen. This design seemed to provide more consistent flow control, less clogging, and had fewer maintenance requirements. One potential problem with this design is that the outlet riser entered at the chamber separation wall and the last few centimeters of water did not drain completely from the sedimentation basin. Increasing the slope of the sedimentation basin floor may help alleviate this situation.

Table 2-7 Incidences of Mosquito Breeding – Sand Filters

District	Site	Number of Times	
		Breeding Observed	Abatement Performed
7 (Los Angeles)	Eastern Regional MS	6	6
	Foothill MS	2	2
	Termination P&R	8	6
11 (San Diego)	La Costa P&R	32	1
	SR-78/I-5 P&R	27	0
	Escondido MS	7	0

In the Delaware sand filter, water filled the pretreatment sediment chamber and on two occasions of heavy rain backed up into the inlet pipe. After periods of extended dryness, the filter drained slowly during the following storm.

2.6 Cost

2.6.1 Construction

Actual construction costs for the sand filters are shown in Table 2-8. The costs in District 11 were much less than those for District 7, because of differences in the design between the two districts. In District 7, all of the facility excavations were particularly deep in order to intercept existing storm drain systems or to reduce the device footprint at maintenance stations and park-and-ride lots where space was at a premium. Because of the depth, extensive shoring was required during the construction phase. In addition, pumps were required to return the treated runoff to the storm drain systems. In District 11, all of the devices were constructed to use gravity flow so that no pumping was necessary. In addition, the excavations were generally less, further reducing the cost.

Table 2-8 Actual Construction Costs for Sand Filters (1999 dollars)

District	Site	Actual Cost $	Actual Cost w/o Monitoring $	Cost[a]/WQV $/m³
7 (Los Angeles)	Eastern Regional MS	353,702	342,660	2,979
	Foothill MS	485,946	476,106	2,194
	Termination P&R	471,637	463,461	2,088
11 (San Diego)	La Costa P&R	239,678	225,285	787
	78/I-5 P&R	222,529	211,631	1,997
	Escondido MS	453,012	416,714	3,472

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Adjusted construction costs for the Austin and Delaware sand filters are presented in Table 2-9. The actual Austin sand filter costs were reduced to the values shown in Table 2-9 for the following reasons:

- The three Austin sand filters in District 7 were installed in areas where existing conditions did not allow for gravity drainage and space constraints required extensive shoring. Including the cost of pumps and shoring costs, due to limited space, between Districts 7 and 11 adds 45 percent to 67 percent above the adjusted construction cost, and these costs were excluded in the adjusted cost.

- Removal of existing storage bins at one location caused greater than usual clearing and grubbing cost. Including the original clearing and grubbing cost would increase the adjusted construction cost for that location by 20 percent. Instead, the average clearing and grubbing cost for similar BMPs was used for estimating the adjusted construction cost.

- Rebuilding storage bins at one location caused greater than usual facility restoration cost. Including the original facility restoration cost would increase the adjusted construction cost for that location by 15 percent. Instead, the average facility reconstruction cost for similar BMPs was used for estimating the adjusted construction cost.

- Costs attributed to miscellaneous site-specific factors would increase cost by up to 3 percent over the adjusted construction cost. These costs were excluded in the adjusted cost.

Table 2-9 Adjusted Construction Costs for Sand Filters (1999 dollars)

Sand Filter	Adjusted Construction Cost, $	Cost/WQV $/m^3
Austin Sand Filter		
Mean (5)	242,799	1,447
High	314,346	2,118
Low	203,484	746
Delaware Sand Filter		
One location	230,145	1,912

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

The actual Delaware sand filter costs were reduced for the following reasons:

- The cost of the Delaware sand filter was adjusted because of contractor inexperience with the extensive cast-in-place construction. This change is estimated to increase cost by 64 percent above the adjusted construction cost. This cost was excluded in the adjusted cost.
- The Delaware type sand filter incurred additional cost due to the device being subject to heavy traffic loads, adding approximately $65,000 to the total cost. While this cost would be incurred in most situations, it could be avoided if the filter were located away from heavy traffic or shielded from such traffic with a barricade. Alternative non-traffic bearing covers used to cover the MCTT units were constructed for about $560/m^2. Using non-traffic bearing covers would cost about $30,000, resulting in a $35,000 dollar savings. The cost for traffic bearing covers would increase cost by 15 percent over the adjusted construction cost. The cost of non-traffic bearing covers was used in lieu of traffic bearing in estimating the adjusted construction cost.

Delaware sand filters are useful in perimeter applications, although this requires that the design team address covering the structure to meet the requirements of the intended use of the retrofitted facility. In the Pilot Program this application was in a maintenance yard, thus requiring a cover that will allow vehicle loading over the structure. Maintenance of the structure during the monitoring was also addressed in the design and construction, requiring full access to the sand filter chamber. During construction, it was necessary to pay special attention to the layout, forming and concrete placement to meet the design parameters of the structure.

All sand filter installations were in park-and-ride lots or maintenance stations and subsequently did not incur traffic control costs. If sand filters are constructed roadside, they could incur traffic control cost typical of EDBs, in which traffic control accounted for an average of 9 percent of the adjusted construction cost. Traffic control costs were not used to estimate adjusted construction cost.

2.6.2 Operation and Maintenance

Table 2-10 shows the average annual operations and maintenance equipment and field hours experienced for each sand filter during the course of the study. The operation and maintenance hours were generally higher in District 7 due to numerous problems encountered with the pumps. Pumps had to be replaced during the study at both the Eastern MS and Termination P&R. In addition, Termination P&R had problems receiving enough power during the evening hours when park-and-ride lights were on, thus requiring more maintenance. Field hours include inspections, maintenance and vector control.

Table 2-10 Actual Operation and Maintenance Hours for Sand Filters

District	Site	Average Annual	
		Equipment Hours	Field Hours
7 (Los Angeles)	Eastern Regional MS	2	128
	Foothill MS	2	52
	Termination P&R	1	187
	Average Value	**2**	**122**
11 (San Diego)	La Costa P&R	0	70
	78/I-5 P&R	0	58
	Escondido MS	0	58
	Average Value	**0**	**62**

Termination P&R needed more maintenance than other District 7 sites, which were maintenance stations, because of greater accumulation of wind-blown debris and more work associated with pump maintenance. At the Eastern MS, the sand filter was found to be leaking during the 1998-1999 season, and additional integrity testing was performed during 1999-2000 to ensure proper functioning of the sand filter. At the La Costa P&R, the weep holes in the drain plugs routinely had to be cleared after storm events.

Table 2-11 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 2-11 Actual Average Annual Maintenance Effort – Sand Filters

Activity	Labor Hours	Equipment and Materials $
Inspections	12	0
Maintenance	40	40
Vector control*	41	0
Administration	65	0
Direct cost	-	832
Total	158	$ 872

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate a sand filter or reflect the lessons learned during the course of the study. Table 2-12 presents the expected maintenance costs that would be incurred under the final version of the MID (Version 17) for a sand filter serving about 2 ha, constructed following the recommendations in Section 2.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Design refinements will eliminate the need for activities such as dewatering, pump maintenance, and vector control. Only four hours are shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. This estimate also assumes that the facility is constructed of concrete and no vegetation maintenance is required. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Equipment generally consists of a single truck for the crew, their tools, and disposal of material removed from the sand filter.

Table 2-12 Expected Annual Maintenance Costs for Final Version of MID – Sand Filter

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	4	0	176
Maintenance	36	125	1,709
Vector control	0	0	0
Administration	3	0	132
Direct costs	-	888	888
Total	43	$1,013	**$2,905**

2.7 Criteria, Specifications and Guidelines

The findings of this study show that sand filters are technically feasible depending on site specific conditions. However, there are several design and operational issues that warrant additional study. Future research on construction methods and materials for sand filters is needed to improve the cost/benefit ratio for these devices. In addition, evaluation of alternative media may allow the targeting of specific constituents or improvement in the performance for constituents, such as nitrate, which are not effectively removed by a sand medium. This section discusses various guidelines for the siting, design, construction and operation of sand filters derived from the experiences in this study.

2.7.1 Siting

The original siting criteria seem to have been generally successful at locating sand filters where they could operate effectively. Although there is concern about the effect of excessive sediment loading on filter life, the devices performed well when installed in maintenance yards where sediment and other debris collected from highways and roadsides are temporarily stored. The lack of sufficient head to drive these devices with gravity flow was overcome at some sites with the use of pumps. Due to a variety of problems, including power delivery issues, the pumps have not performed well. Based on the results of this study, the primary siting criteria that are recommended for future installations include the following:

- To avoid the use of pumps, sufficient hydraulic head should be available to operate filters by gravity flow (about 1 m), which may require modification of the existing drainage system.

- If construction is planned up-gradient of the proposed location, it should be completed before installation of the sand in the filter.

- Sand filters are most appropriate for sites with a relatively high level of imperviousness.

2.7.2 Design

Because these devices have limited implementation history in California, design engineers were unfamiliar with basin configuration, filter sizing and appropriate sand for the filter. Consequently, standard design details need to be developed for these devices so that engineers with limited experience can successfully incorporate them in future projects when desired. Design recommendations for the Austin filter in addition to the filter configuration and sizing guidance described in the City of Austin criteria (http://www.ci.austin.tx.us/watershed/regulation.htm) include:

- When possible, use standardized sand filter designs and prefabricated vaults, where a concrete vault is needed.
- Minimize basin depth to save excavation and shoring costs and to avoid the need for pumps.
- Use locally available sand specification that complies with Caltrans Standard Specifications for fine aggregate in Sections 90-2.02 and 90-3, which is generally equivalent to the requirements for fine aggregate contained in ASTM C-33.
- Include ramps into each basin to facilitate access where side slopes are steeper than 1:4 (V:H), with width appropriate for required maintenance equipment.
- Transfer water from the sedimentation basin to the filter basin by using a perforated riser surrounded by a trash rack with rate control provided by an orifice plate attached to the riser outlet. The outlet riser should enter at the floor of the sedimentation chamber rather than the wall to ensure that the chamber will completely drain between storm events.
- Provide energy dissipation (riprap or rock gabion) in front of the riser outlet to prevent scouring of the sand filter bed.
- Do not use level spreaders in the filter basin to distribute the runoff.
- Slope the sedimentation chamber floor toward the riser outlet for easier maintenance and improved draining.
- Cover the sand filter or add locations to attach netting to keep unwanted birds out of open sand filters if a problem is likely to occur during operation of the device.

There are other types of sand filter designs not tested in this study, such as earthen wall design, partial sedimentation design (combined sedimentation and filtration basin) and under-pavement configuration that may be more economical, less intrusive on workspace, and acceptably fulfill other requirements. The Delaware-style filter appeared to operate effectively when designed according guidelines described by Young et al. (1996).

2.7.3 Construction

Determining the location of all utilities prior to construction may be difficult due to limited documentation of utility locations. It is suggested that a small (1–2 percent) contingency is provided in case unknown utilities are encountered. In addition, unsuitable material was encountered at many of the construction sites. Conducting sufficient borings before going out for bid may avoid the delays and expense of contract change orders associated with removal of this material.

2.7.4 Operation and Maintenance

Several factors contributed to the low maintenance requirements for the sand filters. The basins were constructed of concrete; consequently, no vegetation maintenance was required, and slope stability was not an issue as it was at other sites. Where there is a reason to restrict infiltration due to groundwater quality concerns another benefit of constructing the basin of concrete is that it eliminated the possible risk of groundwater contamination from runoff infiltrating through the basin inverts. Of course, the initial construction cost is significantly higher than it would be at a comparable site with earthen walls and floors. In areas with the potential for groundwater contamination, earthen basins can be lined with an impermeable membrane or compacted clay. Additional reduction in maintenance costs could be expected by eliminating the spreader ditch in the filtration basin and by not siting sand filters where pumping is required. Further research is recommended to investigate capital cost reduction strategies and potential performance enhancement through the use of alternate media.

Rainfall in southern California is much lower (about 250 mm/yr) than it is in the Austin area (about 800 mm/yr) where most of the previous research on sand filters has been conducted. Less runoff reduces the sediment load to the filter, since influent sediment concentrations are similar to those in Austin. Consequently, the interval between major maintenance activities would be expected to be as much as three times greater than that observed in Austin. However, major maintenance of the sand bed appears to be needed during the third wet season for many of the devices.

Based on the low level of maintenance required in this study, recommended future maintenance activities include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, including inspection for standing water, sediment, trash and debris.
- Schedule semiannual inspection for beginning and end of wet season to identify potential problems.
- Remove accumulated trash and debris in the sedimentation basin and from the riser pipe and bed during routine inspections.

- Inspect the facility once during the wet season after a large rain event to determine whether the facility is draining completely within 72 hours.
- Remove the top 50 mm of sand and dispose of sediment if facility drain time exceeds 72 hours. Restore media depth to 450 mm when overall media depth drops to 300 mm.
- Remove accumulated sediment in the sedimentation basin every 10 years or when the sediment occupies 10 percent of the basin volume, whichever occurs first.

3 EXTENDED DETENTION BASINS

3.1 Siting

Five extended detention basins (EDBs) were sited as part of this study, two sites in District 7 and three in District 11. All sites were located within the highway right-of-way and collected runoff exclusively from the highway.

Siting of extended detention basins was generally straightforward since adequate space and safety considerations were the primary constraints. Space constraints included room for the basin, topography to provide sufficient head to operate the outlet works, and sufficient area to allow for access by maintenance vehicles. Other siting criteria included safe maintenance ingress and egress routes. These devices have one of the lowest hydraulic head requirements for successful implementation. However, retrofitting the basins into the existing storm drain system where slopes were often very low occasionally produced basin bottom slopes that were less than optimum for good drainage (e.g., the I-15/SR-78 site). Where this happened, the facility was modified to create drainage that would comply with the criterion of fully emptying within 72 hours.

Primary siting criteria included:

- Sufficient space to provide a 9 m clear recovery zone for motorists (or installation of guardrail)
- Sufficient head to allow operation by gravity flow

According to previous guidance, tributary areas greater than 4 ha are generally preferred since there is a larger water volume to treat and this allows the use of larger discharge orifices in the basin outlet riser that are more resistant to clogging. Because of the integration of Caltrans and urban drainage systems and the generally linear nature of Caltrans facilities, very few locations with large drainage areas exist solely within Caltrans rights-of-way; however, during highway reconstruction drainage areas could be consolidated when hydraulically feasible to create larger catchments. In addition, as discussed later, the EDBs with tributary areas of less than 4 ha operated successfully without orifice clogging, making revision of previous guidance prudent.

As shown in Table 3-1 only one site with a drainage area of greater than 4 ha was identified in this pilot study; however, only 28 percent of that watershed was paved and therefore produced a relatively smaller water quality volume than would most highway catchments of that size. The best prospects for siting EDBs to serve large drainage areas entirely within highway rights-of-way are probably in interchanges.

Table 3-1 Summary of Contributing Watershed Characteristics for EDB

Site Location	Watershed Area Hectare	Impervious Cover %
I-5/I-605	2.75	54
I-605/SR-91	0.40	100
I-5/SR-56	2.14	69
I-15/SR-78	5.42	28
I-5/Manchester	1.94	56

3.2 Design

The basic design criteria involved detention time, length/width ratio, and depth. Additional design criteria included side slope ratio, maintenance access, basin shape, inlet/outlet type, and in-line or off-line configuration. The study included a concrete-lined basin site (I-5/I-605). All other sites were unlined. This was done to compare the removal efficiencies and maintenance requirements of the two designs. Table 3-2 provides the specific criteria used to size each detention basin.

Table 3-2 Design Characteristics of the EDBs

Site Location	Type	Design Storm mm	WQV m^3	Design Storm Water Depth m	Maximum Water Depth m	Basin Material	Length- to-Width Ratio
I-5/I-605	Off-line	25	365	0.60	1.36	Concrete	4.5:1
I-605/SR-91	In-line	25	70	0.60	1.17	Earthen	9:1
I-5/SR-56	In-line	33	391	0.50	1.10	Earthen	6:1
I-15/SR-78	In-line	48	1,123	1.15	2.50	Earthen	10:1
I-5/Manchester	Off-line	33	253	0.83	1.22	Earthen	3:1

The extended detention basins were designed for a full-basin (water quality volume) drawdown time of 72 hours.

Since most storms are much smaller than the design water quality storm, the goal was to produce a drawdown time of at least 24 hours for average conditions rather than full basin conditions. The primary objective for this specification was to provide adequate time for sediment deposition.

To enhance particle settling, the hydraulic flow length of the basin was extended by requiring a minimum length to width ratio of 3:1 for the basin, locating the inlets and outlets as far apart as possible. Relatively shallow depths in detention basins can improve removal efficiencies, but there is potential for resuspension of settled material. Therefore, the water depths in the basin for the design storm were designed to be between 0.5 and 1.2 m. Incorporating long flow paths in the design may result in very low slopes in the basin resulting in poor drainage, such as occurred at the I-15/SR-78 site. Adding a concrete low flow channel when the slope is less than about 1 percent could help alleviate this problem.

Of concern is stabilization of basin side slopes to prevent erosion and contribution of additional sediment to the runoff. During this study, vegetation was not particularly effective for stabilizing slopes steeper than 1:4 (V:H). This was likely the result of poor soil conditions and inadequate moisture. In some instances, the side slopes were steeper, as in the I-5/I-605 and I-605/SR-91 basins, where the slopes adjacent to the freeway were 1:2 (V:H). Embankment slopes were compacted in an effort to prevent surficial erosion and ensure structural integrity.

Inlet structures for all basins except the I-5/I-605 were designed to dissipate flow energy at the inlet point in order to limit erosion and promote quiescent conditions in the basin. Riprap or concrete aprons were used to reduce the velocity and to distribute flows. Riprap energy dissipation at some sites had to be removed and replaced with a concrete apron to prevent mosquito breeding in water ponded continuously in the riprap. In addition, a riprap berm at the I-5/SR-56 site was used to increase the length-to-width ratio, but resulted in standing water between the rocks. A simple earthen berm could perform the same function and eliminate the ponded water. Sediment forebays common to EDB designs throughout the nation were not used in Caltrans designs due to the low sediment load expected from the highly impervious highway tributary areas.

District 11 sites used an outlet riser with the riser overflow height set at the 1 yr, 24 hr storage elevation. A screen was placed around the outlet riser to ensure that the orifices would not become clogged with debris. The basins used either a separate riser or broad crested weir for overflow of runoff for the 25 yr and greater year storms.

In District 7, a standpipe with orifices sized to discharge the water quality volume was used. The standpipe was surrounded by crushed rock to prevent trash and debris from clogging the orifices. The concrete outlet structure allows the 25 yr event to discharge via weir flow. An emergency spillway was provided at both District 7 sites to discharge runoff that exceeded the design storm.

The use of different outlet designs in Districts 7 and 11 allowed for comparison and evaluation of performance to determine the better choice. Figures 3-1 and 3-2 show the two types of outlet structures used. The District 11 screen type design is preferred since the outlet orifices can be visually inspected, and maintenance access is improved as compared to the District 7 riprap design.

The extended detention basins were designed to be either off-line or in-line. The off-line basins have an upstream weir at the diversion structure to divert flows greater than the design storm away from the basin to the storm drain system. The in-line basins receive all storm runoff for the tributary area and have an overflow weir at the discharge structure to allow excess stormwater to flow through the basin while retaining the water quality volume for further settling. The decision to configure the basins as off-line or in-line was based on the existing storm drain configuration.

Figure 3-1 District 11 Outlet Riser

Figure 3-2 District 7 Outlet Riser

Figures 3-3 and 3-4 show an unlined basin and the concrete-lined basin, and a schematic diagram is presented in Figure 3-5. The I-5/SR-56 facility is located in District 11 and is an in-line basin. The I-5/I-605 EDB is located in District 7 and is an off-line basin.

3.3 Construction

The specific issues that occurred during construction of the EDBs centered on constructability, unknown field conditions, and coordination with concurrent construction projects.

3.3.1 Constructability

The two main issues related to the constructability of the extended detention basins were the delivery of specialized components, such as canal gates, and the precise elevation measurements required at some sites due to low site relief. Anticipating a long lead-time, many specialized items were ordered prior to the start of construction; however, they still did not arrive on schedule. To minimize delays, it is suggested that the manufacturing time for construction materials be verified prior to specifying the product.

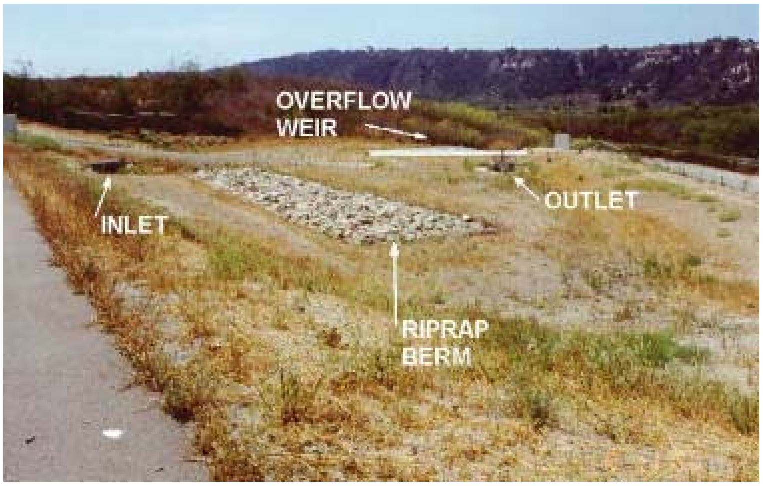


Figure 3-3 I-5/SR-56 Unlined Basin

Riprap berm was used to increase the flow length. Water stays pooled in berm and has caused mosquito problems.

Figure 3-4 I-5/I-605 Concrete Lined Basin

Some resuspension of sediments has occurred near inlet.

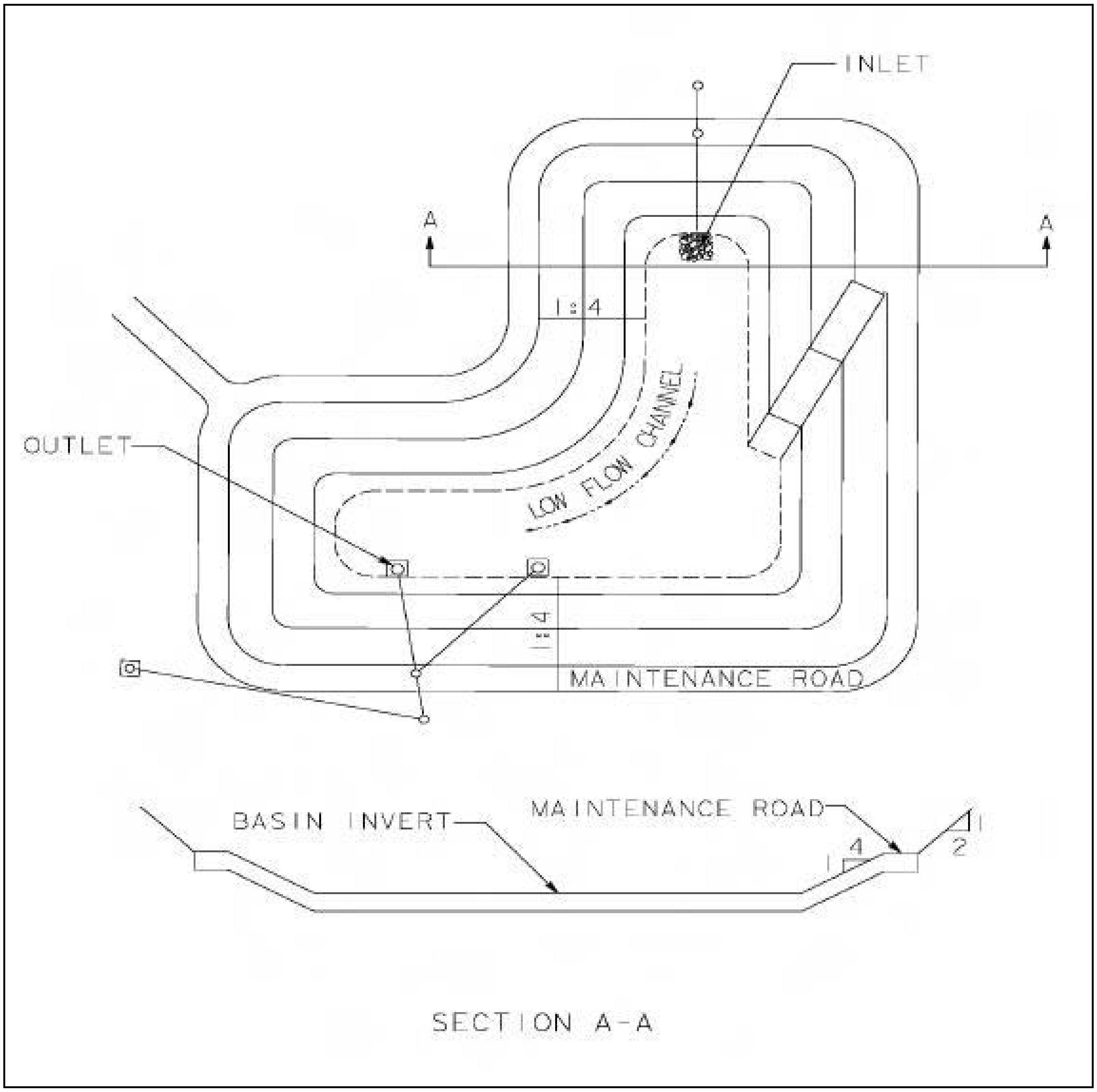


Figure 3-5 Schematic of Extended Detention Basin

Limited hydraulic head, precise tolerances are required. At the I-15/SR-78 EDB, small errors in measurement resulted in ponded water when the outlet structure was constructed at an elevation higher than shown on the plans. This situation was mitigated by two actions. The outlet structure was modified to lower the elevation by grinding the concrete in the structure, and a low-flow swale was graded in the basin.

Tire ruts and other irregular surface features downstream of the outlet of the I-5/I-605 site (in the maintenance road area) resulted in ponded water and mosquito breeding. Asphalt surfacing was installed in order to eliminate this problem.

3.3.2 Unknown Field Conditions

The largest impact on construction activities was the discovery of unsuitable material encountered during the excavation of the basins. For instance, large boulders and broken concrete that had been disposed at the I-15/SR-78 site were discovered during construction. The presence of the debris was not detected during the design geotechnical subsurface investigation (2 soil borings), and the cost of the change order to remove the debris exceeded the original contract cost. Similarly, trash and debris were encountered in the excavation at the I-5/Manchester site. An appropriate site evaluation performed during the siting and design phases of the project should alert designers to this problem and help prevent costly contract change orders. Better tracking of material disposal onsite and recording the locations on as-built plans may prevent these problems. In addition, discussion with local maintenance staff may reveal undocumented information on field conditions.

As in many of the other BMP sites, buried utilities were present and required relocation. For instance, construction of the I-5/SR-56 EDB required relocation of an electrical line owned by San Diego Gas and Electric, delaying the start of construction of the BMP.

3.3.3 Coordination

The main coordination issue encountered during construction of the extended detention basins was the need to include Caltrans traffic personnel early in the design process. For instance, during the final construction walk-through of the I-5/I-605 and I-605/SR-91 EDBs the need for metal beam guardrail along the roadway was identified because of the proximity of above-ground structures to the edge of the travel way. Additionally, an access road was needed around the I-5/I-605 site to increase the safety of maintenance vehicles exiting from the site and merging with freeway traffic.

3.4 Maintenance

The EDBs were maintained at a state-of-the-art level through a formal maintenance program that is described in the MID (see Appendix D). The sites were inspected monthly for general maintenance, including checking the inlet and outlet structures, side slopes and overall site for signs of erosion, woody vegetation, graffiti, and vandalism. Monthly inspections were also performed for indications of burrowing rodent activity that could endanger the structural integrity of the facility. The side slopes and invert were planted for erosion control, and coverage was assessed monthly. In addition, monthly and before every target storm for monitoring, the site was inspected for trash and debris accumulation in the inlet and outlet structures. Other maintenance items included inspection for vectors monthly and after every target storm.

To ensure that the EDBs met the required drain time of 72 hours for the design storm, each site was assessed after a design storm. The basins were inspected for vegetation coverage in October of every year to ensure 70 percent coverage; the sites were reseeded at this time if coverage did not meet the criteria. Sediment accumulation in the invert was inspected and characterized (based on hazardous thresholds) on approximately June 1 of each year. During the wet season, the EDBs were inspected weekly for endangered and threatened species and species of special concern.

Figure 3-6 shows the average number of hours required to maintain the EDBs. An average of 72 hours was spent in the field completing inspections and maintenance at the sites, not including vector control agency hours. Hydroseeding of the basins and vegetation trimming and removal required the most hours, followed by site inspections. Vegetation maintenance was required at all sites including the concrete lined EDB at I-5/I-605. This site required vegetation maintenance around the perimeter of the site, with virtually no savings in maintenance time as compared to the unlined sites. The unlined basins failed to fully sustain vegetation and were hydroseeded each year of the study to reestablish vegetation as required in the earlier versions of the MID.

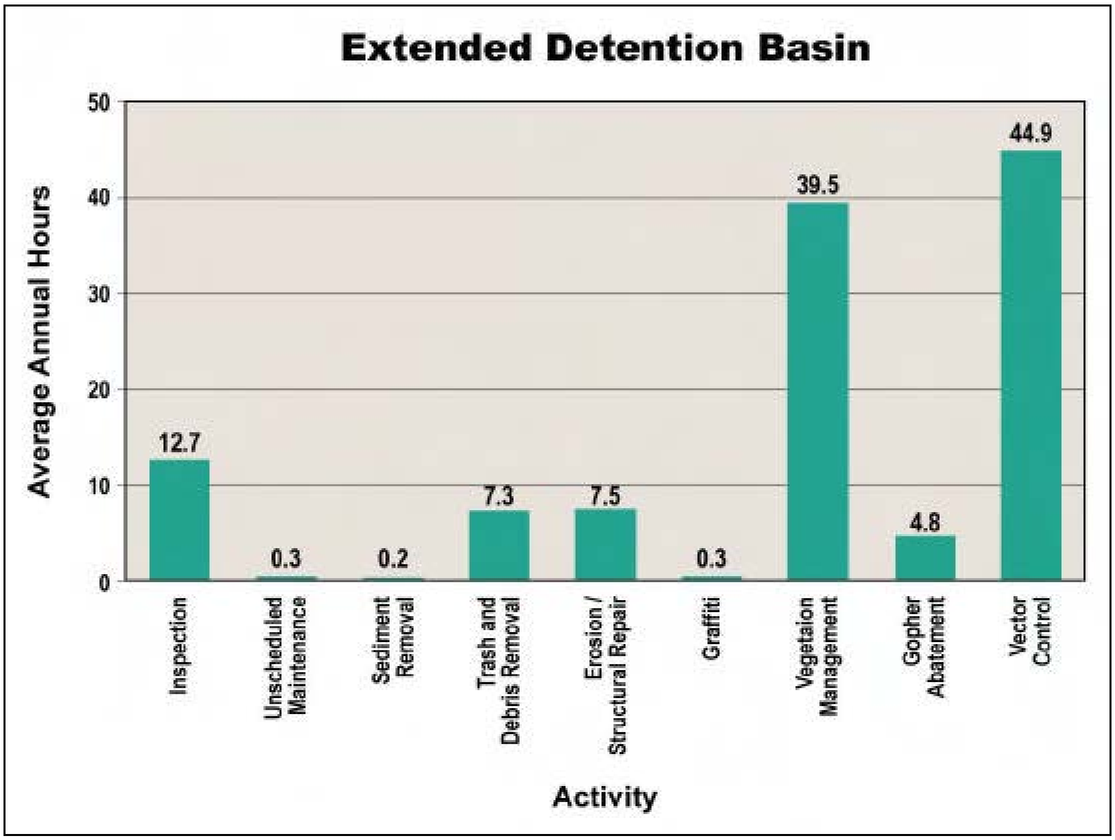


Figure 3-6 Field Maintenance Activities at EDBs (1999-2001)

The vast majority of maintenance activities at the extended detention basins were associated with plant establishment and management. Less time was required for activities related to collection of trash and debris, sediment removal or other items directly associated with EDB performance. Vector abatement was required periodically at several of the sites; however, this maintenance item can be avoided with proper design to eliminate standing water in the facility structures.

A potentially major maintenance item for an extended detention basin is the removal of accumulated sediment; however, during the 3 years of monitoring, the total amount of accumulated sediment (average of all sites) was less than 20 mm throughout the basin, or less than 3 percent of basin volume. This suggests that sediment removal may not be necessary more than once every 10 years based on the criteria that removal should occur when the sediment occupies more than 10 percent of the basin volume.

The outlet structures in District 7 were surrounded with riprap that held small pools of water and had a greater tendency to collect debris that was not easily accessible. Also, maintenance inspections were difficult due to lack of visibility of the outlet orifice(s).

Vector breeding and abatement occurred primarily at two sites. The I-5/SR-56 basin contained a riprap berm and riprap energy dissipation at the inlet. Small pockets of water were held in the rock and did not dry up quickly, providing a breeding ground for mosquitoes. At the I-5/I-605 EDB, the outlet structure was designed with a sump that held a permanent pool of water and breeding was often observed. The sump was filled in at the site in February 2001, and there were no further observations of breeding. Table 3-3 shows the number of occurrences of mosquito breeding and number of abatement actions that were taken.

Table 3-3 Incidences of Mosquito Breeding - EDB

District	Site	Number of Times	
		Breeding Observed	Abatement Performed
7 (Los Angeles)	I-5/I-605	20	18
	I-605/SR-91	0	0
11 (San Diego)	I-5/SR-56	51	4
	I-15/SR-78	3	0
	I-5/Manchester	0	0

A potential maintenance concern at the beginning of the study was the establishment of wetland vegetation in the earthen basins. It was thought that the appearance of wetland plants or harborage of endangered species could result in maintenance constraints. However, consultation with regulators resulted in the agreement that basins would not be regulated as wetlands as long as they were operated as treatment systems and regular maintenance was provided. Of the four unlined basins, three had minimal vegetation for most of the year, mostly grasses. The I-605/SR-91 basin had the most complete coverage by vegetation, while the San Diego sites tended to have numerous bare spots, particularly near the basin invert. Maintenance requirements were adequate to control nuisance vegetation.

3.5 Performance

3.5.1 Chemical Monitoring

Table 3-4 presents the average removal efficiencies for the constituents monitored during the pilot study at the unlined basins. The concentrations are the mean of the EMCs for the entire monitoring period. The column labeled "Significance" indicates the probability that the influent and effluent concentrations are not significantly different, based on an ANOVA. Load reductions shown in Table 3-5 are computed based on total estimated wet season influent and effluent runoff volumes for all four sites and the concentrations reported in Table 3-4. The EDBs were best at removing particulate constituents, while removal of nutrients and dissolved metals was comparatively modest and generally not statistically significant. Infiltration also accounted for some of the reduction in the constituent load in the effluent for the unlined basin sites. The data from the concrete lined I-5/I-605 site was analyzed separately because its performance was significantly worse than the other sites and no infiltration occurred.

Table 3-6 presents the concentration reduction for the concrete lined basin located at the I-5/I-605 site. Based on an ANOVA, none of the removals are statistically significant. All of the earthen basins had significantly better removal efficiencies than the concrete-lined basin. In four events at the lined basin, there was an export of suspended solids, which suggests that resuspension of particulates was occurring. The average TSS concentration reduction for the concrete lined basin was 40 percent, while the average for all other basins for TSS was 73 percent. The difference in load removed is even greater because of the infiltration that occurred in the unlined basins. Although the infiltration of stormwater is clearly beneficial to surface receiving waters, there is the potential for groundwater contamination, which was not evaluated in this study. No load reduction is shown for the I-5/I-605 basin since it is the same as the concentration reduction (no infiltration occurs in the concrete lined basin).

There were substantial differences in the amount of infiltration that occurred in the earthen basins. On average, approximately 40 percent of the runoff entering the unlined basins infiltrated and was not discharged. The percentage ranged from a high at the I-605/SR-91 basin of about 60 percent to a low at the I-5/SR-56 site of only about 8 percent. Soil and climatic conditions and local water table elevation are likely the principal causes of this difference. The I-5/SR-56 basin is located on the coast where humidity is higher and the basin invert is within a few meters of sea level. Conversely, the I-605/SR-91 is located well inland in Los Angeles County where the climate is much warmer and the humidity is less, resulting in lower soil moisture content in the basin floor at the beginning of storms. It should be noted that these infiltration volumes are rough estimates. On many occasions at certain sites the volume discharged was greater than the measured influent volumes and adjustments were made to the volumes to resolve this physical impossibility.

Table 3-4 Concentration Reduction of Unlined EDBs

Constituent	Mean EMC Influent mg/L	Mean EMC Effluent mg/L	Removal %	Significance P
TSS	137	39	72	<0.000
NO_3-N	1.06	0.98	8	0.529
TKN	2.24	1.85	17	0.206
Total N[a]	3.30	2.83	14	-
Ortho-phosphate	0.11	0.14	-22	0.332
Particulate P	0.52	0.32	39	<0.000
Phosphorus	0.52	0.32	39	0.001
Total Cu	0.053	0.022	58	<0.000
Total Pb	0.087	0.024	72	<0.000
Total Zn	0.418	0.115	73	<0.000
Particulate Cu	0.041	0.010	76	<0.000
Particulate Pb	0.084	0.022	74	<0.000
Particulate Zn	0.347	0.055	84	<0.000
Dissolved Cu	0.012	0.012	0	0.899
Dissolved Pb	0.003	0.002	29	0.078
Dissolved Zn	0.071	0.060	16	0.279
TPH-Oil [c]	2.800	2.300	18	0.773
TPH-Diesel [c]	1.900	1.300	32	0.321
TPH-Gasoline [c]	0.050b	0.050b	-	-
Fecal Coliform [c]	900 MPN/100mL	2000 MPN/100mL	-122	0.607

[a] Sum of NO_3-N and TKN
[b] Equals value of reporting limit
[c] TPH and Coliform are collected by grab method and may not accurately reflect removal

Table 3-5 Load Reduction of Unlined EDB

Constituent	Load, kg/yr		
	Influent	Effluent	% Removal
TSS	1417	302	79
NO_3-N	10.9	7.6	30
TKN	23.1	14.4	38
Total N	34.0	22.0	35
Ortho-phosphate	1.17	1.07	8
Particulate P	4.19	1.41	66
Phosphorus	5.36	2.48	54
Total Cu	0.551	0.176	68
Total Pb	0.898	0.189	79
Total Zn	4.317	0.892	79
Particulate Cu	0.422	0.078	82
Particulate Pb	0.863	0.171	80
Particulate Zn	3.581	0.425	88
Dissolved Cu	0.129	0.098	24
Dissolved Pb	0.035	0.019	46
Dissolved Zn	0.735	0.467	36

Table 3-6 Concentration Reduction of Concrete - Lined EDB

Constituent	Mean EMC Influent mg/L	Mean EMC Effluent mg/L	Removal %	Significance P
TSS	96	58	40	0.119
NO_3-N	0.90	0.84	8	0.898
TKN	2.05	1.72	16	0.670
Total N[a]	2.96	2.56	14	-
Ortho-phosphate	0.18	0.16	10	0.909
Particulate P	0.31	0.26	16	0.292
Phosphorus	0.49	0.42	15	0.426
Total Cu	0.025	0.018	27	0.247
Total Pb	0.049	0.035	30	0.174
Total Zn	0.221	0.103	54	0.119
Particulate Cu	0.016	0.008	50	0.832
Particulate Pb	0.060	0.027	55	0.513
Particulate Zn	0.153	0.053	65	0.127
Dissolved Cu	0.012	0.011	8	0.832
Dissolved Pb	0.007	0.004	42	0.382
Dissolved Zn	0.087	0.053	39	0.415
TPH-Oil [b]	0.900	0.800	11	0.739
TPH-Diesel [b]	1.100	1.100	0	0.981
TPH-Gasoline [b]	0.050[c]	0.050[c]	-	-
Fecal Coliform [b]	6700 MPN/100mL	7500 MPN/100mL	-12	0.900

[a] Sum of NO_3-N and TKN
[b] TPH and Coliform are collected by grab method and may not accurately reflect removal
[c] Equals value of reporting limit

The I-605/SR-91 facility performed the best of all the sites, having an average TSS load reduction efficiency of 85 percent. This was largely due to the greater infiltration that occurred at the site during small rainfall events. The Manchester site also had comparatively good constituent removal. Its average residence time was the longest of all the sites.

EDB removal efficiencies reported by Young et al. (1996) indicated sediment reduction (TSS) of 68 to 90 percent, total phosphorus reduction of 42 to 50 percent, total nitrogen reduction of 28 to 40 percent and total heavy metals reduction of 42 to 50 percent. This study found that the TSS and metals removals were within the ranges reported by Young et al. (1996). However, removal efficiencies for nitrogen and phosphorus were lower.

Table 3-7 shows the performance of each extended detention basin for TSS and total copper as representative examples. These detailed results are presented as an example to illustrate the variation in performance among the different sites. Note that the concentration reduction in the earthen basins for TSS is closely associated with influent concentration.

Table 3-7 Removal Efficiency of TSS and Total Cu for each EDB

Site	TSS (mg/L)				Total Cu, ug/L			
	Inf	Eff	Conc. Reduction %	Load Reduction %	Inf	Eff	Conc. Reduction %	Load Reduction %
I-5/I-605	95.6	57.6	40	40	25.4	18.5	27	27
I-605/SR-91	83.0	32.7	61	85	38.5	24.6	36	76
I-5/SR-56	88.7	39.9	55	62	34.2	17.0	50	58
I-15/SR-78	186.9	48.3	74	80	57.2	20.2	65	73
I-5/Manchester	206.9	55.0	73	80	88.0	33.0	63	72

Many design guidelines for EDBs contain minimum requirements for length-to-width ratio of the basins. This requirement is normally predicated on the assumption that the basins are not well mixed and plug flow predominates at least some of the time. Figure 3-7 presents a comparison of average TSS concentration reduction and L:W ratio for the EDBs in this study. The basin with the shortest L:W ratio (Manchester) had substantially the same TSS removal as the basin with the largest ratio (I-5/SR-78). Consequently, there appears to be no significant advantage in designing basins with a ratio of greater than 3:1.

As with the other technologies, a linear regression analysis of influent and effluent concentrations was performed. Table 3-8 shows the expected concentration and the amount of uncertainty at the 90 percent confidence level for each constituent for both lined and unlined basins. The regression analysis was less effective at identifying an association between influent and effluent concentrations for the concrete lined basin. This was primarily the result of highly variable effluent quality at this site, with effluent concentrations higher than influent concentrations for a number of events. In addition, there were normally only about 13 data points for each constituent, while the other four sites combined had a total of about 55 points.

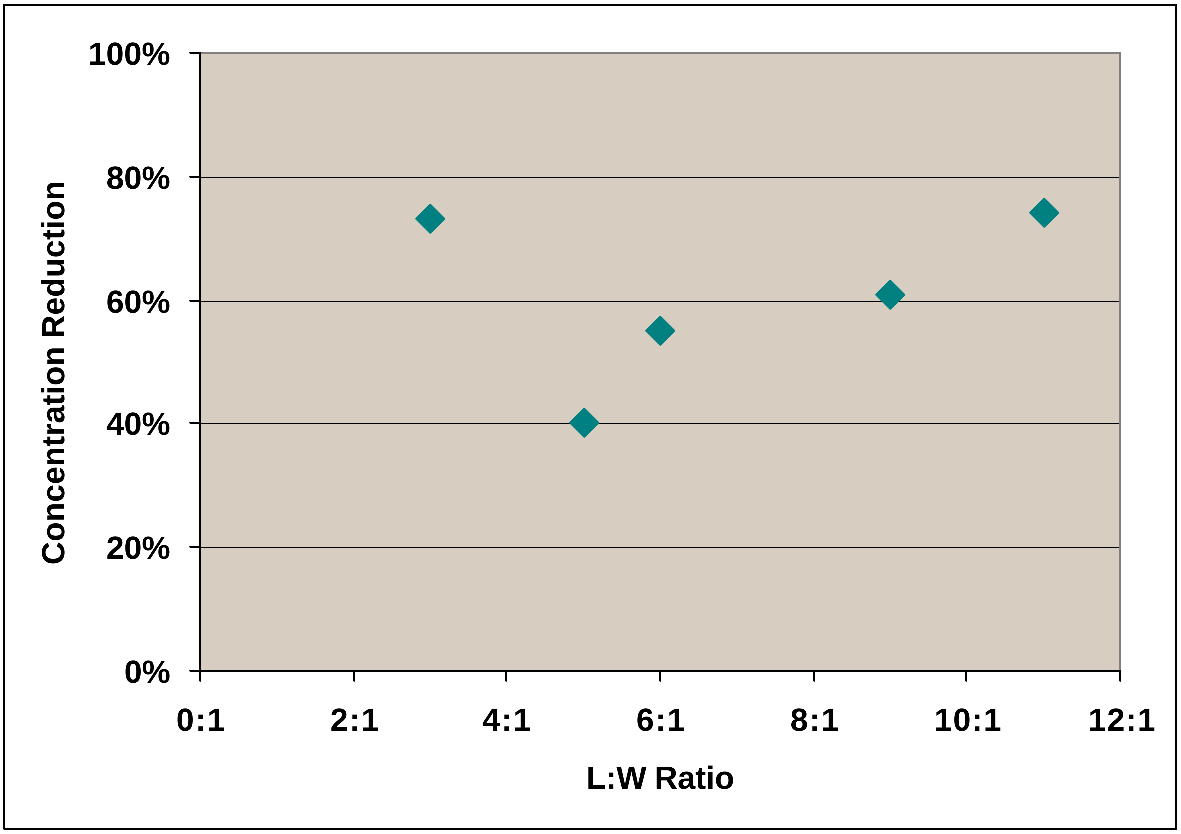


Figure 3-7 TSS Concentration Reduction as a Function of Length-to-Width Ratio in EDBs

3.5.2 Empirical Observations

Accumulation of trash and debris on the outlet riser was generally not found to be a problem. Floatable materials tended to accumulate on the shore downwind of the prevailing breeze. This was especially evident at the I-5/SR-56 site, where trash accumulated in the apex of the basin, away from the outlet. Consequently, placing the maintenance road in this area could facilitate access to the accumulated trash. In addition, locating the outlet structure upwind could further reduce the likelihood of clogging.

In general, sediment accumulated over the entire invert at each site with some concentration near the inlet of each basin. Resuspension of particles at the inlet of the basins was observed on several occasions including: five of the 32 inspections at the I-5/I-605 EDB, three of 32 inspections at the I-5/Manchester EDB and five of the 23 inspections at I-605/SR-91. At the I-5/I-605 basin, this was due to the lack of energy dissipation. There were very few occurrences of resuspension of particles near the basin outlets. At the I-5/I-605 basin, soil at the eastern slope near the freeway had eroded and accumulated in the EDB basin due to lack of vegetative cover.

Table 3-8 Predicted Effluent Concentrations – EDBs

Constituent	Unlined EDB: Expected Conc [a]	Unlined EDB: Uncertainty, ±	Lined EDB: Expected Conc [a]	Lined EDB: Uncertainty, ±
TSS	0.11x+23.6	$30.9\left(\frac{1}{55}+\frac{(x-139)^2}{498318}\right)^{0.5}$	57.1	28.3
NO_3-N	0.74x+0.19	$0.77\left(\frac{1}{57}+\frac{(x-1.06)^2}{35}\right)^{0.5}$	1.12x-0.16	$0.45\left(\frac{1}{13}+\frac{(x-0.93)^2}{8.72}\right)^{0.5}$
TKN	0.77x+0.20	$1.67\left(\frac{1}{58}+\frac{(x-2.21)^2}{78}\right)^{0.5}$	0.91x-0.15	$0.79\left(\frac{1}{13}+\frac{(x-2.11)^2}{52}\right)^{0.5}$
Particulate Phosphorus	0.10	0.03	0.15	0.11
Ortho-Phosphate	1.0x+0.02	$0.19\left(\frac{1}{31}+\frac{(x-0.11)^2}{0.166}\right)^{0.5}$	0.16	0.09
Particulate Cu	0.105x+5.8	$9.69\left(\frac{1}{56}+\frac{(x-38)^2}{58293}\right)^{0.5}$	7.6	2.04
Particulate Pb	0.15x+10.4	$135.2\left(\frac{1}{57}+\frac{(x-79.5)^2}{379984}\right)^{0.5}$	0.48x+12.7	$23.8\left(\frac{1}{13}+\frac{(x-38)^2}{10613}\right)^{0.5}$
Particulate Zn	0.05x+38.7	$66.5\left(\frac{1}{57}+\frac{(x-340)^2}{7672000}\right)^{0.5}$	47.9	15.4
Dissolved Cu	0.91x+1.3	$5.31\left(\frac{1}{57}+\frac{(x-12.4)^2}{2310}\right)^{0.5}$	1.14x-2.45	$5.89\left(\frac{1}{13}+\frac{(x-12)^2}{981}\right)^{0.5}$
Dissolved Pb	0.37x+1.18	$2.97\left(\frac{1}{57}+\frac{(x-3.4)^2}{739}\right)^{0.5}$	0.66x+0.30	$9.38\left(\frac{1}{13}+\frac{(x-7.5)^2}{1025}\right)^{0.5}$
Dissolved Zn	0.57x+19.1	$44.1\left(\frac{1}{57}+\frac{(x-68)^2}{198956}\right)^{0.5}$	0.64x+5.26	$31.1\left(\frac{1}{13}+\frac{(x-76)^2}{73533}\right)^{0.5}$

[a] Concentrations in mg/L except for metals, which are in µg/L

x = influent concentration of interest

On two occasions at the I-5/SR-56 basin, water was observed to be short-circuiting through the riprap berm that was constructed to increase the effective length to width ratio of the basin. During two events at the same site (events with rainfall greater than 38 mm), water was observed discharging into the standpipe overflow weir.

At the District 11 sites with the riser pipe outlet design, water was found to discharge through the riser pipe boltholes. This flow had an impact on the detention time, given the small diameter of the orifices used. Figure 3-8 shows the residence time for various volumes at the Manchester EDB based on the difference between the centroids of the influent and effluent hydrographs. The theoretical residence times were calculated by routing a synthetic hydrograph through the basin. The measured residence times were substantially longer than the theoretical residence times except for small storms. This was typical at all the extended detention basin sites. Regardless, the drain time of 48 to 72 hours was met for most of these events.

There were very few observations of clogging of the orifices at any of the EDB sites. The smallest orifice used in the District 11 sites had a diameter of 25 mm (1 in). In District 7, the smallest orifice was at the I-605/SR-91 basin where the orifice at the basin invert and had a diameter of 13 mm (½ in). Consequently, EDBs can be successfully implemented in relatively small drainage areas (0.40 ha).

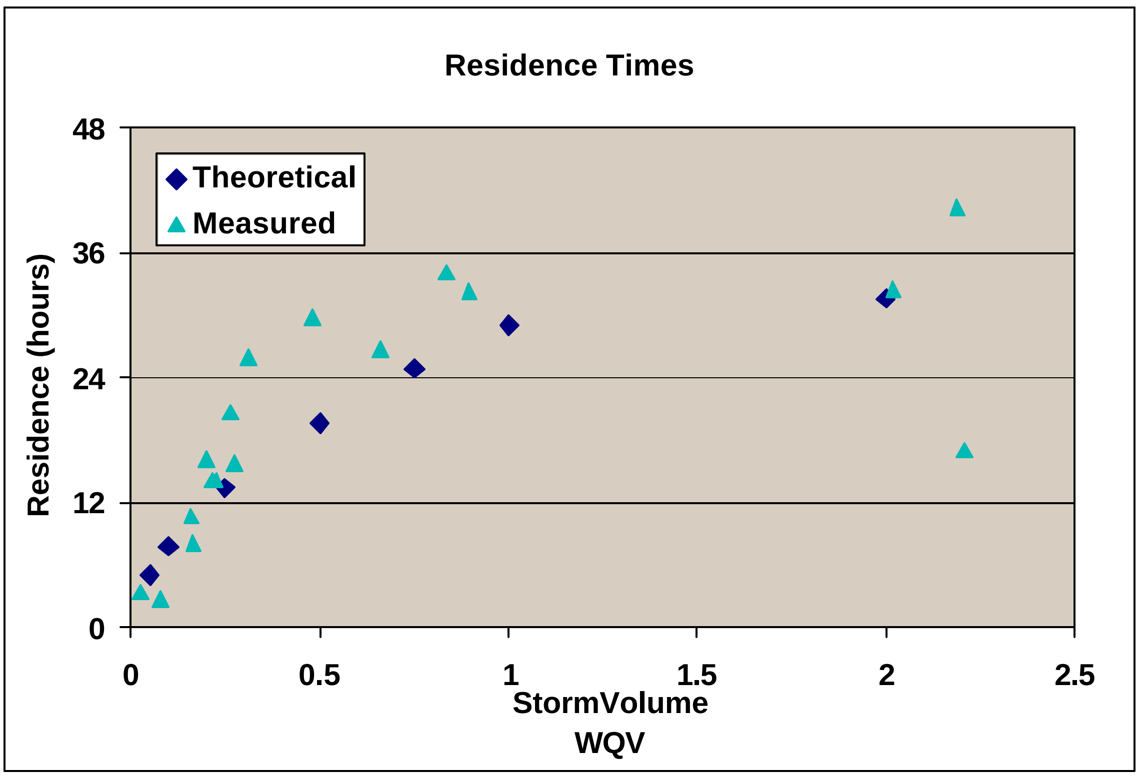


Figure 3-8 Theoretical vs. Measured Residence Time at Manchester EDB

3.6 Cost

3.6.1 Construction

Table 3-9 shows the actual construction costs with and without monitoring equipment and related appurtenances for each extended detention basin site. The table also presents the cost per cubic meter of water quality volume, using actual cost without monitoring.

The sites that had the smallest design volume, I-605/SR-91 and I-5/Manchester, had the largest cost per cubic meter treated. Part of the cost at the Manchester site is attributable to modifications of the storm drain system to increase the area contributing to the basin, which required an open cut across an active freeway ramp. The higher normalized costs for these sites tend to support the presence of economies of scale for EDBs. The I-15/SR-78 construction costs were higher due to the unsuitable material (broken concrete) and a resulting change order to remove the material ($715,605). The I-5/I-605 construction cost was higher than the cost of the I-605/SR-91 EDB primarily due to the cost of concrete for the basin lining ($46,200), and the access road needed around the I-5/I-605 site for access added additional cost.

Table 3-9 Actual Construction Costs for EDBs (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
I-5/I-605	169,732	127,202	348
I-605/SR-91	111,871	77,389	1,106
I-5/SR-56	161,853	143,555	367
I-15/SR-78	847,712	819,852	730
I-5/Manchester	370,408	329,833	1,304

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Table 3-10 presents the adjusted costs for detention basins. The reasons for adjusting the actual costs downward include:

- A significant number of buried man made objects were encountered at the I-15/SR-78 site. The additional work needed to remove the buried material would have increased the cost by 103 percent over the adjusted construction cost. This cost was excluded from the adjusted cost; instead, the average buried materials cost of similar BMPs was used.

- The I-5/I-605 location was constructed with a concrete liner. Including the cost of the liner would have increased the adjusted cost by 42 percent for that location. This cost was excluded from the adjusted cost.

- At the Manchester location, additional cost was incurred because the basin treated water from catchments on opposite sides of the basin and the runoff was diverted to a single influent point to minimize short-circuiting and to simplify influent for sampling. This resulted in greater than usual conveyance costs. Including the original conveyance cost would increase the adjusted construction cost for that location by 59 percent. The I-15/SR-78 location also incurred greater than usual conveyance cost, which would have increased the cost by 12 percent above the final adjusted cost. The original conveyance cost was not used to estimate the adjusted cost at either location; instead, the average conveyance cost of similar BMPs was used.

- Miscellaneous site-specific factors caused increased construction cost. This cost would have increased the adjusted cost by 8 percent at one location and 1 percent at another. These costs were excluded from the adjusted cost.

- At Manchester, higher than usual facility restoration costs were incurred due to an effort to establish trees. Including this cost would have increased the adjusted construction cost by 5 percent. This cost was excluded from the adjusted cost.

Table 3-10 Adjusted Construction Costs for EDBs (1999 dollars)

EDB	Adjusted Construction Cost, $	Cost/WQV $/m^3
Mean (5)	172,737	590
High	356,300	1,307
Low	91,035	303

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

Most of the EDBs were located adjacent to freeways that provided access to the construction sites. Consequently, traffic control costs were a significant budget item, accounting for 9 percent of the total EDB adjusted construction cost.

3.6.2 Operation and Maintenance

Table 3-11 shows the average annual operation and maintenance hours for each EDB. The table also provides a breakdown of average annual field labor hours and the average annual hours for equipment. Field hours include inspections, maintenance and vector control.

Table 3-11 Actual Operation and Maintenance Hours for EDBs

District	Site	Average Annual	
		Equipment Hours	**Field Hours**
7 (Los Angeles)	I-5/I-605	32	198
	I-605/SR-91	10	149
	Average Value	**21**	**174**
11 (San Diego)	I-5/SR-56	0	108
	I-15/SR-78	0	74
	I-5/Manchester	0	59
	Average Value	**0**	**80**

Table 3-12 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are comprised of the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 3-12 Actual Average Annual Maintenance Effort - EDB

Activity	Labor Hours	Equipment & Materials, $
Inspections	13	0
Maintenance	60	43
Vector control*	45	0
Administration	70	0
Direct cost	-	915
Total	**188**	**958**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate an EDB nor do they reflect the design lessons learned during the course of the study. Table 3-13 presents the expected maintenance costs that would be incurred under the final version of the MID for an EDB serving about 2 ha, constructed following the recommendations in Section 3.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Design refinements may eliminate the need for activities such as dewatering, and vector control. Only 4 hours are shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. This estimate also assumes that the facility is an earthen basin and vegetation maintenance is required. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Equipment generally consists of a single truck for the crew and their tools.

Table 3-13 Expected Annual Maintenance Costs for Final Version of MID – EDB

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	4	7	183
Maintenance	49	126	2,282
Vector control	0	0	0
Administration	3	0	132
Materials	-	535	535
Total	**56**	**$668**	**$3,132**

3.7 Criteria, Specifications and Guidelines

The extended detention basin technology has been previously researched and few additional research needs remain. This study found little correlation between length-to-width ratios from 3:1 to 10:1, and pollutant removal. Whether or not this performance would be achieved at lower ratios is unknown, and further work to explore this point may be warranted. If this specification could be relaxed, EDBs could be implemented at sites where a larger aspect ratio may be difficult to obtain.

Based on the results of this study, extended detention basins are considered technically feasible depending on site specific conditions.

This section discusses various guidelines for the siting, design, construction, operation and maintenance of EDBs. These guidelines are based on lessons learned through experience and observations during the project.

3.7.1 Siting

From the results of this study, the primary siting criteria recommended for future installations include the following:

- Provide adequate space for installation, maintenance activities, and safety considerations
- Contributing watershed area should be at least 2 ha to reduce fixed costs and minimize clogging potential of small orifices.
- An appropriate site evaluation should be done to identify unsuitable subsurface material and prevent costly contract change orders.
- Check for sufficient available hydraulic head to facilitate complete drainage after 72 hours and avoid ponding in the basin invert.

3.7.2 Design

Proper design of extended detention basins is imperative to improve performance, reduce maintenance, and reduce costs. Based on the observations and measurements in this study, the following guidelines are recommended:

- Locate, size, and shape EDBs relative to topography using terrain-fitting design to optimize use of available space and enhance appearance.
- Use earthen (unlined) basins where space is available and groundwater conditions permit because of their lower initial cost and better constituent removal; however, additional evaluation is needed since there is appreciable infiltration in the basins and the potential impacts on groundwater quality are unknown.
- Use a 72 hr drain time and a minimum 3:1 length-to-width ratio to provide constituent removal comparable to that reported for the best performing detention basins in other studies.
- Use earthen basin side slopes of 1:4 (V:H) or flatter. Where steeper side slopes are unavoidable, consider other slope stability measures where vegetation is difficult to establish.
- Include energy dissipation in the inlet design for all basins to reduce resuspension of accumulated sediment. The preferred design is poured-in-place concrete using

a design that does not have a permanent sump to eliminate standing water and associated vector problems.

- Use an outlet design with an orifice in a riser, surrounded by a screen mesh for debris control. Seal all boltholes in the riser pipe and outlet structure to prevent flow from leaking out other openings.
- Design inlet, outlet, and basin so that no standing water is present after 72 hours. This requires a positive slope in the basin invert of about 1 percent minimum.
- For sites with minimal positive slope of the basin invert (<1 percent), incorporate a concrete low flow channel to reduce the potential for standing water.
- If the side slopes exceed 1:4 (V:H), incorporate a ramp in the design to facilitate access to the basin floor for maintenance activities.
- Develop standard details for BMP items. Because BMP details are not standardized, greater detail is required than for typical Caltrans plans.
- Minimize paved access road consistent with maintenance vehicle turnaround and DHS requirements.
- For locations adjacent to active roadways, seek out and place high priority on traffic engineer's comments during design.
- Avoid above-ground structures near the roadway that will require a setback or guardrail protection.

3.7.3 Construction

Several issues arose during the construction of the detention basins, and lessons were learned on how to improve the construction. Listed below are guidelines that should improve the construction process:

- To minimize construction delays, verify manufacturing time for construction materials prior to specifying the product.
- Quality control is critical for drainage items with minimal slopes.
- Discuss with local maintenance staff to attempt to discern undocumented information on utility lines and other buried objects.
- Use a locally appropriate erosion control seed mix for the specific project and location.

3.7.4 Operation and Maintenance

Based on the level of maintenance required in this study, recommended future maintenance activities include:

- Perform inspections and maintenance as recommended in MID (Appendix D, Version 17), which includes inspection for standing water, slope stability, presence of burrows, sediment, trash and debris, and erosion control plantings.

- Observe drain time for the design storm after completion or modification of the facility to confirm that the desired drain time has been achieved. If necessary, modify the outlet orifice to achieve design values.

- Schedule semiannual inspection for the beginning and end of the wet season to identify potential operational problems.

- Remove accumulated trash and debris in the basin and around the riser pipe during the semiannual inspections. The frequency of this activity may be altered to meet specific site conditions.

- Trim vegetation at the beginning and end of the wet season and inspect monthly to prevent establishment of woody vegetation and for aesthetic and vector control reasons.

- Remove accumulated sediment and regrade about every 10 years or whenever the accumulated sediment volume exceeds 10 percent of the basin volume. Inspect the basin each year for accumulated sediment volume

- Follow maintenance plan in accordance with regulatory requirements to avoid the establishment of jurisdictional wetlands.

4 WET BASIN

4.1 Siting

One wet basin was sited in District 11 as part of this study. The site is located within the highway right-of-way and collects runoff from the northbound lanes of I-5. Siting requirements included:

- A high water table or other source of water to provide continuous baseflow
- A soil substrate ranging in texture from loam to clay
- Sufficient space for the basin, maintenance access, and a clear recovery zone

Table 4-1 summarizes the characteristics of the contributing watershed for the site selected. Identifying a location in southern California with perennial flow in the highway environment proved to be the most difficult criterion to meet. However, wetland vegetation can be sustained with interruption of baseflow for up to several months, meaning that sites receiving baseflow only during the wet season could be considered. The performance of this design alternative may differ substantially from that reported for the installation monitored in this study.

Table 4-1 Summary of Contributing Watershed Characteristics – Wet Basin

Site Location	Watershed Area Hectare	Impervious Cover %
I-5/La Costa	1.7	48

Since the basin was constructed in sandy material rather than in the preferred substrate, an impermeable liner was included in the design to improve the water-holding capability of the basin and ensure continuous circulation through the basin. To install the liner, the basin was over-excavated by 0.5 m and the liner was installed along the bottom and side slopes. The liner met the following criteria:

- Thickness: minimum 0.76 mm PVC
- Specific gravity: 1.30 ± 0.03 by ASTM D 792
- Tensile strength: 15 to 21 MPa by ASTM D 882 and D 412
- % elongation: 200 by ASTM D 882 and D 412
- Minimum width: 1.8 m

4.2 Design

The pilot is an off-line, earthen, extended wet detention pond and was designed for a full-basin (water quality volume) drawdown time of 24 hours. The facility is pictured in Figure 4-1. The site was designed with two separate cells: a forebay and a wet extended detention pond. The forebay was designed to accommodate approximately 25 percent of the total basin volume. Other forebay design criteria include:

- Reinforced slope protection for energy dissipation and flow dispersion
- Side slopes of 1:4 (V:H) and flatter for erosion control
- Shallow bench (0.30 m deep) around the sides of the forebay to enhance vegetation growth and public safety
- Gabion wall spillway to disperse the outflow evenly to the main pond
- Maintenance access road directly to the invert of the forebay
- Two separate inlets, one for the perennial source water and one for water quality design inflow

Figure 4-1 La Costa Wet Basin

The primary function of the wet basin is to create a potentially favorable environment for physical, biological, and chemical processes that reduce pollutants in stormwater runoff. Other elements incorporated into the current design include:

- A meandering flow path to increase residence time and provide a greater runoff-to-soil (and vegetation) interface;
- Side slopes of 1:3 (V:H) between the basin invert and the shallow bench for erosion control and increased wetted perimeter;
- A 1:6 (V:H) side slope around the sides of the wet basin to enhance vegetation growth and public safety and increase the littoral zone area;
- A diverse selection of plant species to enhance pollutant removal through filtration and biological uptake and degradation;
- Pond stocked with Gambusia affinis to minimize mosquito breeding;
- An expanded width near the outlet of the basin to further reduce velocity and trap finer sediment;
- Basin outlet designed to be submerged to prohibit floating material from discharging;
- A permanent pool volume equal to three times the water quality volume (see following discussion);
- An extended detention riser outlet designed to release the design storm over a period of 24 hours;
- A rock slope protected emergency overflow spillway at the maximum design water quality water surface; and
- A canal gate located in the water quality outlet structure to provide basin drainage; an additional canal gate was provided at the inlet structure to shut off the low flow for basin maintenance.

Inflow to the basin occurs at a single point, and treated runoff is discharged through a single orifice set at the permanent pool water surface elevation. A debris screen prevents the orifice from clogging. A canal gate at the basin invert is provided in the water quality outlet structure to drain the basin if the outlet orifice should clog. The weir of the water quality outlet structure riser was set at the 1 yr, 24 hr storage elevation. Surcharge from larger storms discharges over the rock slope protection spillway adjacent to the existing trapezoidal channel. Design characteristics for the basin are summarized in Table 4-2.

Table 4-2 Design Characteristics of the La Costa Wet Basin

Site	Type	Design Storm mm	WQV m^3	Permanent Pool Volume m^3	Avg. Perm. Pool Depth m
I-5/La Costa	Off-line	34	259	777	0.7

Through agreement with the plaintiffs, a deviation was made from the original design guidelines for the volume calculations of the permanent pool as outlined in the project Scoping Study (RBF, 1998a). This deviation resulted from the realization that the site could support a larger wet basin than required in the Scoping Study and that the larger size would incorporate some of the terrain-fitting concepts that improve the aesthetics of the device. According to the original guidelines, the permanent pool volume should equal the water quality volume, which is then increased by a factor of 10 percent to accommodate reduction in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. However, according to Young et al. (1996), a common requirement is that the permanent pool be three times the water quality volume. Since this requirement was larger, the permanent pool volume was designed using the larger volume to maximize constituent removal.

It should be noted that there are a wide variety of sizing recommendations for wet basins, some of which are shown in Table 4-3. These alternative guidelines would result in a smaller basin than that constructed at the La Costa site. Based on data from the National Urban Runoff Program (U.S. EPA, 1983), a smaller size may provide only slightly less pollutant removal than the design monitored here, while affording substantial cost savings. Additional research is needed to establish the relationship between permanent pool volume and pollutant removal, so that the most cost effective design can be identified.

Wet basin vegetation design consists of four planting zones, as shown in Figure 4-2. The designed water surface elevation affects zones 2 and 3, the shallow water bench and zone of periodic inundation, respectively. The shallow water bench was initially specified for vegetation planted in water depths of 150 to 300 mm. This zone was extended to the permanent pool water surface elevation. The zone of periodic inundation is the temporary water storage volume impounded between the permanent pool and the overflow weir (i.e., the water quality storage volume). Selection criteria for the plants included native species and those suitable for stormwater treatment.

Table 4-3 Comparison of Recommended Permanent Pool Volumes – Wet Basin

Rule	Volume for La Costa Site (runoff depth)
3 times the 1 yr, 24 hr storm (CT WQV)	45 mm (1.77 in.) built volume
Equal to the runoff from the San Diego design rainfall (15.2 mm)	6.7 mm (0.26 in.)
3 times a typical WQV of 13 mm of runoff	38 mm (1.5 in.)
3 times the mean storm runoff depth (17 mm)	22.4 mm (0.88 in.)
Equal to runoff from 6-month storm	11.2 mm (0.44 in.)
13 mm over the watershed	13 mm (0.5 in.)
13 mm over the impervious area	6.1 mm (0.24 in.)
2 weeks retention	13 mm (0.5 in.)

Contemporary design guidance for the geometry of the wet pond cross-section supports gradual side slopes transitioning to a main pond area with a depth of from 1 to 2 meters. Young et al. (1996) recommend: “Gradual side slopes [to] enhance safety and help prevent erosion and make it easier to establish dense vegetation.” Young further notes that slopes steeper than 1:3 (V:H) should be lined with riprap for stability with a preferred slope ratio of 1:10 (V:H), creating a littoral zone that accounts for 25 to 50 percent of the permanent pool surface.

The La Costa wet pond site generally met the open water and cross-section geometric guidelines described by Young. The pond established dense vegetation along the shoreline which likely played a role in precluding side slope erosion. Safety at the site was not a major concern since the principal pedestrian access routes were restricted by a chain-link fence.

A post-operation review of the site with representatives of the San Diego County Vector Control Agency was held to discuss the pond operation with respect to vector breeding and abatement. The Agency preferred limiting the shallow area of the pond (and by extension the amount of surface area occupied by vegetation) to reduce the potential habitat for mosquito breeding and enhance the access to the pond for vector control surveillance and abatement. A 1:2 (V:H) side slope ratio was recommended with a pond depth of from 1.1 to 1.9 meters to ensure permanent open water beyond the shore area.

In areas where pedestrian access is restricted or prohibited, steeper side slopes (1:2 (V:H)) may be a viable alternative. Erosion and bank sloughing concerns can likely be mitigated through the use of geotextiles. Vegetation density and surface area is expected to be reduced as compared to a pond developed using traditional design criteria. Reducing the quantity of vegetation may have a performance penalty since uptake will be reduced; however, sedimentation appears to be the primary removal mechanism for this BMP (Minton, 2002). Vegetation should still be periodically harvested to allow access for vector control personnel, to limit vector breeding opportunities and provide a mechanism for nutrient export rather than allowing the basin to fill with decaying organics.

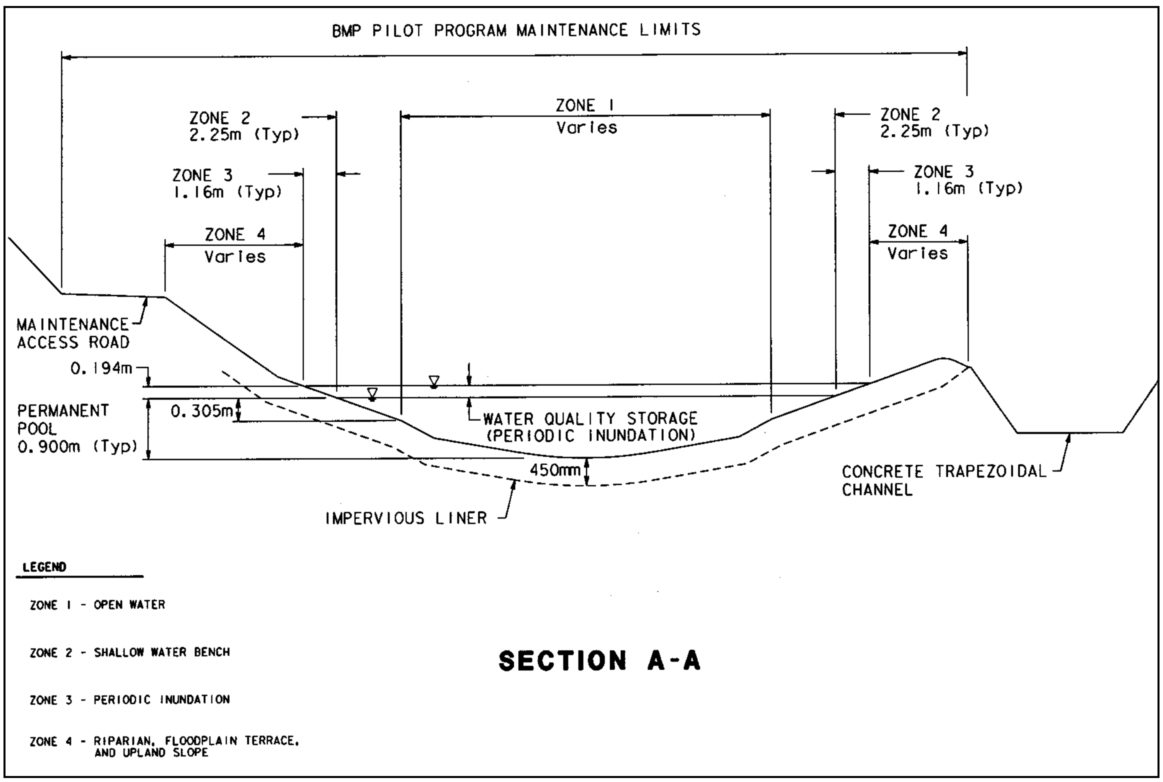


Figure 4-2 Cross-Section of La Costa Wet Basin

4.3 Construction

The main issues during construction of the wet pond centered around constructability and unknown field conditions.

4.3.1 Constructability

The primary issues related to the constructability of the wet pond were the delivery of specialized components such as canal gates and flumes, and the installation of the impermeable pond liner. In anticipation of a long lead-time for delivery, many specialized items were ordered prior to the start of construction; however, they still did not arrive on schedule.

Construction of the pond liner proceeded without incident but required specialized experience and subgrade preparation. Groundwater was encountered during the excavation and was drained by gravity to the adjacent open channel. The subgrade surface was graded with extra care to ensure a smooth homogeneous surface to preclude damage to the impermeable liner. A specialty contractor installed the liner and supervised the backfill operation (cover over the liner) to ensure that liner integrity was maintained.

4.3.2 Unknown Field Conditions

There were essentially no issues related to unknown field conditions associated with the wet pond. Groundwater was expected during the excavation and was encountered. Dewatering was accomplished by gravity drainage to a settling pond, where the water was pumped to a Baker™ tank prior to being discharged to the adjacent creek. A small amount of pyrite in the groundwater that was encountered during the excavation was determined to be non-hazardous.

The plans were modified to include a retaining wall 1.2 m high and 15 m long during construction along the northeast access road. Field conditions did not allow construction of the slope as shown on the drawings (the slope would have been locally over-steepened, a condition that did not show on the base topography); consequently, the wall was constructed to maintain the pond footprint as designed.

4.4 Maintenance

The wet basin was maintained at a state-of-the-art level through a formal maintenance program that is described in the MID. The site was inspected monthly for:

- General maintenance, including checking the inlet and outlet structures, side slopes and overall site for signs of erosion, woody vegetation, graffiti, and vandalism

- Indications of burrowing rodent activity that could endanger the structural integrity of the site
- Accumulation of trash and debris in the inlet and outlet structures
- Presence of endangered and/or threatened species or species of special concern
- Presence of vectors

To ensure that the wet basin met the required drain time of 24 hours for the design storm, the site was assessed after every monitored storm. The basin was inspected annually in May for plant coverage and density in Zone 1 (Figure 4-2) to ensure efficacy of vector abatement and quarterly in Zone 2. Sediment accumulation in the invert was inspected and characterized (based on hazardous thresholds) on approximately June 1 of each year. There were no deviations from the MID.

Figure 4-3 shows the average number of hours required to maintain the wet basin. An average of 388 hr/yr, not including vector control agency hours, was spent in the field completing inspections and maintenance at the site, making this device the most maintenance intensive of any of those evaluated in this study. The most time-consuming activities, totaling more than 350 hr/yr, were those associated with vegetation management. These activities were prompted by concerns of the vector control agencies that the dense vegetation in the shallow water zones hampered the ability of the mosquito fish to adequately control all mosquito larvae; however, vegetation harvesting had the additional benefit of removing nutrients from the system. Less time was required for activities related to collection of trash and debris, sediment removal or other items directly associated with basin performance.

Table 4-4 shows the number of occurrences of mosquito breeding and number of abatement actions that were taken. Mosquito larvae were frequently observed in the basin despite the presence of mosquito fish, which were introduced as predators.

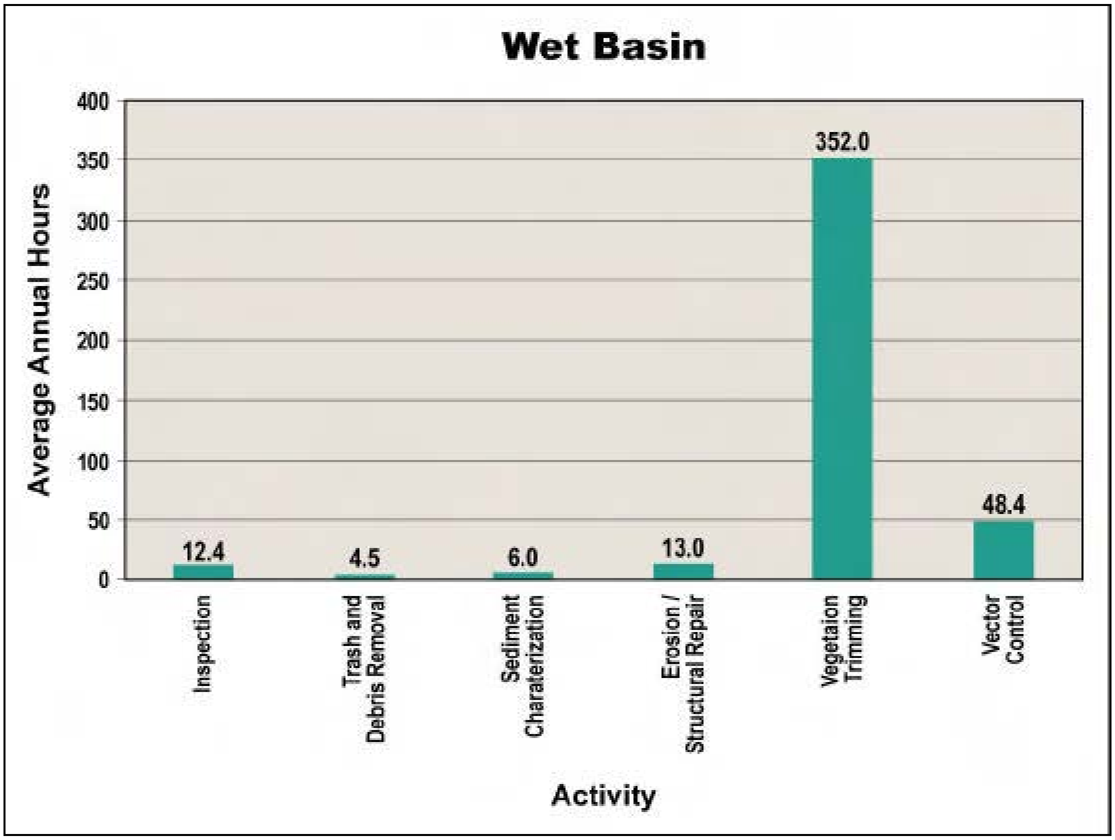


Figure 4-3 Field Maintenance Activities at Wet Basin (1999-2001)

Table 4-4 Incidences of Mosquito Breeding – Wet Basin

Site	Number of Times: Breeding Observed	Number of Times: Abatement Performed
I-5/La Costa	34	5

4.5 Performance

4.5.1 Chemical Monitoring

A summary of the wet weather water quality monitoring data is presented in Table 4-5, along with the probability that the average influent and effluent concentrations are not significantly different. The wet basin was best at removing particulate constituents including metals from stormwater, but was less effective at removing phosphorus, where the influent and effluent concentrations were not statistically different. TSS and total metals removals were the highest of any of the devices evaluated in this study. The reductions observed in this study exceed those reported by Winer (2000) for all constituents except total phosphorus. The lower performance for this constituent is likely related to the relatively high concentrations of phosphorus present in the permanent pool at the start of storm events.

Grab samples were collected from the influent and effluent and analyzed for each constituent under ambient (baseflow) conditions during the wet season. The results are shown Table 4-6. The concentration of suspended solids was low, and there was no additional removal. There was a reduction of nitrate, but the concentration of TKN increased. The mean baseflow effluent concentration of nitrate may be misleading since the magnitude of the reported value is largely a function of the large variance of the individual sample values. The geometric mean of those same samples is only 1.17 mg/L, rather than the mean of 7.9 mg/L shown in Table 4-6. The reported value for nitrate also reduces the total nitrogen reduction for baseflow conditions substantially.

During dry weather, nitrate concentrations decreased, TKN increased and the total nitrogen decreased. The reduction in nitrate concentration was likely caused mainly by plant uptake. The TKN may have increased during dry weather as plants decayed and fell into the water, adding organic nitrogen. The TKN increase was relatively small in this system as compared to the nitrate decrease, resulting in a net decrease in total nitrogen (estimated as the sum of nitrate and TKN) during dry weather. On an average annual basis, most of the nutrient removal occurred during dry weather rather than during storm events. This is consistent with one of the principles for the operation of this type of wet pond design, which is to effectively store 75 percent of the storm runoff in the permanent pool for an indefinite period of time, allowing for uptake by the basin vegetation. Subsequent harvesting of the vegetation then removes these constituents from the system, thereby providing a pollutant removal mechanism as demonstrated by the overall nitrogen reduction observed.

Table 4-5 Concentration Reduction of the Wet Basin for Storm Runoff

Constituent	Mean Storm EMC		Storm Removal %	Significance P
	Influent mg/L	Effluent mg/L		
TSS	210	14	94	<0.000
NO_3-N	2.79	0.65	77	0.029
TKN	3.01	2.20	27	0.260
Total N[a]	5.80	2.84	51	-
Ortho-phosphate	0.12	0.43	-266	0.237
Phosphorus	0.93	0.88	5	0.773
Total Cu	0.097	0.011	89	<0.000
Total Pb	0.294	0.006	98	<0.000
Total Zn	0.414	0.037	91	<0.000
Dissolved Cu	0.020	0.009	57	0.007
Dissolved Pb	0.009	0.002	76	0.045
Dissolved Zn	0.056	0.033	41	0.049
TPH-Oil [b]	4.8	3.0	38	0.651
TPH-Diesel [b]	3.3	0.3	91	0.169
TPH-Gasoline [b]	<0.050[c]	<0.050[c]	-	-
Fecal Coliform [b]	11700 MPN/100mL	100 MPN/100mL	99	0.213

Note- The concentrations are the mean of the EMCs for the entire monitoring period.
[a] Sum of NO_3-N and TKN
[b] TPH and Coliform are collected by grab method and may not accurately reflect removal
[c] Equals value of reporting limit

Table 4-6 Concentration Reduction observed in Wet Season Baseflow

Constituent	Mean Baseflow EMC		Baseflow Removal %	Significance P
	Influent mg/L	Effluent mg/L		
TSS	15.82	12.50	21	0.716
NO_3-N	15.52	7.85	49	<0.000
TKN	1.67	1.86	-11	0.548
Total N[a]	17.19	9.72	43	-
Ortho-phosphate	0.96	1.18	-24	0.714
Phosphorus	2.23	1.13	49	0.528
Total Cu	0.063	0.029	54	0.434
Total Pb	0.004	0.001	62	0.096
Total Zn	0.072	0.027	62	0.005
Dissolved Cu	0.053	0.005	90	0.010
Dissolved Pb	0.001	0.001	22	0.182
Dissolved Zn	0.058	0.032	45	0.006
TPH-Oil [b]	0.30	0.20	33	0.455
TPH-Diesel [b]	0.40	0.10[c]	75	0.370
TPH-Gasoline [b]	0.10[c]	0.10[c]	-	-
Fecal Coliform [b]	4400 MPN/100mL	20 MPN/100mL	99	0.251

[a] Sum of NO_3-N and TKN
[b] TPH and Coliform are collected by grab method and may not accurately reflect removal
[c] Equals value of reporting limit

A regression analysis was performed on the paired storm samples and the results are shown in Table 4-7. It is particularly interesting that effluent concentration is independent of influent concentration for almost all constituents at the 90 percent confidence level. At the 95 percent level, the relationship between influent and effluent TKN concentrations also is not statistically significant. Part of the lack of correlation may be the result of the relatively fewer samples collected at this single site compared to the BMPs implemented at several locations. However, much of the observed performance may be related to processes within the wet basin during storm events.

These data suggest that for wet ponds with a large permanent pool volume (3 times the volume of the 1 yr, 24 hr storm in this case) the primary process during periods of storm runoff is displacement of the permanent pool with some minor mixing with the influent runoff. This is suggested by the similarity in the effluent TSS concentrations during storms (14 mg/L) and dry weather (12.5 mg/L). Consequently, a one-way ANOVA was performed to compare the wet weather discharges to the ambient baseflow discharges during the wet season. This analysis indicated no significant difference between the effluent concentrations measured during storm events and those observed during dry weather for every constituent except total lead. The concentration of total lead in stormwater influent was approximately 70 times that observed in the influent during dry weather, which indicates that if the difference between ambient and stormwater influent concentrations is sufficiently large, then there is enough mixing to result in different effluent concentrations under dry and wet weather conditions.

Table 4-7 Predicted Effluent Concentrations – Wet Basin

Constituent	Expected Concentration [a]	Uncertainty, ±
TSS	11.8	4.0
NO_3-N	0.45	0.25
TKN	0.21x + 1.57	$1.44\left(\frac{1}{13}+\frac{(x-2.93)^2}{57}\right)^{0.5}$
Particulate P	0.21	0.06
Ortho-Phosphate	0.33	0.28
Particulate Cu	1.9	0.5
Particulate Pb	3.4	1.1
Particulate Zn	4.6	1.6
Dissolved Cu	8.7	3.1
Dissolved Pb	2.2	0.8
Dissolved Zn	32.8	7.8

[a] Concentrations in mg/L except for metals, which are in µg/L; *x* = influent concentration

The displacement model also explains the relatively low removals observed during wet weather for nitrogen and phosphorus. The baseflow influent concentrations shown for total nitrogen (17.2 mg/L) and total phosphorus (2.2 mg/L) in Table 4-6 are extremely high for surface water, and although the concentrations are reduced during the residence time within the pond, the concentrations are nearly as large as the concentrations in untreated highway runoff resulting in a calculated removal that is at the low end of the range reported by the U.S. EPA (1993). One might therefore expect a wide range of observed reductions for other studies, depending primarily on differences in the quality of the runoff that sustains the permanent pool.

Consequently, the expected effluent quality from a wet basin with a large permanent pool is determined primarily by the quality of the perennial flow that sustains the permanent pool and the transformations that occur to that water during its residence within the basin. This also suggests that a good estimate of the expected effluent quality during wet weather can be obtained by sampling the wet basin baseflow discharge during dry weather.

4.5.2 Empirical Observations

A sand bag berm was built in the dry weather flow inlet channel to help divert water into the wet basin for monitoring purposes (to maintain a precise dry weather pond volume). This low flow diversion berm was destroyed by the high flow rates during storm events larger than about 5 mm. There were observations of trash, sediment, and vegetation blocking influent outfall.

Vegetation re-growth after the harvest was rapid, contributing to the large number of hours required for vegetation management. The amount of open water space was approximately 55 percent in March 2001, nearly the same as before the harvest in August 2000. Consequently, major vegetation removal would be required every year to meet the expectations of the vector control agency.

4.6 Cost

4.6.1 Construction

Table 4-8 shows the actual construction costs with and without monitoring equipment and related appurtenances for the wet basin. The table also presents the cost per cubic meter of water quality volume, using actual cost without monitoring.

Table 4-8 Actual Construction Costs for Wet Basin (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
I-5/La Costa	708,526	691,496	2,670

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Adjusted construction costs for the wet basin are presented in Table 4-9. The major reasons for cost adjustment included:

- The wet basin was constructed with a liner to ensure no infiltration losses during the pilot program. Lining would increase the adjusted cost by 15 percent. Lining was required at this location because the baseflow was not sufficient to maintain the designed permanent water level considering all losses. This was a design decision for this wet basin in order to maintain a sufficient level to ensure a year-round wet pool; this, in turn, ensures conditions supportive of wetland vegetation. If groundwater contamination is not a concern and if site-specific conditions allow, a wet basin could be designed without a liner, while sustaining wetland vegetation during dry periods of some length. The liner cost was excluded from the adjusted cost.

- A lane closure throughout the wet basin construction caused greater than usual traffic control cost because grading and inlet construction was necessary up to the edge of pavement. The traffic control cost of similar BMPs was substituted for the original traffic control cost. Using the original traffic control cost would increase the adjusted cost by 8 percent. This added cost was excluded from the adjusted cost.
- A geogrid access road was installed. Using asphalt concrete (AC) pavement in lieu of geogrid for the access road would decrease the cost of the access road by 49 percent. Using geogrid in the cost analysis would increase the total adjusted cost by 5 percent. The cost of AC was substituted for the geogrid so that the increased cost due to installing geogrid was excluded from the adjusted cost.
- The site chosen had several large trees, which, along with a large footprint caused greater than usual clearing and grubbing cost. Including the original clearing and grubbing cost would increase the adjusted cost by 7 percent. This additional cost was excluded from the adjusted cost; instead, the average clearing and grubbing cost of similar BMPs was used.
- Greater than usual conveyance costs were incurred. Including the original conveyance cost would increase the adjusted construction cost by 7 percent. The original conveyance cost was not used to estimate the adjusted cost; instead, the average conveyance cost of similar basin type BMPs was used.
- Costs were incurred for monitoring flumes, other structures associated with the flumes, and the additional cost of stainless steel over alternative materials. If included, these costs would add 9 percent to the adjusted construction cost. These costs were excluded from the adjusted costs.
- Miscellaneous site-specific factors caused increased construction cost. This cost would increase the adjusted cost by 4 percent. These costs were excluded from the adjusted cost.

Table 4-9 Adjusted Construction Costs for Wet Basin (1999 dollars)

Wet Basin	Adjusted Construction Cost, $	Cost/WQV $/m^3
One Location	448,412	1,731

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

The traffic control costs at this site were particularly high due to the need to close a lane near the off-ramp for 6 months during construction. Consequently, the adjusted traffic control costs account for 6 percent of the adjusted construction cost.

As mentioned previously, there exist a number of suggested sizing criteria relating the permanent pool to the water quality volume, average storm at the site, and other factors. This basin was sized to provide a permanent pool equal to three times the water quality volume, which in this study was the runoff produced by the 1 yr, 24 hr storm. Design guidelines from other sources generally recommended a much smaller permanent pool often based on mean storm size at the site, rather than on the largest storm one would expect to occur annually. A smaller permanent pool would result in a less costly installation, while providing only slightly less pollutant removal (U.S. EPA, 1983).

4.6.2 Operation and Maintenance

All effort related to the operation and maintenance of the wet basin was compiled separately from the effort associated with sampling activities, empirical observations, and analysis of the water samples. On average, 436 hours were required for field activities annually, including inspections, maintenance and vector control activities. No specialized equipment was required for these activities. It is possible that the presence of endangered species could impact the schedule, effort and ability to perform maintenance over the long-term. Consultation with appropriate regulatory agencies on the issue of maintenance impacts should there be endangered species present was initiated and is ongoing to determine the scope of mitigation that would be required if endangered species took up harborage in the device.

Table 4-10 presents the cost of the requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are comprised of the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 4-10 Actual Average Annual Maintenance Effort – Wet Basin

Activity	Labor Hours	Equipment & Materials $
Inspections	13	0
Maintenance	376	0
Vector control*	48	0
Administration	49	0
Direct cost	-	2,148
Total	**486**	**$2,148**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate a wet basin under the latest version of the MID or reflect the design lessons learned during the course of the study. Table 4-11 presents the expected maintenance costs that would be incurred under the final version of the MID for a wet basin serving about 2 ha, constructed following the recommendations in Section 4.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Only 8 hours are shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. Labor hours have been converted to cost assuming a burdened hourly rate of $44 except for biological assessments when a rate of $70 was used (see Appendix D for documentation). Vector control hours were converted to cost assuming an hourly rate of $62. Equipment generally consists of a single truck for the crew and their tools.

Table 4-11 Expected Annual Maintenance Costs for Final Version of MID – Wet Basin

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	8	0	352
Maintenance	262	375	11,903
Vector control	12	0	744
Administration	3	0	133
Materials	-	4,500	4,500
Total	**285**	**$ 4,875**	**$17,632**

4.7 Criteria, Specifications and Guidelines

Based on the results of this study, wet basins are considered technically feasible depending on site specific conditions. This section discusses various guidelines for the siting, design, construction, operation and maintenance of wet basins. These are based on lessons learned through the experience and observations made during the project.

4.7.1 Siting

Based on the results of this study, the primary siting criteria recommended for wet basins include:

- A high water table or other source of water to provide baseflow sufficient to maintain the plant community and vector prevention attributes desired.
- The soil substrate should range in texture from loam to clay.
- Provide sufficient space for the basin, maintenance access, and a clear recovery zone.
- Perform a site evaluation to identify unsuitable material in the subgrade.
- BMP retrofit would benefit from early planning in reconstruction projects to take advantage of possible drainage system reconstruction, to direct additional flow to the site and to coordinate with the right-of-way acquisition processes to accommodate the land requirements for wet basins.
- To avoid costly linings, avoid locations where available baseflow is insufficient to circulate the basin considering all losses, including infiltration.

4.7.2 Design

Proper design of wet basins is imperative for performance, to reduce maintenance, and lower costs. Based on the observations and measurements in this study, the following guidelines are recommended:

- Locate, size, and shape wet basins relative to topography and provide extended flow paths to maximize their treatment potential.
- Use unlined basins where soil type and groundwater elevation permit because of their lower initial cost; however, additional investigation is needed to determine the potential impacts to groundwater quality.
- The 3:1 permanent pool to water quality volume ratio and 24 hr drain time for the water quality volume resulted in removal comparable to those reported for wet basins in other studies. Many other criteria for sizing the permanent pool have been recommended, which may reduce the facility size, while providing only slightly less pollutant removal. A 1:1 permanent pool to water quality volume ratio has been determined to be feasible by others but testing is needed to verify performance of less conservative designs.
- Include energy dissipation in the inlet design and a sediment forebay to reduce resuspension of accumulated sediment and facilitate maintenance.
- Design inlet structures to direct baseflow and runoff to the wet pond without interfering with the diversion stream hydraulics, or resulting in sedimentation.
- Include a concrete maintenance ramp in the design to facilitate access to the forebay for maintenance activities.
- Minimize paved access road consistent with maintenance vehicle turnaround and requirements for access to all parts of the basin for vector control.
- Select appropriate wetland vegetation to minimize the potential for formation of monocultures or introduction of invasive species that would increase maintenance.
- Consider 1:2 (V:H) side slopes where pedestrian access is restricted or prohibited
- Where side slopes steeper than 1:2 (V:H) are used, stabilize with a geotextile and prohibit run-on.

4.7.3 Construction

Several issues occurred during the construction of the wet basin and lessons were learned on how to improve the construction. Listed below are guidelines that should improve the construction process.

- Verify manufacturing time for construction materials prior to specifying the product to minimize delays.

- Seek out and place high priority on traffic engineer's comments during design for those sites adjacent to highways.
- Avoid above-ground structures near the roadway that will require a setback or guardrail protection.
- Consult with local maintenance staff to attempt to discern undocumented information on utility lines and other buried objects.

4.7.4 Operation and Maintenance

Based on the results of this study, recommended maintenance items include:

- Perform schedule inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes inspection for burrows, inspection for sediment and general maintenance inspection.
- Introduce mosquito fish and maintain vegetation to assist their movements to control mosquitoes, as well as to provide access for vector inspectors. An annual vegetation harvest in August appears to be optimum, in that it is after the bird breeding season, mosquito fish can provide the needed control until vegetation reaches late summer density, and there is time for regrowth for runoff treatment purposes before the wet season.
- Observe drain time for the design storm after completion or modification of the facility to confirm that the desired drain time has been obtained. If necessary, modify orifice to achieve design values.
- Schedule semiannual inspection in August and February to identify potential operational problems.
- Remove accumulated trash and debris in the basin at the middle and end of the wet season. The frequency of this activity may be altered to meet specific site conditions.
- Remove accumulated sediment in the forebay and regrade about every 10 years or when the accumulated sediment volume exceeds 10 percent of the basin volume. Inspect the basin each year for accumulated sediment volume.

5 INFILTRATION BASINS

5.1 Siting

Two infiltration basins were sited as part of this study. One site was located in District 7 at the I-605/SR-91 interchange and the other in District 11 at the offramp of southbound I-5 at La Costa Avenue. Both sites were located within the highway right-of-way and collected runoff exclusively from the highway (District 11) and from the highway and a maintenance station (District 7).

Site characteristics considered during the siting of the infiltration basins included:

- Hydrologic Soil Type A or B
- Minimum infiltration rate of 7 mm/hr
- Minimum separation between the basin invert and water table of 0.6 to 1.2 m
- Sufficient area for siting the infiltration basin
- Thirty-meter setback from structures foundations
- Maintenance access

The permeability of the soil was the most important characteristic in the siting of the infiltration basins. Fourteen sites were initially evaluated using a weighted decision matrix. Five sites with the best preliminary scores were the subjects of a detailed geotechnical investigation. Where test wells indicated sufficient separation between the anticipated basin invert and the water table, in-drill-hole field permeability tests were conducted. Table 5-1 shows the groundwater depth and permeability rates determined at these sites during this investigation.

Table 5-1 Infiltration Basin Permeability Rates

Site	Permeability mm/hr	Groundwater Depth *bgs, m
I-605 /SR-91	5.8	>9
I-5/La Costa	22.3	1.45
I-5/Manchester (E)	-	0.84
I-5/Manchester (W)	-	1.14
SR-78/I-15	0.9	9.14

*bgs = below ground surface

Two sites displayed acceptable infiltration capacities and water table levels, I-605/SR-91 in District 7 and I-5/La Costa Avenue. in District 11. The I-605/SR-91 location was considered to be only marginally acceptable; however, given the site's surplus available space and access characteristics, it was considered a suitable location. Table 5-2 summarizes the watershed characteristics for the chosen sites.

Table 5-2 Summary of Contributing Watershed Characteristics for Infiltration Basins

Site	Land Use	Watershed Area Hectare	Impervious Cover %
I-605/SR-91	Highway/MS	1.70	68
I-5/La Costa Avenue	Highway	1.30	72

5.2 Design

The design of the infiltration basins was based on infiltration rate, drain time, capture volume, groundwater separation distance, and proximity to adjacent structures. Additional factors considered in the design included basin shape, side slope ratio, maintenance access, vegetation type, inlet configuration and in-line or off-line configuration. Table 5-3 provides characteristics used to size each infiltration basin.

Table 5-3 Design Characteristics of the Infiltration Basins

Site	Design Storm mm	WQV m^3	Basin Design Depth m	Basin Invert Surface Area m^2
I-605/SR-91	25	432	0.22	1963
I-5/La Costa Avenue	33	407	0.90	450

The basins were designed to drain within 72 hours based on the infiltration rate and the water quality volume to be treated. Groundwater separation also has an effect on the drain time of the basins, so the basin inverts were designed to have a minimum 0.60-m separation from the seasonally high groundwater elevation. The basin floor was as flat as possible to ensure an even infiltration surface. The side slopes were 1:3 and 1:4 (V:H) for the I-605/SR-91 and I-5/La Costa Avenue sites, respectively.

An energy dissipation device was used at the inlet to reduce inflow velocities and to distribute flow evenly over the basin floor. The inlet pipe entered at the basin invert elevation to help prevent erosion.

The infiltration basins were designed to be off-line. At I-605/SR-91, a weir in the inlet structure was placed at an elevation so that once the design storm volume was captured, the excess runoff would be diverted away from the basin. At the I-5/La Costa Avenue basin the existing inlets were fitted with weir plates to accommodate the 1 yr storm peak discharge.

The initial designs were later modified to address problems identified at the sites. The sump used to dissipate energy at I-605/SR-91 had to be filled in because it became a breeding habitat for mosquitoes. At the I-5/La Costa Avenue basin modifications to the original design elevations were made to accommodate the higher groundwater elevation measured during construction. Figures 5-1 and 5-2 show the La Costa Avenue and I-605/SR-91 infiltration basins. A schematic diagram is presented in Figure 5-3.

Figure 5-1 I-5/La Costa Infiltration Basin

Figure 5-2 I-605/SR-91 Infiltration Basin

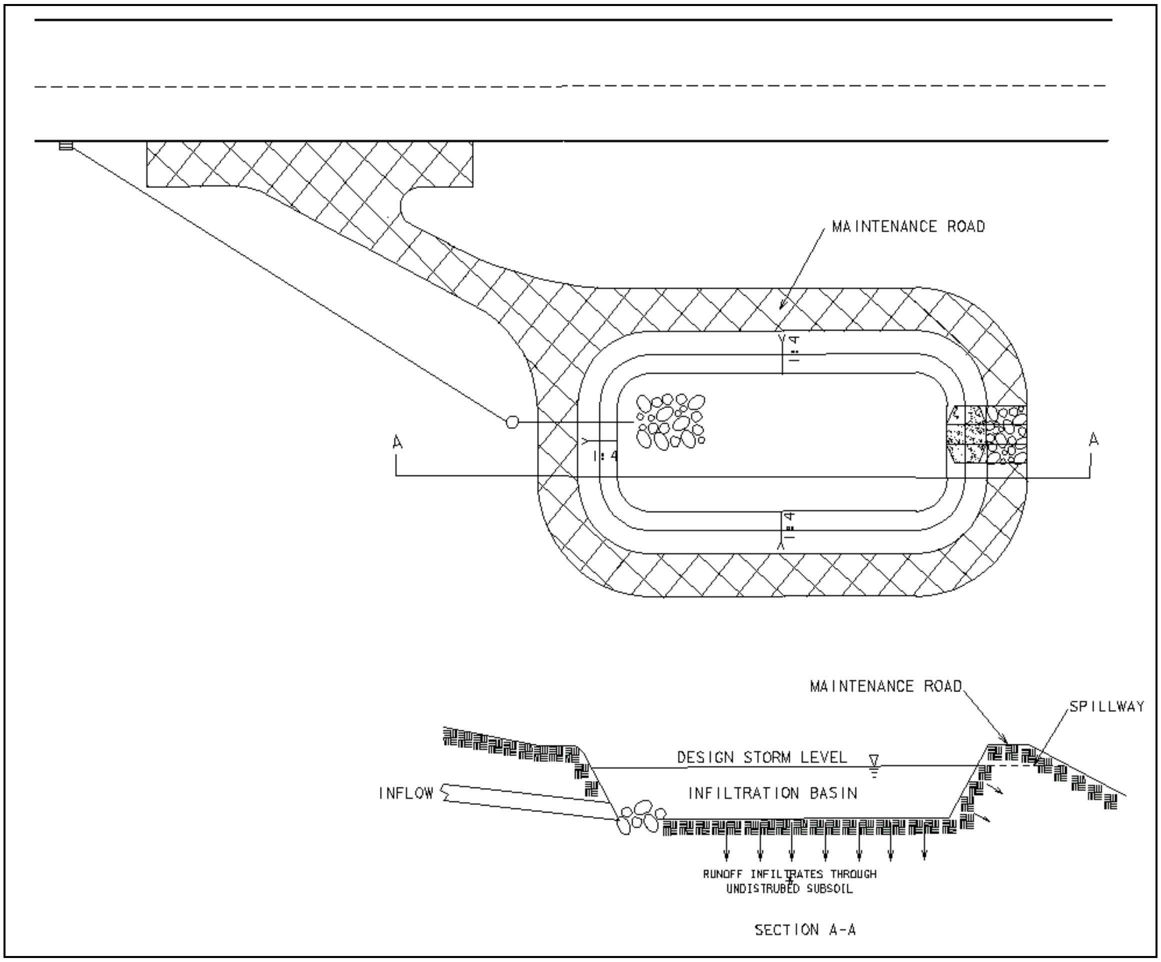


Figure 5-3 Schematic of Infiltration Basin

5.3 Construction

During construction of the La Costa Avenue infiltration basin, it was discovered that the groundwater was higher than previously measured. The basin invert was raised to an elevation of 2 m, 0.5 m higher than the original design to provide the minimum required separation between the invert of the basin and the measured groundwater elevation. The inlet to the basin from the storm drain system was also raised by the same amount. This realignment was accommodated in the remainder of the storm drain system by flattening the grade in the pipe.

Compaction of the soil during construction was avoided at each site to the greatest extent possible. Excavation of the basin was done from the sides rather than the basin floor. Only light equipment was used on the basin floor, and the floor was then tilled upon completion of excavation. Vegetation was established to help maintain and improve the infiltration capacity of the basin floor by root penetration.

5.3.1 Unknown Field Conditions

Problems with the excavation of the infiltration basins included excessive surface mulch, utility conflicts, and low relief. These problems were encountered at I-605/SR-91, where the variability in the thickness of a mulch layer was not detected during the design geotechnical investigation, requiring additional soil to be brought in to form the perimeter berm. An unknown temporary electrical system also was encountered, requiring additional efforts to protect the system during excavation. Also at I-605/SR-91, the runoff that was normally tributary to the basin site was not flowing through the existing outlet pipe because of blockage by soil. A new headwall was constructed to service the bypass flows from the basin.

As noted previously, the groundwater elevation rose substantially at the La Costa site from the time of the initial site investigation (December 1997) to the time of the start of construction (August 1998). The basin construction proceeded under marginal conditions; however, as construction was completed, the water table continued to rise, ultimately coming within about 0.3 m of the basin invert. The infiltration basin ultimately failed and a forensic analysis of the basin to determine the cause of failure was completed (URS, 1999a; see also Appendix B). The analysis indicates that the cause of failure was the high water table. Poor local soil conditions may have been a contributing factor.

5.3.2 Impacts to Freeways

During construction of the infiltration basin within the freeway right-of-way at La Costa Avenue, it was necessary to close a lane at night to install the storm drain located under the highway shoulder.

5.4 Maintenance

The sites were inspected monthly for:

- General maintenance needs, which included checking the inlet structure, side slopes, and overall site for signs of erosion, woody vegetation, graffiti, and vandalism
- Indications of burrowing rodent activity that could endanger the structural integrity of the site
- Coverage and effectiveness of vegetation planted for erosion control on the side slopes and basin invert
- Trash and debris accumulation in the inlet structures
- Presence of vectors

To ensure that the infiltration basins met the required drain time of 72 hours for the design storm WQV, each site was assessed after every target storm. The basins were inspected annually in September for vegetation coverage to ensure 70 percent coverage; annually in June to measure sediment accumulation in the invert; and characterized (based on hazardous material thresholds) on May 1 of each year. During the wet season, the infiltration basins were inspected weekly for endangered and threatened species and species of special concern. The basins were inspected for standing water annually on May 1.

As shown in Figure 5-4, the most significant field activity was trimming and removing vegetation, followed by structural repair, hydroseeding and inspections. The time required for inspections reflects the requirements of the MID. An average of 106 hours was spent on maintenance of the infiltration basin, not including the vector control agency hours. A net was placed over the La Costa Avenue infiltration basin so that the site did not become a habitat for fairy shrimp, a federally listed endangered species that can be transported by birds. The presence of fairy shrimp may have precluded maintenance and operation activities at the site. The net was required since the basin did not meet the design drain time due to high groundwater.

Table 5-4 shows the number of observations of mosquito breeding at the infiltration basins along with the number of abatements performed. Because the La Costa Avenue infiltration basin failed to drain completely, it was stocked with mosquito fish to help reduce the breeding. Breeding at the I-605/SR-91 site occurred in the inlet structure stilling well, which was subsequently filled with concrete, thus eliminating this problem.

GLACVCD monitored the I-605/SR-91 infiltration basin and SDCoVC monitored the I-5/La Costa infiltration basin. GLACVCD had a more aggressive approach in abatement of mosquitoes. Since the I-5/La Costa Avenue infiltration basin was located near Batiquitos Lagoon, SDCoVC performed mosquito abatement less frequently.

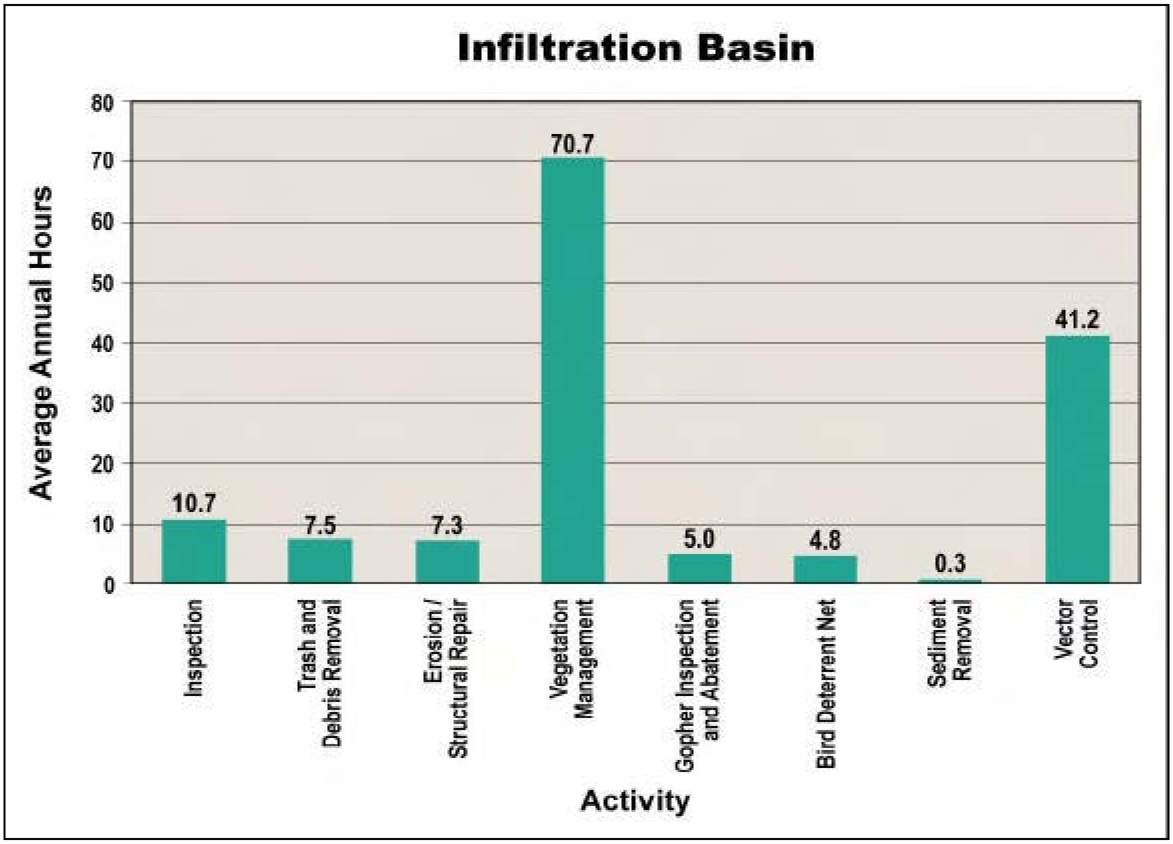


Figure 5-4 Field Maintenance Activities at Infiltration Basins (1999-2001)

Table 5-4 Incidences of Mosquito Breeding – Infiltration Basins

District	Site	Number of Times	
		Breeding Observed	Abatement Performed
7 (Los Angeles)	I-605/SR-91	3	3
11 (San Diego)	I-5/La Costa Avenue	37	3

5.5 Performance

5.5.1 Chemical Monitoring

Constituent removal is considered to be 100 percent for infiltration devices when the entire WQV is infiltrated and no water is discharged to surface waters. However, bypass can occur fairly regularly if the design storm selected for treatment is not sufficiently large. Bypass flows were not monitored as part of this study.

Baseline groundwater sampling was conducted prior to construction and during operation of the infiltration basins. However, it is difficult to interpret groundwater movement and due to the relatively short time frame of the project it is not possible to draw any conclusions from the data.

Core samples in the infiltration basins were collected to determine the rate at which constituents were transported into the subsurface. Samples of soil were collected from depths of 0.3 m and 0.6 m and were analyzed for zinc, lead, copper, and total petroleum hydrocarbons. An initial sample was collected from the I-605/SR-91 IB site when construction was completed in January 1999. Additional samples were collected there in June 2000 and May 2001. There was little difference in results from the samples. However, the pilot study may not be of sufficient duration to fully discover the potential for pollutants to be transported within the site soil. The average concentrations determined in these tests are shown in Table 5-5.

Table 5-5 I-605 / SR-91 Infiltration Basin Soil Samples

Constituent	Soil Sample Concentration (mg/kg)								
	Depth 0.0-0.2 m			Depth 0.3-0.5 m			Depth 0.6-0.8 m		
	Jan 1999	Jun 2000	May 2001	Jan 1999	Jun 2000	May 2001	Jan 1999	Jun 2000	May 2001
Total Cu	Na	22.8	20.1	19.5	16.1	16.4	15.5	16.1	12.7
Total Pb	Na	39.4	6.7	5.1	3.4	6.4	3.8	3.5	3.5
Total Zn	Na	54.4	46.9	45.9	35.8	42.2	39.9	36.6	31
TRPH	Na	<10[a]	<333[a]	<10[a]	<10[a]	<333[a]	<10[a]	<10[a]	<333[a]

[a] Detection Limit. The DL of 10 is based upon use of Freon and the IR method. This cannot be achieved with hexane and gravimetric procedures used after June 2000.

5.5.2 Empirical Observations

During and after each target storm event, observations were made at the infiltration basin sites. The most notable observation was that the La Costa Avenue site was not draining within 72 hours. Water remained in the La Costa Avenue infiltration basin continuously, only drying up in the summer months. The top 0.3 m of soil over the center of the basin was over-excavated and backfilled with more permeable material shortly after completion of construction to try to remedy this situation; however, the basin held water continuously during and for weeks following the wet season.

The I-605/SR-91 infiltration basin functioned as designed. The maximum measured drain time was 34 hours. The basin did bypass runoff during seven events that were larger than the design storm. Before the start of the 2000-2001 wet season, the overflow weir plate height was increased to the maximum height to minimize the flow bypass. Some sediment deposition was noted near the inlet but no noticeable deposition occurred in other areas of the basin. Some minor erosion was noted on the north side slope. The vegetation coverage was good over the duration of the period of the study.

5.6 Cost

5.6.1 Construction

Table 5-6 shows the actual construction costs with and without monitoring equipment and related appurtenances for each infiltration basin site. The table also presents the cost per cubic meter of water treated, using actual cost without monitoring.

Table 5-6 Actual Construction Costs for Infiltration Basins (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
I-605/SR-91	268,130	267,980	620
I-5/La Costa	272,676	267,724	658

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Table 5-7 presents the adjusted costs for the infiltration basins. The major reasons for cost adjustment included:

- At the I-605/SR-91 site, a significant overburden of landscaping mulch, along with a large footprint, caused greater than usual clearing and grubbing costs. Including the original clearing and grubbing cost would increase the adjusted cost by 14 percent. This additional cost was excluded from the adjusted cost; instead, the average clearing and grubbing cost of similar BMPs was used.

- The I-605/SR-91 site incurred greater than usual traffic control cost. Including the original traffic control cost would increase the adjusted cost by 7 percent. This additional cost was excluded from the adjusted cost; instead, the average traffic control cost of similar BMPs was used.

- Greater than usual conveyance costs were incurred at the La Costa Avenue location. Including the original conveyance cost would increase the adjusted construction cost by 63 percent. The original conveyance cost was not used to estimate the adjusted cost at either location; instead, the average conveyance cost of similar BMPs was used.

- Costs were incurred for monitoring flumes, other structures associated with the flumes, and the additional cost of stainless steel over alternative materials. These costs were excluded from the adjusted costs. If these costs were included, the adjusted construction cost would increase by 6 percent.

- The costs of miscellaneous site-specific factors caused increased construction cost. This cost would increase the adjusted cost by 2 percent at one location and 28 percent at another. These costs were excluded from the adjusted cost.

Table 5-7 Adjusted Construction Costs for Infiltration Basins (1999 dollars)

Infiltration Basins	Adjusted Construction Cost, $	Cost/WQV $/m^3
Mean (2)	155,110	369
High	171,707	397
Low	138,512	340

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

Construction access for future infiltration basins sites likely will be from active freeway lanes; consequently, adjusted traffic control costs are a significant budget item, accounting for 18 percent of the total infiltration basin adjusted construction cost. Traffic control costs were particularly high at the I-605/SR-91 site where a lane was taken for 6 months during construction.

5.6.2 Operation and Maintenance

The I-5/La Costa Avenue infiltration basin became operational on January 24, 1999, and received reduced monitoring after the first storm event, since the basin never completely drained during the wet season. The infiltration basin received only empirical observations for the remainder of the study. The operation and maintenance hours are provided for the two sites in Table 5-8. Field hours include inspections, maintenance and vector control.

Table 5-8 Actual Operation and Maintenance Hours for Infiltration Basins

Site Name	Average Annual Equipment Hours	Average Annual Field Hours
I-605/SR-91	52	205
I-5/La Costa	0	90

Table 5-9 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 5-9 Actual Average Annual Maintenance Effort – Infiltration Basin

Activity	Labor Hours	Equipment & Materials $
Inspections	11	-
Maintenance	95	156
Vector control*	41	-
Administration	91	-
Direct cost	-	2,969
Total	**238**	**$3,125**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown in Table 5-9 do not correspond to the effort that would routinely be required to operate an infiltration basin or reflect the design lessons learned during the course of the study. Table 5-10 presents the expected maintenance costs that would be incurred under the final version of the MID for an infiltration basin serving about 2 ha, constructed following the recommendations in Section 5.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Design refinements will eliminate the need for activities such as vector control. Only one hour is shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. This estimate also assumes that vegetation maintenance is required. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Equipment generally consists of a single truck for the crew and their tools.

Table 5-10 Expected Annual Maintenance Costs for Final Version of MID – Infiltration Basin

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	52	127	2,415
Vector control	0	0	0
Administration	3	0	132
Materials	-	435	435
Total	**56**	**$562**	**$3,026**

5.7 Criteria, Specifications and Guidelines

This section provides guidance on siting and design of infiltration basins based on lessons learned during the siting, design, construction, operation and maintenance of the infiltration basins. Additional criteria and guidelines for siting of infiltration devices can be found in Appendices A and B. The parties in this study worked cooperatively to develop interim guidelines for siting infiltration basins to respond to requests by the State Regional Water Quality Control Boards; however, determination of whether there is a potential threat to groundwater quality requires further investigation. Based on the findings of this study, infiltration basins can be technically feasible for use on Caltrans facilities; however, two important questions remain unanswered. The primary research question left unresolved is the potential impact of the infiltrated runoff on groundwater quality. Additional study of these potential impacts is certainly warranted. In addition, further study of the pilot installations is recommended to better establish the expected life of these devices and the long-term cost of operation and maintenance.

5.7.1 Siting

The key element in siting infiltration basins is identifying sites with appropriate soil and hydrogeologic properties. Because of problems with the performance of the La Costa Avenue site, a peer review study was conducted to determine the cause of failure (URS, 1999a). The peer review study concluded that under ideal conditions an infiltration basin with an infiltration rate as low as 11 mm/hr and a groundwater separation of only 0.6 m would drain within 72 hours (or 7 mm/hr if the separation is at least 1.2 m). Because of the variability in soil textures at a site, it would be prudent to add a margin of safety to these numbers. In addition, guidance manuals in other areas are now recommending a minimum infiltration rate of 12 mm/hr. Preliminary selection criteria for infiltration basins should include:

- Determine the soil type (consider RCS soil type 'A, B or C' only) from mapping and consult USDA soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil shall not have more than 30 percent clay or more than 40 percent clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.

- Groundwater separation should be at least 1.2 m from the basin invert to the measured groundwater elevation. However, 3 m of separation is preferred. If groundwater separation is less than 3 m, secondary screening should be conducted as described below. There is concern at the state and regional levels of the impact on groundwater quality from infiltrated runoff.

- Site area sufficient for the basin footprint and 9 m setback from the edge of traveled way, calculated by assuming an infiltration rate and checking the area required according to the method provided below.

- Locate the site away from buildings, slopes and highway pavement (greater than 6 m) and wells and bridge structures (greater than 30 m). Sites constructed of fill, having a base flow or with a slope greater than 15 percent, should not be considered.

- Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.

- Assure there is adequate maintenance access available.

- Base flow should not be present in the tributary watershed.

Secondary screening methods based on site geotechnical investigation are listed below.

- If a more detailed investigation to determine the groundwater elevation is required per the guidance above, establish at least two monitoring wells, one near the basin but down gradient by no more than approximately 10 m and the other within the proposed basin footprint. The two wells shall be observed over a wet and dry season; this observation period shall be extended to a second wet season if the initially observed wet season produces rainfall less than 80 percent of that in a normal year. The minimum acceptable spacing between the proposed infiltration basin invert and the seasonal high water table, as measured at either of the two established monitoring wells, is 1.2 m. A registered engineer or geologist must oversee the detailed investigation, and must also consider other potential factors that may influence the groundwater elevation such as local or regional groundwater recharge projects, future urbanization or agriculture. The geotechnical engineer shall also examine the soil borings for indications of previous high water.

- At least three in-hole conductivity tests shall be performed using USBR 7300-89 or Bouwer-Rice procedures (the latter if groundwater is encountered within the boring), two tests at different locations within the proposed basin and the third down gradient by no more than approximately 10 m. The tests shall measure permeability in the side slopes and the bed within a depth of 3 m of the invert.
- The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 13 mm/hr. If any test hole shows less than the minimum value, the sites shall be disqualified from further consideration.
- Use the minimum measured value of hydraulic conductivity multiplied by a safety factor of 0.5 to determine basin invert area.
- Exclude from consideration sites constructed in fill or partially in fill unless no silts or clays are present in the soil boring. Fill tends to be compacted, with clays in a dispersed rather than flocculated state, greatly reducing permeability.
- The geotechnical investigation should be such that a good understanding is gained as to how the stormwater runoff will move in the soil (horizontally or vertically), and if there are any geological conditions that could inhibit the movement of water.

5.7.2 Design

Based on the observations and measurements in this study, the following guidelines are recommended:

- Locate, size and shape the infiltration basin relative to topography.
- Provide pretreatment if sediment loading is a maintenance concern for the basin.
- Include energy dissipation in the inlet design for the basins. The preferred design is poured-in-place concrete using a design that does not have a permanent sump to reduce opportunity for standing water and associated vector problems.
- Configure basin so the last water to infiltrate stands in a small area with good accessibility so that maintenance is confined to a smaller location.
- Minimize paved access road consistent with maintenance vehicle turnaround and requirements of vector control agencies.

- Determine the basin invert area using the following equation:

$$A = \frac{WQV}{kt}$$

where A = Basin invert area (m^2)

WQV = water quality volume (m^3)

k = 0.5 times the lowest field-measured hydraulic conductivity (m/hr)

t = drawdown time (hr)

- Do not use vertical piping, either for distribution or infiltration enhancement to avoid device classification as a Class V injection well per 40 CFR146.5(e)(4).

5.7.3 Construction

Listed below are guidelines that should improve the construction process:

- Sufficient borings should be made before the job is put out for bid to determine the presence of any subsurface unsuitable materials and consequently to avoid the delays and expense incurred with contract change orders.
- Before construction begins, stabilize the entire area draining to the facility. If impossible, place a diversion berm around the perimeter of the infiltration site to prevent sediment entrance during construction.
- Place excavated material such that it cannot be washed back into the basin if a storm occurs during construction of the facility.
- Build the basin without driving heavy equipment over the infiltration surface. Any equipment driven on the surface should have extra-wide (“low pressure”) treads or tires. Prior to any construction, rope off the infiltration area to stop entrance by unwanted equipment.
- After final grading, till the infiltration surface deeply.
- Use appropriate erosion control seed mix for the specific project and location.

5.7.4 Operation and Maintenance

Recommended operation and maintenance guidelines include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes ensuring vegetation of the basin side slopes and invert, inspection for standing water, trash and debris, sediment accumulation, and slope stability.

- Observe drain time for the design storm after completion or modification of the facility to confirm that the desired drain time has been obtained.
- Schedule semiannual inspections for the beginning and end of the wet season to identify potential problems.
- Remove accumulated trash and debris in the trench at the start and end of the wet season.
- Inspect for standing water at the end of the wet season.
- Trim vegetation at the beginning and end of the wet season to prevent establishment of woody vegetation and for aesthetic and vector reasons.
- Inspect for minimum 70 percent vegetation coverage in the basin before the start of the wet season and reseed/replant as necessary.
- Remove accumulated sediment and regrade when the accumulated sediment volume exceeds 10 percent of the basin.
- If erosion is occurring within the basin, revegetate immediately and stabilize with an erosion control mulch or mat until vegetation cover is established.
- To avoid reversing soil development, scarification or other disturbance should only be performed when there are actual signs of clogging, rather than on a routine basis. Always remove deposited sediments before scarification, and use a hand-guided rotary tiller, if possible, or a disc harrow pulled by a very light tractor.

6 INFILTRATION TRENCHES

6.1 Siting

Two infiltration trenches were sited as part of this study. One site was located in District 7 at the Altadena Maintenance Station and the other in District 11 at the Carlsbad Maintenance Station. All runoff to the trenches originated within the maintenance stations.

Several criteria were used to site the infiltration trenches, including:

- Hydrological Soil Type A or B
- Minimum infiltration rate of 7 mm/hr
- Minimum separation between the basin invert and water table of 0.6 to 1.2 m
- Sufficient area for siting the infiltration trench
- 30-m setback from foundations
- Maintenance access

The permeability of the soil was the most important consideration in the siting of the infiltration trenches. Initially, 37 sites were evaluated using a weighted decision matrix. Eight sites with the best preliminary scores were the subjects of a detailed geotechnical investigation. In-drill-hole field permeability tests were conducted at the selected sites to determine if the soils had suitable infiltration rates and groundwater separation. Table 6-1 shows the permeability rates determined at these sites.

Table 6-1 - Infiltration Trench Permeability Rates

Site and District	Permeability mm/hr	Groundwater Depth m
Altadena – D7	39.6	> 10
Carlsbad – D11	31.3	> 5
Cerritos – D7	2.7	> 9
Cerritos – D7	5.8	> 9
Escondido – D11	-	0.9
Kearny Mesa – D11	0.08	>15
San Fernando D7	0.08	> 6
Tarzana – D7	0.12	>15
Westdale – D7	0.01	>15

Two sites demonstrated acceptable infiltration capacities and water table levels, Altadena MS and Carlsbad MS. Table 6-2 shows a summary of the watershed characteristics for the selected sites.

Table 6-2 Summary of Contributing Watershed Characteristics for Infiltration Trench

Site	Watershed Area Hectare	Impervious Cover %
Altadena MS	0.7	100
Carlsbad MS	0.7	100

6.2 Design

The design of the infiltration trenches was based on infiltration rate, drain time, and water quality volume. Additional criteria for design included trench shape, dimensions, and rock matrix specifications. Table 6-3 provides lists the characteristics of each infiltration trench.

Table 6-3 Design Characteristics of the Infiltration Trenches

Site	Design Storm mm	WQV m^3	Trench Depth m	Bottom Surface Area m^2
Altadena MS	25	172	3	161
Carlsbad MS	33	83 *	4	94

*Carlsbad MS infiltration trench was sized per Caltrans Stormwater Quality Handbook for 83 m^3; however, the WQV based on the 1 yr, 24 hr storm is 222 m^3.

The trenches were designed to drain within 72 hours. Since groundwater separation affects the drain time of the trenches, a minimum separation of 1.2 m was desired. The inverts of the trenches were more than 5 m from the water table. Two different consultants designed the two trenches and used different methods to determine trench size. Both approaches are legitimate.

The Altadena trench was sized using the following equation:

$$WQV = A * i * C$$

where

WQV = water quality volume (m^3)

A = drainage area (m^2)

i = m. of rainfall (m)

C = runoff coefficient

The trench volume was determined by assuming the WQV would fill the 35 percent void space. This volume was divided by the infiltration rate and drain time to determine what bottom surface area would be needed to drain the trench within 72 hours.

$$SA = \frac{V}{I * t}$$

where

SA = bottom surface area (m^2)

V = volume of trench (m^3)

I = infiltration rate (m/hr)

t = time to drain (72 hr)

The volume divided by the bottom surface area determined the depth.

$$d = \frac{V}{SA}$$

where

d = Depth (m)

V = Volume of trench (m^3)

SA = Bottom surface area (m^3)

The Carlsbad trench was sized per the Caltrans *Storm Water Quality Handbook*, (Caltrans, 1996) PDIIB (1), storm volume chart. Based on Zone 1, Riverside, and

100 percent impervious area (a conservative assumption), the unit basin storage volume was 119.2 m^3/ha. The basin storage volume was determined by the equation:

$$V = 119.2\ m^3/ha * \text{Catchment Area}$$

The trench volume was determined by assuming that 30 percent void space would remain after filling the trench with rock, which was the recommendation of the supplier. The site constraints for the trench were a width of 2 m and length of about 45 m. The depth was determined by dividing the volume by the surface area, as shown in the previous equation. The time to drain was determined by dividing the WQV by the infiltration rate. The recommended maximum depth for an infiltration trench is 2.5 m (Schueler, 1987), but both trenches were deeper than this recommended value because of horizontal area sizing constraints.

The trench rock specified for each infiltration trench was originally 25 mm to 75 mm but was changed to 100 mm minus, a locally available rock. The exact specification is shown in Table 6-4. There is a difference in the rock specified for each infiltration trench, but differences in trench rock size have little effect on the void space available.

Table 6-4 Infiltration Trench Rock Specifications

Carlsbad MS		Altadena MS	
Sieve Size mm	**% Passing**	**Sieve Size mm**	**% Passing**
100	100	75	100
75	50-80	38	87-100
50	0-20	25	30-65
37.5	0-5	19	0-12

A biofiltration strip was designed to intercept runoff before it entered the infiltration trench at each location. The strips were to provide pretreatment by removing sediment. Shown in Figures 6-1 and 6-2 are the infiltration trenches and associated biofiltration strips. Figure 6-3 presents a schematic diagram of an infiltration trench.

Figure 6-1 Carlsbad Maintenance Station

Figure 6-2 Altadena Maintenance Station

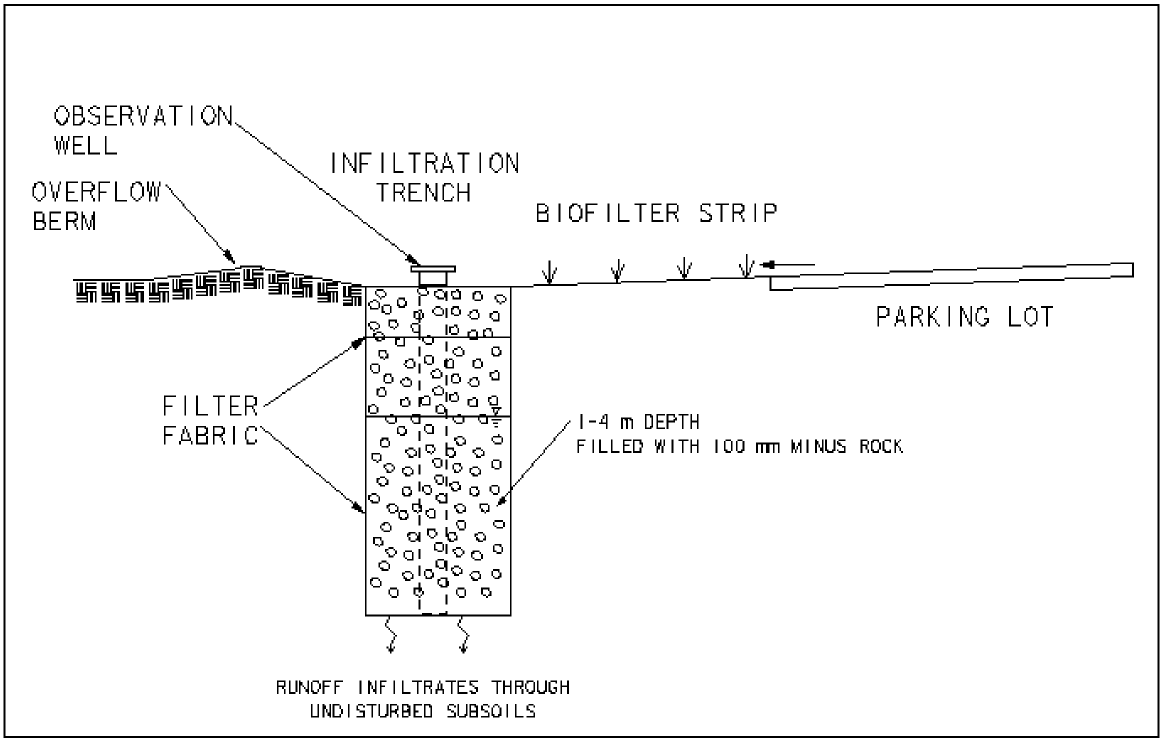


Figure 6-3 – Schematic of Infiltration Trench

6.3 Construction

Issues that occurred during construction of the infiltration trenches centered on constructability issues, unknown field conditions, and operational impacts to maintenance stations.

6.3.1 Constructability Issues

The design of the infiltration trench originally specified the use of 25 mm to 75 mm rock as backfill material. During construction, it was found that this rock gradation was unavailable locally and would have to be brought in from out of state. To avoid delays, the backfill material was changed to “100 mm minus” natural rounded rock, which was available locally. The change did not significantly affect the storage volume of the infiltration trenches but was a deviation from the original design specification.

6.3.2 Unknown Field Conditions

Problems with the excavation of the infiltration trenches included encountering unsuitable materials, underground utility conflicts, utility easement conflicts, and excavation pavement problems. Unsuitable materials (wet clayey soil) were encountered at the Carlsbad site in an area to be paved adjacent to the trench, requiring removal and replacement with aggregate base to get sheet flow back to the site. Geotechnical reinforcing fabric recommended by the geotechnical engineer was utilized to stabilize the unsuitable materials, minimizing unsuitable material removal and replacement.

In constructing BMPs within maintenance facilities, underground utility lines serving the facility were routinely encountered. Underground utilities in maintenance stations may have been modified numerous times as changes occurred at the station, and existing documentation of utility locations in maintenance stations may be unreliable. Replacement, rerouting, or avoidance of the utility represents an additional cost and often results in project delays. Better as-built plans could reduce the number of contract change orders by correctly identifying the location of utilities; however, hydraulic considerations may require that a BMP be sited in a certain location despite the presence of identified conflicts.

There are often easements to utility service providers within Caltrans maintenance facilities. Although the land is state property, the easement holder can place restrictions on or even prohibit construction within an easement, depending on the rights provided in the easement documents. At the Altadena MS the area originally proposed for the infiltration trench (parallel to the curb and behind the existing concrete storage bays) was within an easement granted to the City of Pasadena Water Department and the Foothill Municipal Water District. Two water mains ran parallel to the curb, and no construction was permitted within the easement. Neither the easement nor the water mains were shown on the as-built drawings or were known to the Maintenance Station Supervisor or the Caltrans Permit Inspector. Work was subsequently suspended while the BMP design was modified to avoid any construction within the easement.

For construction within paved areas, the existing pavement is typically sawcut to provide a firm edge to join to the new paving. In some cases, the existing pavement condition was such that disturbance by the BMP construction caused it to become unserviceable. The unsuitable pavement section had to be removed and replaced at the Altadena MS. Although the pavement was somewhat deteriorated prior to construction, it would not otherwise have required replacement. At the Carlsbad MS, saw-cutting the existing pavement caused fractures at the proposed joint location. The fractured pieces had to be removed in order to make a suitable joint between the existing and new pavement section.

6.3.3 Impacts to Maintenance Stations

Maintenance stations were impacted by the loss of the available space normally used for parking vehicles or for storing equipment and materials. Access to certain areas within the maintenance station was blocked during construction. This restricted the hours of various construction activities. In some cases, the sequence of operations was unacceptable to the operators of the maintenance stations. At Altadena, three existing storage bins were demolished to provide space for BMP installation and had to be replaced and relocated prior to construction of the trench at a cost of almost $60,000.

6.4 Maintenance

A formal maintenance program was established to maintain the infiltration trenches at the highest level. Sites were inspected monthly for general maintenance items that included checking the inlet structure, side slopes and overall site for signs of erosion, woody vegetation, graffiti, and vandalism, and indications of burrowing rodent activity that could endanger the structural integrity of the site. In addition, monthly and before every target storm, the sites were inspected for trash and debris accumulation in the inlet structures. Other maintenance items included inspection for vectors monthly and after every target storm.

To ensure that the infiltration trenches met the required drain time of 72 hours for the design storm, the water level in the monitoring well at each site was observed after each target storm. Sediment accumulation in the invert was inspected monthly during the dry season and after every storm greater than 12.5 mm. The trenches were inspected annually in May for standing water.

Infiltration trenches required the least maintenance of any of the BMPs evaluated in this study; approximately 17 field hours were spent on the operation and maintenance of each site, not including vector control agency hours. As shown in Figure 6-4, inspection of the infiltration trench was the largest field activity, requiring approximately 8 hr/yr. The time required for inspections reflects the requirements of the MID.

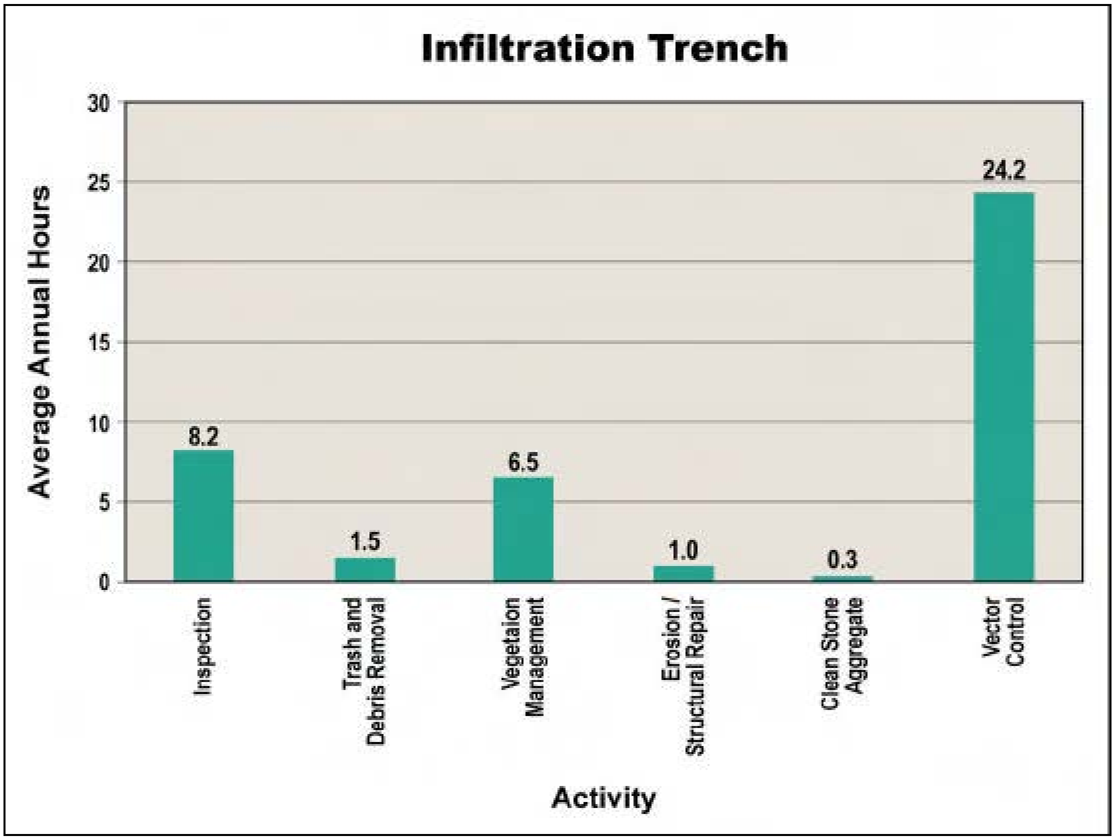


Figure 6-4 Field Maintenance Activities at Infiltration Trenches (1999-2001)

6.5 Performance

6.5.1 Chemical Monitoring

Constituent removal is considered 100 percent for this technology for storm events smaller than the water quality design storm, since the entire runoff volume is infiltrated and no water is discharged to surface waters.

Baseline sampling was conducted prior to construction and during operation of the infiltration trenches; however, it is difficult to understand groundwater movement and due to the relatively short timeframe of the project it is not possible to draw any conclusions from the data.

Collection of samples from the vadose zone was attempted at the Altadena maintenance stations because the groundwater depth was greater than 10 m below the trench floor, as well as at Carlsbad maintenance station where groundwater was 2 m below the trench floor. For the vadose samples, a lysimeter was installed and samples were to be collected at a depth of 1 - 2 m below the trench floor; however, samples were never successfully collected despite repeated attempts. Based on review of the sampling procedures, site lithology and performance of the lysimeters, the most likely causes preventing the lysimeters from collecting samples was that the silica flour encasing the lysimeter may have dried out and/or water was not available to be collected.

6.5.2 Empirical Observations

During and after each target storm event, observations were made at the infiltration trench sites. At the Carlsbad MS and Altadena MS infiltration trenches, it was observed that water was flowing out of the trench overflow for storm events larger than the design storm. This occurred on four occasions at Altadena and five occasions at Carlsbad. As designed, the infiltration trenches filled and discharged through the overflow pipe or overflow weir.

The Altadena MS never took more than approximately 36 hours for complete infiltration. The Carlsbad site infiltrated at a rate slower than the designed rate and generally took longer than 72 hours to drain; however, no mosquito breeding was observed at either of the trenches.

Sediment deposits were observed on the media at both sites. On two occasions, resuspension of particles was noted where flow enters the infiltration trench at Carlsbad MS. Erosion was noted at Carlsbad MS at the interface between the strip and trench.

6.6 Cost

6.6.1 Construction

Table 6-5 shows the actual construction costs with and without monitoring equipment and related appurtenances for each infiltration trench, with pretreatment biofiltration strip included. The table also presents the cost per cubic meter of water treated, using actual cost without monitoring. The cost per WQV is higher for Carlsbad MS partially due to structurally unsuitable soil below the subgrade that had to be removed and replaced. Carlsbad construction costs include the one biofiltration strip providing pretreatment.

Table 6-5 Actual Construction Costs for Infiltration Trenches and Pretreatment Biofiltration Strip (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
Altadena MS	293,588	252,845	1,470
Carlsbad MS	202,838	179,620	2,164

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

The adjusted costs for the infiltration trenches and pretreatment strips are presented in Table 6-6. The major reasons for cost adjustment included:

- Rebuilding storage bins at one location caused greater than usual facility restoration cost. Including the original facility restoration cost would increase the adjusted construction cost for that location by 22 percent. Instead, the average facility reconstruction cost for similar BMPs was used for estimating the adjusted construction cost.

- One location incurred cost due to the limited space available for construction, which would increase the adjusted cost by 56 percent. This cost was excluded from the adjusted construction cost.

- Due to the accelerated nature of construction, sod was used for the vegetated strips. The cost of using soil preparation and hydroseeding in lieu of sod was substituted for the sod cost. Using sod would increase the adjusted cost at one site by 4 percent, while the using hydroseeding cost at the other site had a negligible effect on adjusted cost.

Table 6-6 Adjusted Construction Costs for Infiltration Trenches with Pretreatment Biofiltration Strip (1999 dollars)

Infiltration Trenches	Adjusted Construction Cost ($)	Cost/WQV ($/m^3)
Mean (2)	146,154	733
High	156,975	775
Low	135,333	691

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

All infiltration trench installations were in maintenance stations and did not incur traffic control costs. If constructed roadside, infiltration trenches could incur traffic control cost typical of EDBs, in which traffic control accounted for an average of 9 percent of the adjusted construction cost. Traffic control costs were not used to estimate adjusted construction cost.

6.6.2 Operation and Maintenance

Table 6-7 includes average annual hours spent on field activities for the infiltration trenches for the 1999-2001 seasons. Field hours include inspections, maintenance and vector control.

Table 6-7 Actual Operation and Maintenance Hours for Infiltration Trenches

Site	Average Annual	
	Equipment Hours	Field Hours
Altadena MS	0	39
Carlsbad MS	0	44

Table 6-8 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 6-8 Actual Average Annual Maintenance Effort – Infiltration Trench

Activity	Labor Hours	Equipment & Materials $
Inspections	8	-
Maintenance	9	0
Vector control*	24	-
Administration	57	-
Direct cost	-	723
Total	**98**	**$ 723**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate an infiltration trench or reflect the design lessons learned during the course of the study. Table 6-9 presents the expected maintenance costs that would be incurred under the final version of the MID for an infiltration trench serving about 2 ha, constructed following the recommendations in Section 6.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Long-term maintenance (resulting from clogging of trench) was not required during this study; consequently, further research is needed to determine the expected lifetime of this type of device. Design refinements will eliminate the need for activities such as vector control. Only one hour is shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Equipment generally consists of a single truck for the crew and their tools.

Table 6-9 Expected Annual Maintenance Costs for Final Version of MID – Infiltration Trench

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	23	251	1,263
Vector control	0	0	0
Administration	3	0	132
Materials	-	1,200	1,200
Total	27	$1,451	**$2,639***

* Rehabilitation cost due to clogging is unknown

6.7 Criteria, Specifications and Guidelines

Based on the results of this study, infiltration trenches are considered technical feasible depending on site specific conditions. This section lists various suggestions for the siting, design, construction, operation, and maintenance of infiltration trenches. These are based on lessons learned through experience and observations made during the project. In deference to advocacy of the State Water Resources Control Board and the local Regional Water Quality Control Boards, the parties in this study worked cooperatively to develop interim guidelines for siting infiltration trenches; however, determination of whether there is a potential threat to groundwater quality requires further investigation. This project was not successful in determining the potential impact to groundwater quality from infiltrated runoff. Additional investigation is also needed to determine the maintenance interval for sediment removal and the extent and frequency to which the trench must be reconstructed during the maintenance operation.

6.7.1 Siting

The specifications and guidelines for siting infiltration trenches are the same as for infiltration basins. See Section 5.7 for a detailed description of these elements.

6.7.2 Design

Based on the observations and measurements in this study, the following guidelines are recommended:

- Provide pretreatment for infiltration trenches (such as with a biofiltration strip) in order to reduce the sediment load.

- Specify locally available trench rock in the range of 25 - 100 mm.

- Determine the trench volume by assuming the WQV will fill the void space based on the computed porosity of the rock matrix.

- Determine the bottom surface area needed to drain the trench within 72 hours by dividing the WQV by the infiltration rate.

- Calculate trench depth using the following equation:

$$d = \frac{WQV + RFV}{SA}$$

where:

D	=	Trench depth
WQV	=	Water quality volume
RFV	=	Rock fill volume
SA	=	Surface area

- The use of vertical piping, either for distribution or infiltration enhancement shall not be allowed to avoid device classification as a Class V injection well per 40 CFR146.5(e)(4).

- Provide observation well to allow observation of drain time.

6.7.3 Construction

Listed below are guidelines that should improve the construction process:

- Sufficient borings should be made before the job is put out for bid to determine the presence of any unsuitable materials and consequently to avoid the delays and expense incurred with contract change orders.

- Stabilize the entire area draining to the facility before construction begins. If impossible, place a diversion berm around the perimeter of the infiltration site to prevent sediment entrance during construction. Stabilize the entire contributing drainage area before allowing any runoff to enter once construction is complete.

6.7.4 Operation and Maintenance

Based on the level of maintenance required in this study, recommended future maintenance activities include:

- Perform inspections and maintenance as recommended in the MID (Version 17) in Appendix D, which includes inspection for standing water, trash and debris, sediment accumulation and general maintenance.

- Observe drain time for the design storm after completion or modification of the facility to confirm that the desired drain time has been obtained.

- Schedule semiannual inspections for the beginning and end of the wet season to identify potential problems.

- Remove accumulated trash and debris in the trench at the start and end of the wet season.

- Inspect for accumulated sediment at the beginning and end of wet season. If sediment is visible on top of the trench, remove top layer of trench, silt, filter fabric and stone; wash stone and reinstall fabric and stone into trench.

- Inspect for standing water at the end of the wet season.

- If it is observed by observation well or surface observation that the trench is clogging, a possible corrective action could include further stabilizing the contributing drainage or by installing additional pretreatment devices before the trench is rehabilitated. If only the filter fabric at the tip of the trench is clogging, it can be removed and replaced before clogging progresses further.

7 BIOFILTRATION SWALES

7.1 Siting

Six biofiltration swales were sited, constructed and monitored for this study: four in District 7 and two in District 11. Natural topographic lows and existing roadside ditches were the primary candidates for conversion to engineered swales. General criteria used for siting the swales included:

- Tributary areas of less than about 4 ha
- Slopes no greater than 5 percent
- A seasonal high water table at least 0.3 to 0.6 m below the surface

The linear nature of the highway system did not provide as many siting opportunities for swales as had been expected. Many of the swales, including three of the four in District 7, were sited in open areas associated with highway interchanges. Site constraints that restricted installation parallel to highways included:

- The mostly impervious nature of rights-of-way in these highly urban areas
- Highways built on fill
- Lack of adjacent right-of-way
- Sound walls and other structural elements located adjacent to the highways
- Concerns about safe access for operation, monitoring, and maintenance crews

Each of the swales treated runoff from highways. The other characteristics of the contributing watersheds for each of the swale installations are summarized in Table 7-1. A typical installation is shown in Figure 7-1 and a schematic diagram is presented in Figure 7-2.

Table 7-1 Summary of Contributing Watershed Characteristics for Biofiltration Swales

Site	Watershed Area Hectare	Impervious Cover %
I-605/SR-91	0.08	95
I-5/I-605	0.28	95
Cerritos MS	0.16	95
I-605/Del Amo Avenue	0.28	95
SR-78/Melrose Drive	0.96	90
I-5/Palomar Road	0.92	90

Figure 7-1 Typical Swale (SR-78/Melrose Drive)

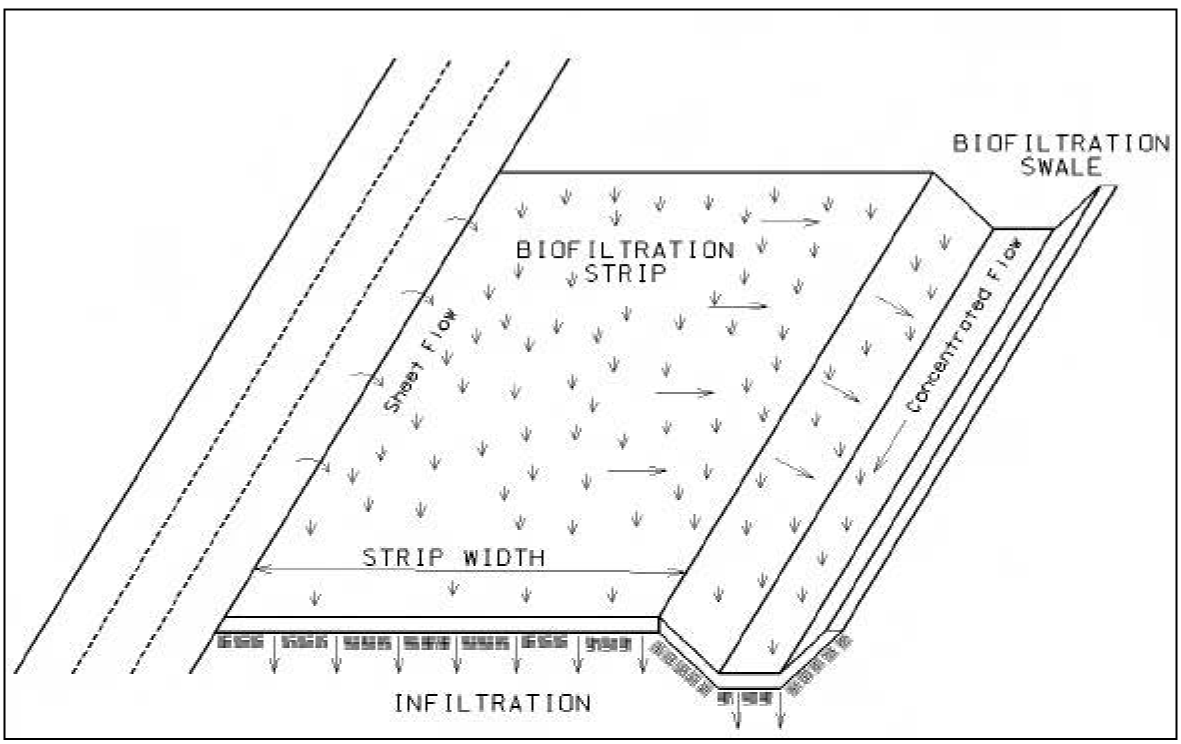


Figure 7-2 Schematic of Biofiltration Swale and Strip

Important considerations for the siting and use of vegetative controls are whether the climate of the area provides suitable growing conditions and whether the existing soil will support the vegetation. A monoculture of salt grass was used for this pilot study. Irrigation was provided at all sites to help establish the vegetation for the pilot study. Once irrigation ended, a mixed vegetation assemblage became established naturally at many of the biofilter sites, indicating that a monoculture of salt grass is not naturally sustainable. These additional species with varying moisture preferences and seasonality appeared to improve the overall vegetated coverage as the sites recovered from periodic disturbances.

Swales are versatile and have potential use both along highways and in auxiliary Caltrans facilities, such as maintenance bases, truck inspection stations, park-and-ride lots, and rest areas. Swales lend themselves well to being part of a "treatment-train" system of BMPs and should be considered whenever siting other BMPs that could benefit from pretreatment, especially infiltration basins and trenches.

7.2 Design

Retrofitting biofiltration swales into the existing drainage system was facilitated by the relatively small head loss associated with this technology. The major design criteria for the swales included:

- Minimum hydraulic residence time of 5 minutes, target of 9 minutes
- Maximum velocity of 0.3 m/s for the water quality design storm
- Maximum longitudinal slope of 5 percent
- Bottom width of 0.6-2.5 m
- Water depth calculated with Manning's equation using a roughness coefficient (n) of 0.2, with the depth about one-half the vegetation height

The actual design parameters for the individual sites are shown in Table 7-2. The guidelines used to design the test sites were mostly successful in creating installations that performed effectively. Each of the swales in District 7 was designed with a stilling basin at the entrance to provide energy dissipation and flow spreading; however, the standing water in them allowed mosquito breeding. A total of 21 mosquito abatement actions were required at the swales in District 7, compared with none at the District 11 sites. Grouting of the District 7 stilling basins eliminated standing water at the sites and stopped the breeding.

One of the main design constraints for several of the biofiltration swales was the protection of existing vegetation, particularly mature trees. This was especially true in areas where a permit was required from the California Coastal Commission or the project was within the boundaries of a local coastal program. Many areas along highways where swales could be implemented may face this same obstacle. However, swale design is flexible enough that this usually not an insurmountable obstacle.

A key element for the performance and viability of biofiltration systems is the selection of the appropriate vegetation for the climate and soil conditions. For the Pilot Study, salt grass (*Distichlis spicata*) was selected because it is a native plant, is perennial, and adapts to conditions in the area (it should not require irrigation if planted at the right time of year). In addition, salt grass was selected because it could be grown as sod, which was judged to provide the best means of achieving full coverage in a short time schedule.

Table 7-2 Design Characteristics of the Biofiltration Swales

Site	Design Storm mm	Peak WQ Flow, L/s	Length m	Width m	Slope
I-605/SR-91	25	2	40	1.5	0.020
I-5/I-605	25	7	40	2	0.020
Cerritos MS	25	4	20	1.5	0.021
I-605/Del Amo Avenue	25	6	54	1	0.020
SR-78/Melrose Drive*	46	106	20	3	0.008
			86	6	
I-5/Palomar Road	33	47	142	3	0.0014

* - Melrose has 20 m at a width of 3 m and 86 m at a width of 6 m.

There were two problems associated with this decision. First, salt grass is a warm season grass that is dormant during the winter. Plantings installed in the fall do not become established until the following warm season (May to September). Irrigation was required for initial establishment of salt grass plantings because soil moisture was insufficient during the summer growing season. The second problem was the decision to plant only one species. A monoculture is typically more susceptible to pests, disease, and invasion by weeds, whereas a mix of different species is more resilient to disturbance (URS, 1999b, see Appendix B). Appropriate species for a plant mix are identified in Section 7.7.2.

Future biofilter installations should use a mix of plant species. The salt grass plantings have been successful at achieving the desired initial cover, but this success required a substantial level of effort. Other species combinations may perform the same function with lower short-term and long-term costs.

In some cases, more land was available than required to meet the minimum hydraulic residence times for the biofiltration swales. Consequently, two of the biofiltration swales, at I-5/I-605 and I-605/Del Amo, were modified during the bid period to make more use of the available space and increase the hydraulic residence time of the biofilters. Two widths and lengths are shown for the SR-78/Melrose site, because the first 20 m of the swale is only 3 m wide and expands to the larger dimensions shown in Table 7-2.

All of the swales are in-line devices, meaning they also convey the flood control discharge. The maximum velocity under drainage design conditions was maintained at 1.2 m/s or less to ensure the vegetation was not scoured.

The construction specifications could be improved by requiring appropriate fertilizer and soil amendments in addition to an establishment schedule that includes irrigation. Fertilizing based on actual plant requirements in relation to nutrition provided by the soil would reduce nutrient discharges. To accomplish this, soil should be tested for nutrients and expert guidance used to specify the fertilizer and its application rate for the selected plants. These measures may improve the removal of nutrients in biofilters.

7.3 Construction

As mentioned above, protection of existing trees along the right-of-way and the requirement for rapid establishment of the new vegetation were the main construction constraints. Since the Coastal Commission required that areas within the canopy of existing trees not be extensively disturbed, short concrete channels were constructed to convey the runoff around the trees at the Palomar site.

Rapid vegetation establishment was desired since the projects were located in existing flow areas that would otherwise be subject to erosion and scour; consequently, grass was established through the use of sod. Although this was more expensive than using seed, the sod provided high initial soil stability in the channels where it was installed. Plantings were installed according to the specifications, mainly along the floor of the swales, while hydroseeding was used to stabilize the side slopes.

Winter dormancy affected the quality of plant material installed at the biofilter sites. The nursery contract for sod was implemented in mid-August 1998 because of state budgetary constraints. Plantings were established at the nursery very late in the growing season and most of the sod flats had less than 40 percent cover when they were installed at the pilot sites in December 1998 and February 1999. Once the plantings were installed, low temperatures and bw precipitation substantially delayed the establishment of the salt grass. Irrigation was required at all of the sites for the first year to establish the salt grass, but was not used on the hydroseeded areas. These latter areas generally failed to establish a thick vegetative cover.

7.4 Maintenance

Maintenance activities specified in the MID included weekly inspections for endangered species, and monthly inspections for condition of inlet and outlet structures, side slope stability, debris and sediment accumulation, vegetation height, and presence of burrowing animals. Vegetation was trimmed to 150 mm when the height exceeded 250 mm. Since a monoculture of salt grass was specified, weeds and woody vegetation were removed when observed. The maintenance was later revised to allow other non-woody plant species to compete with the monoculture.

The number of hours of field maintenance activities is shown in Figure 7-3. An average of about 91 hr/yr per site were spent on these activities, with vegetation-related tasks responsible for about 50 of these. This does not include vector control agency hours, which was approximately 42 hours. All of the hours for structural repair were incurred at a single site, Cerritos MS, where the swale was constructed at the bottom of a fill slope and a berm was used to confine the flow. Gopher burrows in the berm consistently compromised structural integrity at this site, allowing water to bypass the swale through the gopher holes. Chicken wire was placed inside the berm to provide a barrier to prevent gophers causing further damage. This extra measure to stabilize the berm was unsuccessful, as the gophers were able to penetrate the wire fence.

At other locations concern about burrowing owls, an endangered species that nest in abandoned gopher burrows, resulted in unsuccessful efforts to eradicate the gophers. Traps were set at the Cerritos, I-605/SR-91 and I-5/I-605 biofiltration swales to capture gophers and prevent damage to the biofilters. The traps were removed at the end of the 1999/2000 wet season after it was decided that eradication of gophers in highway rights-of-way was impractical.

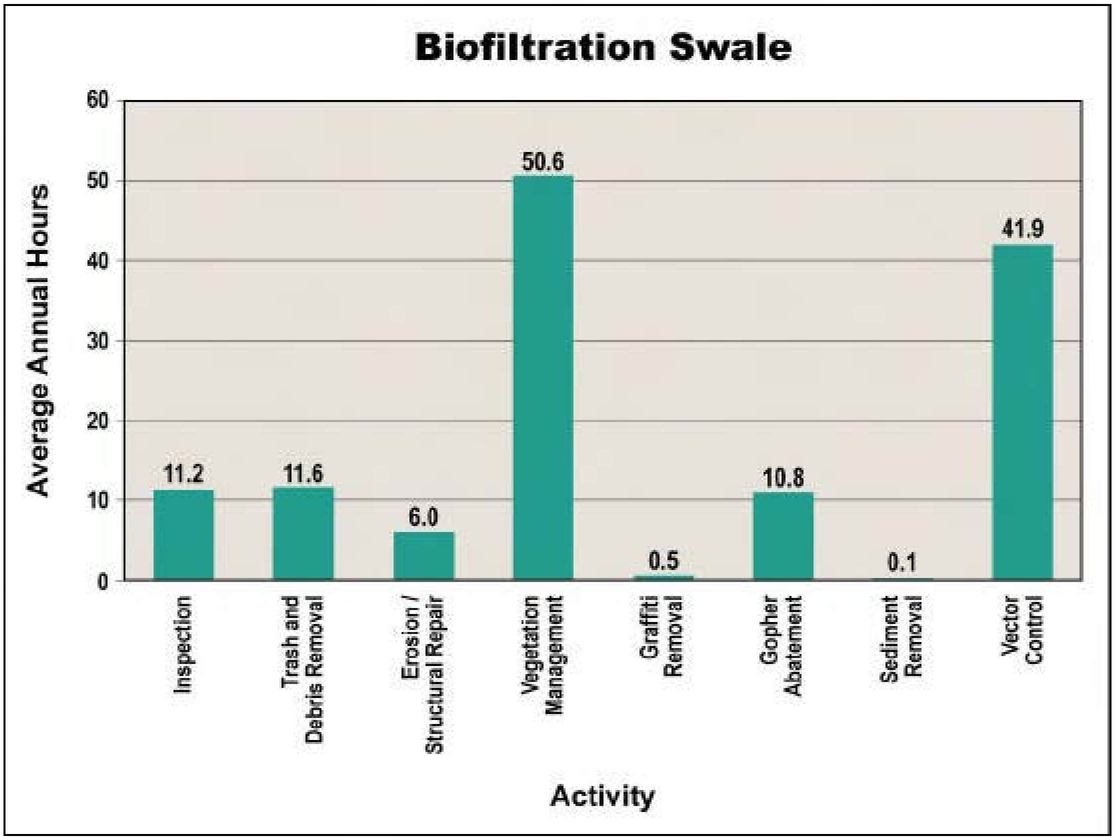


Figure 7-3 Field Maintenance Activities at Swale Sites (1999-2001)

7.5 Performance

7.5.1 Chemical Monitoring

The constituent concentration changes observed in the chemical monitoring program are shown in Table 7-3. The column titled "Significance" is the probability that the influent and effluent concentrations are not significantly different, based on an ANOVA. Since the effluent concentrations for most constituents were not significantly different among the sites ($P<0.05$), the data from all the sites were combined to calculate effectiveness. The load reduction shown in Table 7-4 is the total reduction expected for all the sites in a typical year and is greater than the concentration reduction because of the amount of infiltration that occurs. It should be noted that at Palomar, runoff from the freeway entered the swale along its entire length rather than just through the influent sampling location. Consequently, the influent volumes at this site were estimated as the sum of the measured influent volume and the expected contribution from the ungauged areas assuming a constant runoff coefficient.

Table 7-3 Concentration Reduction of Biofiltration Swales

Constituent	Mean EMC		Removal %	Significance P
	Influent mg/L	Effluent mg/L		
TSS	94	47	49	0.002
NO_3-N	1.22	0.89	27	0.147
TKN	3.43	2.36	31	0.907
Total N[a]	4.64	3.24	30	-
Ortho-phosphate	0.13	0.40	-218	<0.000
Phosphorus	0.26	0.53	-106	0.001
Total Cu	0.049	0.019	63	<0.000
Total Pb	0.099	0.031	68	0.075
Total Zn	0.349	0.079	77	<0.000
Dissolved Cu	0.024	0.012	49	0.067
Dissolved Pb	0.018	0.007	57	0.081
Dissolved Zn	0.170	0.045	74	<0.000
TPH-Oil [b]	3.5	1.7	51	0.107
TPH-Diesel [b]	1.3	0.4	69	0.156
TPH-Gasoline [b]	<0.05[c]	<0.05[c]	-	-
Fecal Coliform [b]	12,300 MPN/100mL	16,000 MPN/100mL	-30	0.707

[a] Considered to be sum of NO_3-N and TKN
[b] TPH and Coliform are collected by grab method and may not accurately reflect removal
[c] Equals value of reporting limit

Table 7-4 Load Reduction of Biofiltration Swales

Constituent	Annual Load, kg		Load Reduction %
	Influent	Effluent	
TSS	619	150	76
NO_3-N	8.00	2.80	65
TKN	22.60	7.40	67
Total N	30.60	10.20	67
Ortho-Phosphate	0.84	1.28	-52
Phosphorus	1.70	1.68	1
Total Cu	0.32	0.06	82
Total Pb	0.65	0.10	85
Total Zn	2.30	0.25	89
Dissolved Cu	0.16	0.04	76
Dissolved Pb	0.12	0.02	80
Dissolved Zn	1.12	0.14	87

Higher removals were observed for metals than for many of the other constituents. The worst performance was for phosphorus, which generally had higher effluent than influent concentrations. The concentration reductions observed for metals are generally better than those compiled by Young et al. (1996). For instance, Young reported concentration reductions for total copper of 46 percent, lead 67 percent, and zinc 63 percent. Reduction of TSS and phosphorus was less than that compiled by Young (83 percent and 29 percent respectively). The increase in fecal coliform concentrations has been reported in other studies such as Barrett et al. (1998), but the amount of phosphorus export was unusual.

Much of the observed load reduction is a function of the amount of infiltration that occurred in the swales. On average, about 50 percent of the runoff that entered the swales infiltrated and was not discharged to surface waters. The amount of infiltration varied greatly with Melrose experiencing the most (80 percent) and I-605/Del Amo the least (33 percent). This high rate of infiltration occurred despite generally unfavorable characteristics for infiltration found in attempting to site infiltration BMPs in the same regions. This is an interesting finding and highlights the importance of vegetation and soil in managing storm runoff quantity and quality.

The load reduction observed in this study is generally comparable to that measured by Barrett et al. (1998) in highway medians and adjacent vegetated channels designed solely for stormwater conveyance. Consequently, swales and other vegetated surfaces that are not engineered specifically for water quality may still provide substantial water quality benefit. Overall, the average load reduction observed for metals in this study also is comparable to that observed in more complex devices such as media filters.

The results of the linear regression analysis of influent and effluent EMCs are shown in Table 7-5. Of the constituents analyzed, only the phosphorus effluent concentrations were independent of influent concentrations. This suggests that a source of phosphorus exists within the swale that is leached at a rate relatively independent of influent concentration. An experiment was conducted to determine whether the salt grass itself was a substantial source of the phosphorus. Results are shown in Appendix F. This track was explored because of a unique property of salt grass. This plant has specialized glands in the leaves that secrete excessive salt, allowing the rain to wash it away (Figure 7-4). Since plant growth is normally nitrogen limited, there is excess phosphorus in the soil moisture that might be transported from the ground to the leaf surface.

Figure 7-4 Salt Crystals on the Leaves of Salt Grass

Samples of both Bermuda grass and salt grass were collected from several sites in District 11 during the wet season and were placed in deionized water for 1 hour. At the end of this time the water was decanted and analyzed for total and dissolved phosphorus. In most cases, the phosphorus concentrations were about twice as large in the water samples that contained salt grass as in those that contained Bermuda. This indicates that phosphorus can be leached from both plant species during their dormant season. The generally higher concentrations that were observed for the salt grass may be related to dissolution of the salt crystals.

Table 7-5 Predicted Effluent Concentrations -Biofiltration Swales

Constituent	Concentration[a]	Uncertainty, ±
TSS	0.42x + 11.0	$54.6\left(\frac{1}{39}+\frac{(x-84.5)^2}{139{,}000}\right)^{0.5}$
NO_3-N	1.31x - 0.03	$0.69\left(\frac{1}{38}+\frac{(x-0.71)^2}{6.1}\right)^{0.5}$
TKN	0.78x + 0.42	$1.50\left(\frac{1}{40}+\frac{(x-2.09)^2}{74}\right)^{0.5}$
Particulate P	0.22	0.11
Ortho-phosphate	0.40	0.12
Particulate Cu	0.18x +2.33	$5.80\left(\frac{1}{37}+\frac{(x-19.4)^2}{7{,}520}\right)^{0.5}$
Particulate Pb	0.28x + 3.5	$29.4\left(\frac{1}{39}+\frac{(x-67)^2}{244{,}000}\right)^{0.5}$
Particulate Zn	0.11x + 13.8	$30.9\left(\frac{1}{38}+\frac{(x-141)^2}{449{,}000}\right)^{0.5}$
Dissolved Cu	0.55x +3.3	$8.13\left(\frac{1}{39}+\frac{(x-16)^2}{4256}\right)^{0.5}$
Dissolved Pb	0.49x + 3.5	$8.87\left(\frac{1}{39}+\frac{(x-13)^2}{9466}\right)^{0.5}$
Dissolved Zn	0.40x + 7.7	$58.6\left(\frac{1}{39}+\frac{(x-99)^2}{213{,}600}\right)^{0.5}$

[a] Concentration in mg/L except for metals, which are in µg/L; *x* = influent concentration

7.5.2 Empirical Observations

As mentioned above, infiltration in the swales was a significant factor in the reduction of constituent loads. Empirical observations during storm events indicated that normally the discharge from the swale did not occur until the moisture in the swale was relatively high. There was generally insufficient discharge for monitoring until at least February of each year.

A problem in swales is channelization, where the runoff is confined to a fairly small region of the swale; however, runoff was generally evenly distributed across the width of the swale at the study sites and no channelization like that reported in other studies (Colwell et al., 2000) was observed. Channelization was probably avoided because the maximum slope was 2.1 percent. Colwell observed that swales with slopes in the range of 1.5 – 2.5 percent maintained a flat bottom unlike many of those with steeper slopes.

The Cerritos swale was constructed by importing fill to create a berm. Numerous problems were encountered at this site where gophers were active. Gophers continually burrowed through the site and created tunnels through the berm. These tunnels allowed flow to bypass the swale and pick up additional sediment. Consequently, creation of swales with the use of berms should be avoided wherever gophers are expected to be active.

Although there is no formal mechanism for litter control in swales, the swales generally retained accumulated litter as documented during the scheduled maintenance visits. For most of the sites, the water depths in the swales were generally not high enough to transport trash and debris. The amount of bypassed litter was not quantified because there was no downstream litter monitoring.

At many of the swale sites other vegetative species introduced naturally or through erosion control efforts competed successfully with the salt grass. Frequent weeding of the sites was needed initially since the MID required pulling weeds over 300 mm high monthly. Later in the study this practice was halted to allow other native non-woody vegetation to establish.

Adopt-A-Highway volunteers inadvertently cut the vegetation below the MID specifications at the Palomar swale in October 2000. The salt grass had difficulty recovering since it is dormant during the winter months. Consequently, weeds were able to overrun the site and many bare spots were created when weeds higher than 300 mm were removed. In addition, extensive gopher damage further reduced the vegetation coverage. A similar situation occurred at the Cerritos swale where the vegetation was cut below the MID specifications. However, at Cerritos, the site was not weeded, and different types of vegetation, primarily Bermuda grass, met the minimum requirement for cover. These inappropriate mowing events demonstrate the need to coordinate all operations and maintenance activities in the highway right-of-way environment. Signage was subsequently used during the pilot study to avoid recurrence of this problem.

7.6 Cost

7.6.1 Construction

Table 7-6 shows the actual construction costs with and without monitoring equipment and related appurtenances for each biofiltration swale site. The table also presents the cost per cubic meter of water treated, using actual cost without monitoring. The two sites in District 11 (SR-78/Melrose and 1-5/Palomar Airport Road) have the lowest cost per WQV and treat the largest area. The sites that treated the smallest total tributary area had a higher unit cost per WQV. This observation tends to support the presence of significant economies of scale for biofiltration swales.

Table 7-6 Actual Construction Costs for Biofiltration Swales (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
I-605/SR-91[b]	64,544	42,820	2,192
I-5/I-605	99,734	73,179	1,125
Cerritos MS	60,383	31,992	780
I-605/Del Amo Avenue	127,823	70,138	1,031
SR 78/Melrose Drive	142,418	133,077	332
I-5/Palomar Road	137,336	136,174	246

[a] Actual cost w/o monitoring.
[b] Adjusted Retrofit Construction Cost Tables; included in Appendix C
SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Adjusted construction costs for the swales are presented in Table 7-7. The major reasons for cost adjustment included:

- Due to the accelerated nature of construction, sod was used for the swales. The cost of using soil preparation and hydroseeding in lieu of sod was substituted for the sod cost. Using sod would increase the adjusted cost by 5 percent to 58 percent. The larger the biofilter, the larger the percent change in adjusted cost because the cost of vegetation begins to dominate the total project cost. The additional cost for using sod was excluded from the adjusted construction cost.

- At the Cerritos MS, limited head required additional grading costs. This cost would increase the adjusted cost by 15 percent. This cost was excluded from the adjusted cost.

- The four swales in District 7 had costs associated with vector control issues that would not have occurred with proper design. These costs would increase the individual adjusted costs by 6 percent to 9 percent. These costs were excluded from the adjusted cost.

- Adjustments to cost attributed to the level of contractor experience caused both increases and decreases to the adjusted cost. Excluding the cost adjustments for contractor experience would result in adjusted cost changes of –12 percent to 27 percent. These cost changes were included in the adjusted cost.

Table 7-7 Adjusted Construction Costs for Biofiltration Swales (1999 dollars)

Swales	Adjusted Construction Cost, $	Cost/WQV $/m^3
Mean (6)	57,818	752
High	100,488	2,005
Low	24,546	182

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

The adjusted traffic control costs account for 28 percent of the total swale adjusted construction cost, excluding the swale near Cerritos MS which only had 7 percent of its adjusted cost attributed to traffic control. Construction crews accessed the Cerritos MS via a surface street, rather than the freeway.

7.6.2 Operation and Maintenance

Table 7-8 shows the average annual operations and maintenance hours for each biofiltration swale. The I-605/Del Amo Avenue swale required additional irrigation in October and November 1999 to restore the vegetation after it was "weeded" by Caltrans maintenance personnel. Field hours include inspections, maintenance and vector control.

Table 7-9 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 7-8 Actual Operation and Maintenance Hours for Biofiltration Swales

District	Site	Average Annual Equipment Hours	Average Annual Field Hours
7 (Los Angeles)	I-605/SR-91	29	133
	I-5/I-605	20	136
	Cerritos MS	34	169
	I-605/Del Amo Avenue	72	146
	Average Value	**39**	**146**
11 San Diego)	SR-78/Melrose Drive	1	106
	I-5/Palomar Road	2	107
	Average Value	**1**	**106**

Table 7-9 Actual Average Annual Maintenance Effort – Biofiltration Swales

Activity	Labor Hours	Equipment & Materials $
Inspections	11	-
Maintenance	80	126
Vector control*	42	-
Administration	113	-
Direct cost	-	2110
Total	**246**	**$ 2,236**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate a biofiltration swale or reflect the design lessons learned during the course of the study. Table 7-10 presents the expected maintenance costs that would be incurred under the final version of the MID for a swale serving about 2 ha, constructed following the recommendations in Section 7.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Design refinements will eliminate the need for activities such as vector control. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Equipment generally consists of a single truck for the crew and their tools.

Table 7-10 Expected Annual Maintenance Costs for Final Version of MID – Biofiltration Swales

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	47	182	2,250
Vector control	0	0	0
Administration	3	0	132
Materials	-	310	310
Total	**51**	**$492**	**$2,736**

7.7 Criteria, Specifications and Guidelines

Based on the findings of this study, swales are considered technically feasible depending on site specific conditions; however, a number of questions remain about their operation and deployment. This study implemented a monoculture of salt grass at all the biofilter sites, so the effectiveness of other grass species for pollutant removal was not quantified. Additional information would also be useful on the minimum vegetation density for effective operation and the limit of their deployment for other areas based on rainfall and climate considerations.

7.7.1 Siting

Based on the results of this study, the primary siting criteria that are recommended for future installations include the following:

- Site swales in natural lows and in cut sections to prevent structural problems caused by burrowing animals.
- Be sure that any proposed site receives sufficient sunlight to support a dense growth of vegetation.

- Consider highway interchanges and any linear pervious areas in the right-of-way as the primary locations for siting swales in an urban setting. Siting opportunities may also be found in auxiliary Caltrans facilities, such as maintenance stations, truck inspections stations, park-and-ride lots and rest areas.

- Swales lend themselves to being part of a “treatment-train” system of BMPs. Consider using swales when siting other BMPs that could benefit from pretreatment, especially infiltration basins and trenches. Also look for opportunities to drain over-the-shoulder sheet flow through a biofiltration strip and then into a biofiltration swale.

- Verify that the natural vegetation in the climate provides a dense enough surface to stabilize the bottom of the swale and to provide effective pollutant removal.

7.7.2 Design

As described in the monitoring section, pollutant load reductions of the swales in this study were similar to those observed in studies of vegetated channels along highways designed solely for stormwater conveyance. Consequently, vegetated surfaces appear to be very robust pollution reduction systems that are not sensitive to many design parameters, such as vegetation type, bottom width, etc. The guidelines summarized below proved effective in this study; however, less engineered systems may also provide substantial pollutant removal. Monitoring of alternative configurations to document their benefits relative to those observed in this study is warranted.

Based on the observations and measurements in this study, the following guidelines are recommended:

- Locate, size, and shape biofiltration BMPs relative to topography and extended flow paths to maximize their treatment potential.
- Swales constructed in cut are preferred, or in fill areas that are far enough from an adjacent slope to minimize the potential for gopher damage. Do not use side slopes constructed of fill, which are prone to structural damage by gophers or other burrowing animals.
- The longitudinal slopes should be less than that which causes scour or transport of sediment. (Colwell et al. (2000) recommends less than 2.5 percent)
- Energy dissipaters may be required but use those that do on include standing water in their design, since this leads to vector problems.
- Use a mixture of drought-tolerant native grasses. In southern California, it is preferable to plant species that grow best during the winter and spring (the wet season), and to schedule biofilter establishment accordingly.
- Minimize use of sod as a primary means of establishing or restoring vegetation in bioswales because it results in increased project costs.

- Use a local erosion control seed mix and planting procedures appropriate for the specific project and location for both the bed and the side slopes. Use of vegetation that occurs naturally in the area can minimize establishment and maintenance costs.
- If channel stability is an issue in the period immediately following construction, consider the use of matting or other temporary erosion control measures rather than specifying the use of sod.
- Local climate should be able to support vegetation without irrigation systems; however, vegetation may become dormant during the dry season without adversely affecting the performance.

Some species suggested for future biofilter plantings in southern California are listed below. (URS, 1999b; included in Appendix B)

Seashore bent grass	Creeping wild rye
California brome	Perennial rye
Tufted hair grass	Pygmy-leaf lupine
Blue wild rye	Foothill meddlers
Red fescue	Purple needle grass
Tall (fowl) manna grass	Tomcat clover
Meadow barley	Regreen hybrid wheat grass

All of these species are capable of performing the design functions of the bioswales. Most of these species are cool season grasses that germinate and grow during the winter rainy season. Therefore, these species should require less irrigation and can be implemented with shorter lead times for growing. Most of the species listed above can be grown from plugs or seed and some of them produce rhizomes like salt grass that might be compatible with a sod planting. Install when season allows for establishment without irrigation. Other studies on the performance of swales, such as Barrett et al. (1998), indicate that the grass species selected do not have a significant impact on pollutant removal as long as slopes and channels are stabilized. Consequently, additional species beyond those listed may provide comparable performance.

7.7.3 Construction

Listed below are guidelines that should improve the construction process:

- Include directions in the specifications for use of appropriate fertilizer and soil amendments based on soil properties determined through testing and compared to the needs of the vegetation requirements.
- Install swales at the time of the year when there is a reasonable chance of successful establishment without irrigation; however, it is recognized that rainfall in a given year may not be sufficient and temporary irrigation may be used at the discretion of the Resident Engineer.

- If sod tiles must be used, they should be placed so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the swale or strip.
- Use a roller on the sod to ensure that no air pockets form between the sod and the soil.
- Soil preparation should be to the extent necessary to establish the vegetative cover.

Remedial plantings have consisted of salt grass plugs, seed, and transplants. This approach is appropriate for plantings during the growing season, but a modified approach should be used if remedial plantings are required during the fall. Plantings during the late fall and early winter season should include a mix of species. Plants that germinate and actively grow during the cooler months of winter and early spring should be overseeded on bare areas. Physical erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season. Erosion controls might include the placement of a blanket, mulch, or other biodegradable cover over the seeded portion of the site.

7.7.4 Operation and Maintenance

It is important that maintenance crews are familiar with the purpose of the swale and that only authorized individuals provide needed maintenance. Based on the level of maintenance required in this study, recommended future maintenance activities include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes inspection of vegetation, observation of flow across swale invert and sediment and debris accumulation.
- Inspect swales at least twice annually for erosion or damage to vegetation, preferably at the end of the wet season to schedule summer maintenance and before major fall runoff to be sure the swale is ready for winter. However, additional inspection after periods of heavy runoff is desirable. The swale should be checked for debris and litter and areas of sediment accumulation.
- Recent research (Colwell et al., 2000) indicates that grass height and mowing frequency have little impact on pollutant removal. Consequently, mowing may only be necessary once or twice a year for safety or aesthetics or to suppress weeds and woody vegetation.
- Trash tends to accumulate in swale areas, particularly along highways. The need for litter removal is determined through periodic inspection, but litter should always be removed prior to mowing.
- Sediment accumulating near culverts and in channels should be removed when it builds up to 75 mm at any spot, or covers vegetation.
- A healthy dense grass should be maintained in the channel and side slopes. Grass damaged during the sediment removal process should be replaced per the MID.
- The Caltrans Integrated Vegetation Management (IVM) Plan should be implemented for vegetated areas.

8 BIOFILTRATION STRIPS

8.1 Siting

Biofiltration strips were sited, constructed, and monitored at three sites as a part of this study. Of these, two were located in District 7 and one in District 11. One of the goals of the siting process was to identify sites where this technology could be constructed in conjunction with infiltration devices (trenches) to provide pretreatment, and a 'treatment-train' approach. Optimum sites for strips are locations receiving overland sheet flow of runoff; however, monitoring required that the flow at a proposed site be concentrated to facilitate measurement and sample collection.

Additional siting criteria for the strips included:

- Soils and moisture adequate to grow relatively dense vegetative stands
- Sufficient space available
- Slope of less than 12 percent

Two of the strips were installed to pretreat runoff entering infiltration trenches at maintenance stations, while one site in District 7 was constructed as a stand-alone facility along a highway shoulder.

The characteristics of the contributing watersheds for each of the strip installations are summarized in Table 8-1. A typical installation is shown in Figure 8-1 and a schematic diagram is presented in Figure 8-2. The District 11 Carlsbad site contains two strips: one used for pretreatment of an infiltration trench (0.7 ha) and one that discharges directly to a municipal street (0.28 ha).

Table 8-1 Summary of Contributing Watershed Characteristics for Biofiltration Strips

Site	Land Use	Watershed Area Hectare	Impervious Cover %
Altadena MS	Maintenance Station	0.70	100
I-605/SR 91	Highway	0.20	100
Carlsbad MS Trench	Maintenance Station	0.70	100
Carlsbad MS Drain	Maintenance Station	0.28	100

Figure 8-1 Biofiltration Strip (District 7, I-605/SR-91)

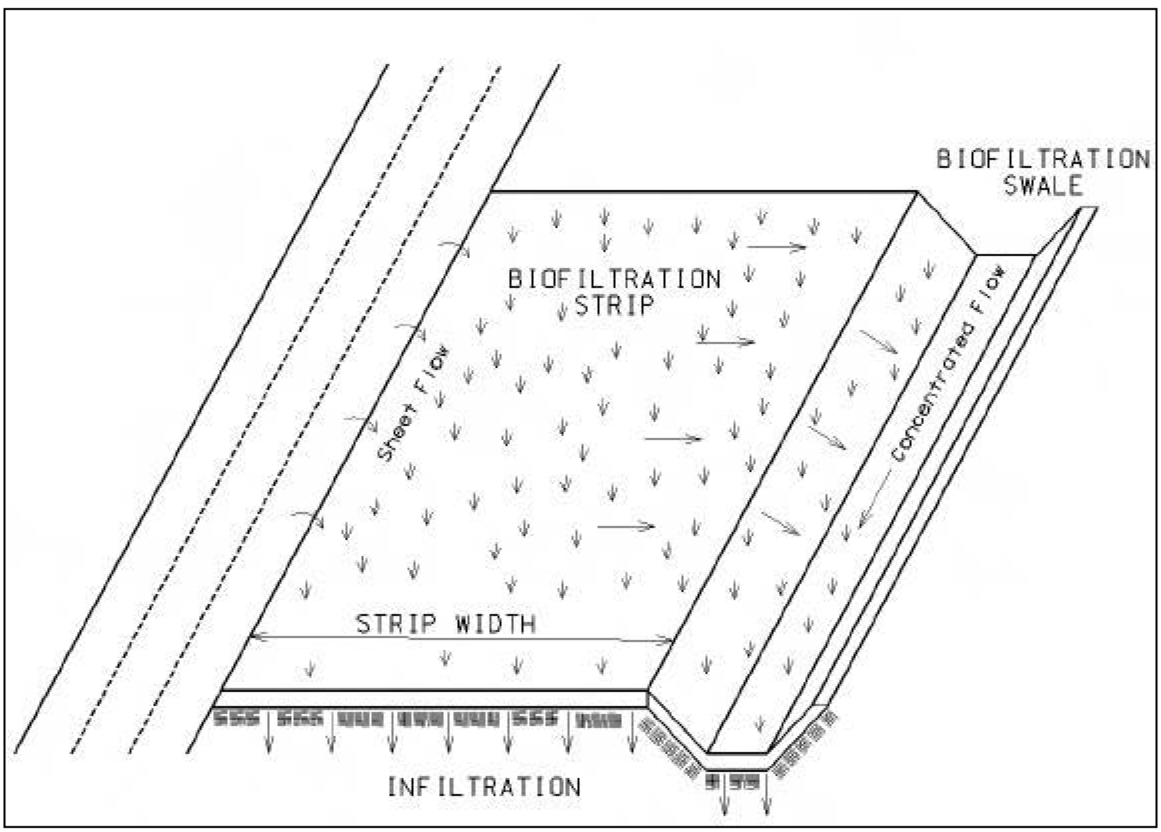


Figure 8-2 Schematic of Biofiltration Strip and Swale

Although the required number of strips was successfully sited, narrow shoulders and conflicts with sound walls and other structures suggest that there will not be abundant opportunities for retrofit with this technology on existing freeways in the most highly urbanized areas. Freeways often retain pervious areas within the right-of-way in less urbanized areas that could become biofiltration strips when drainage systems are rebuilt during highway reconstruction projects.

An important consideration for the siting and use of vegetative controls is whether the climate of the area provides suitable growing conditions. Irrigation was provided at all sites to help establish the vegetation. Once irrigation ceased, a mixed vegetation assemblage became established naturally at many of the biofilter sites that were initially salt grass sod, indicating that a monoculture of salt grass is not naturally sustainable. These additional species with varying moisture preferences and seasonality appeared to improve the overall vegetated coverage as the sites recovered from periodic disturbances.

These BMPs proved to be versatile and have potential use both along highways and in auxiliary Caltrans facilities, such as maintenance bases, truck inspection stations, park-and-ride lots, and rest areas. Biofiltration strips also are well suited to being part of a "treatment-train" system of BMPs and should be considered whenever siting other BMPs that could benefit from pretreatment, especially infiltration basins and trenches.

8.2 Design

Retrofitting biofiltration strips into the existing drainage system was facilitated by the relatively small head loss associated with this technology. The major design criteria for the strips included:

- Slope of no more than 12 percent
- A minimum recommended length in the direction of flow of a filter strip of 8 m
- No gullies or rills that can concentrate overland flow
- Top edge of the filter strip should be level with the plane of the adjacent pavement

The actual design parameters for the individual sites are shown in Table 8-2.

A key element for the performance and viability of biofiltration systems is the selection of appropriate vegetation for the climate and soil conditions. As with biofiltration swales, salt grass was selected because it is a native plant, perennial, and adapted to conditions in the area. In addition, this species could be grown as sod and it was believed that sod would provide the best means of achieving full cover in the given time schedule. There were two problems associated with this decision. First, salt grass is a warm season grass that is dormant during the winter. Plantings installed in the fall do not become established until the following warm season (May to September). Irrigation was required for salt grass plantings because soil moisture is insufficient during the summer growing season. The second problem was the decision to plant only one species. A monoculture is typically more susceptible to pests, disease, and invasion by weeds, whereas a mix of different species is more resilient to disturbance (URS, 1999b).

Table 8-2 Design Characteristics of the Biofiltration Strips

Site	Design Storm mm	WQ Design Peak Flow L/s	Length m	Area m^2	Slope %	WQV m^3
Altadena MS	25	34	8	160	3	172
I-605/SR-91	25	2.8	8	480	2	52
Carlsbad MS Trench	33	37	8	200	1	222
Carlsbad MS Drain	33	17	8	216	1	93

Future biofilter installations should be implemented using a mix of hardy plant species. The salt grass plantings have been successful at achieving the desired cover, but this success has required a substantial level of effort and cost. Other species combinations may perform the same function with lower short-term and long-term costs. A list of species that are suggested for future biofilter plantings in southern California is contained in Section 7.7.2. All of these species are capable of performing the design functions of the biofilters. Most of these species are cool season grasses that germinate and grow during the winter rainy season. Therefore, these species should require less irrigation and can be implemented with shorter lead times for growing. Most of the species can be grown from plugs or seed and some of them produce rhizomes like salt grass that might be compatible with sod planting. Temporary irrigation systems should be considered for all future biofilter installations to supplement natural deficiencies that may occur during plant establishment.

As shown in Table 8-3, there was a wide range of tributary-to-treatment area ratios for the monitored sites. Consequently, the design standard implemented, a width of 8 m, may not be applicable to all sites. The design value was originally derived from Barrett et al. (1998) where it was applied to implementation of strips parallel to highways with a constant pavement width of 15 m, resulting in tributary-to-treatment area ratio of only 2. Since two of the monitored sites were in maintenance stations with treatment areas much larger than the freeway site, the width of 8 m resulted in higher ratios. Because hydraulic loading rates were not a design consideration and removal efficiencies among widely varying loading rates were not distinguishable in this study, the reader is cautioned when reviewing the costs per WQV in the following cost section (Tables 8-8 and 8-9).

Table 8-3 Treatment Ratios for Biofiltration Strip Sites

Site	Tributary Area/Treatment Area Ratio
Altadena MS	43
I-605/SR-91	4
Carlsbad MS w/Trench	35
Carlsbad MS	13

8.3 Construction

A common construction problem encountered at the biofiltration strips was the need to use level spreaders to convert concentrated flow into sheet flow. At the I-605/SR-91 and Carlsbad MS the flows were initially sheet flow, which had to be concentrated so flows could be monitored and then converted back to sheet flow. The Altadena MS originally had concentrated flow, which was monitored and then converted to sheet flow. Flow spreading was a more difficult problem than expected. One of the major difficulties was the construction of a truly level "level spreader." The level spreaders also tended to hold water between events, creating a potential vector problem. At the Altadena MS, mosquito abatement was required on seven occasions before drain plugs were installed to address this issue. Consequently, implementation of biofiltration strips would be preferred in areas where sheet flow predominates.

Rapid vegetation establishment was needed to meet the time schedule of the Pilot Program; consequently, grass was established through the use of sod. Although this could be more expensive than using seed, the sod provided high initial soil stability where it was installed and avoided the potential for erosion and damage. Irrigation was required at all of the sites for the first year to establish the vegetation.

Winter dormancy also affected the quality of plant material installed at the biofilter sites. The nursery contract was implemented in mid-August 1998 because of delays in approval of the State budget. Plantings were established at the nursery very late in the growing season and most of the sod flats had less than 40 percent cover when they were planted in December 1998 and February 1999. Once the plantings were installed, low temperatures and low precipitation substantially delayed the establishment of the salt grass.

Plantings were installed according to the specifications; however, modifications recommended to the specifications include soil testing, appropriate fertilizer and soil amendments in addition to an establishment schedule that includes irrigation. Fertilizer application rates should be based on actual plant requirements in relation to nutrition provided by the soil and based on soil tests for nutrients and expert guidance.

Remedial plantings (for strip maintenance) have consisted of salt grass plugs, seed, and transplants. This approach is appropriate for plantings during the growing season, but a modified approach is recommended if remedial plantings are required during the fall. Plantings during the late fall and early winter season should include a mix of species. Plants that germinate and actively grow during the cooler months of winter and early spring should be overseeded on bare areas.

At the Carlsbad Maintenance Station, establishment of the grass also was hindered by the presence of rabbits, which came into the maintenance yard at night and ate the grass. Once a small fence was installed around the perimeter of the vegetated area, full coverage with the salt grass was rapidly established.

8.4 Maintenance

Maintenance activities were the same as those at the biofiltration swale sites and included weekly inspections for endangered species, and monthly inspections for condition of inlet and outlet structures, side slope stability, debris and sediment accumulation, vegetation height (during the dry season), and presence of burrowing animals. Vegetation was trimmed to 150 mm when the height exceeded 250 mm. Woody vegetation was removed when observed during monthly inspections, weeds were removed only during the first season of plant establishment.

The number of hours of field maintenance activities is shown below in Figure 8-3. An average of about 105 hr/yr were spent on these activities, not including 26 hours for vector control activities. Of these, more than 67 hr/yr were required for vegetation management, included mowing, weeding, irrigation, and rehabilitation of bare areas, to comply with the requirements of the MID. An additional 6 hours were needed just to remove the drain plugs and drain the level spreaders.

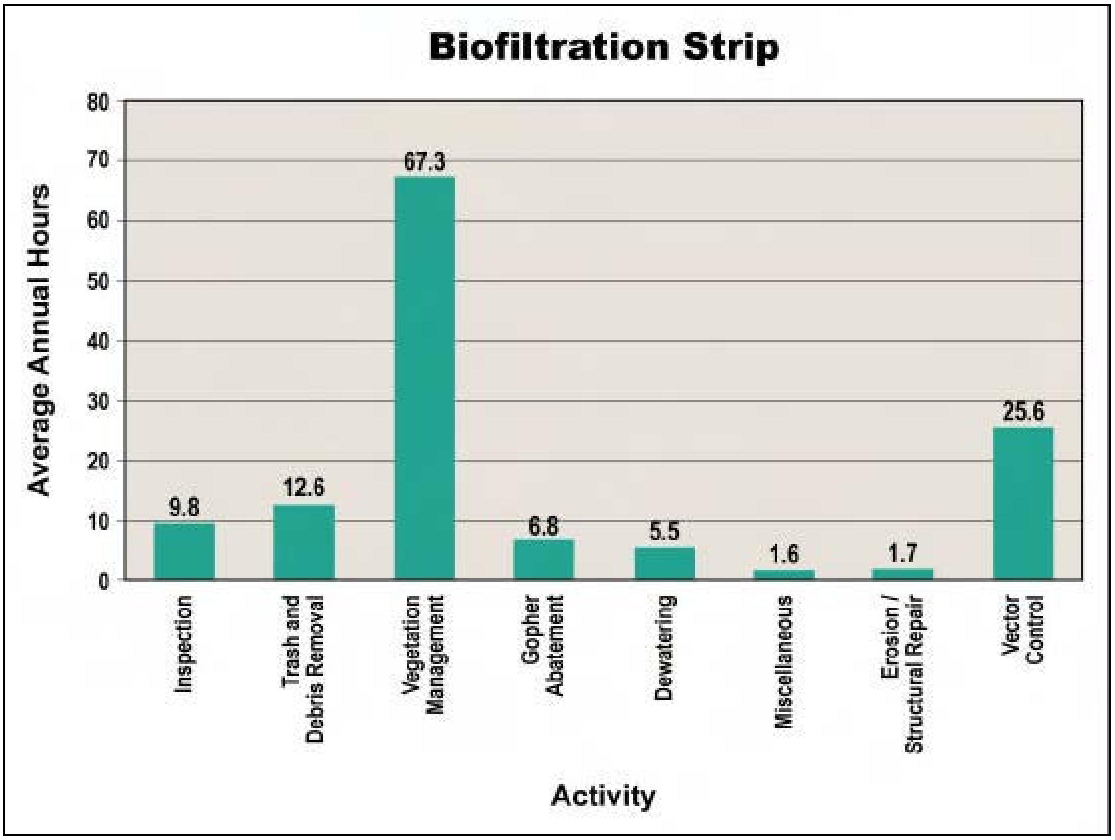


Figure 8-3 Field Maintenance Activities at Strip Sites (1999-2001)

8.5 Performance

8.5.1 *Chemical Monitoring*

Monitoring of the District 7 Altadena MS and I-605/SR-91 sites consisted of paired influent and effluent samples; however, at Carlsbad (District 11) the influent to the strip providing pretreatment to the infiltration trench was monitored, but the effluent from the second strip was monitored. Therefore, the influent and effluent samples were from different contributing areas. Load and concentration reductions were calculated for Carlsbad under the assumption that the runoff coefficient and influent concentrations were the same for both strips.

The results of the chemical monitoring program are shown in Table 8-4. The column titled "Significance" is the probability that the influent and effluent concentrations are not significantly different, based on an ANOVA. The reduction in constituent concentrations is highly variable, with substantial reductions in sediment and metals, but effectively no reduction in nitrogen species and an increase in phosphorus concentration. The concentration reductions observed at this site are greater for sediment and metals than those compiled by Young et al. (1996), but less than those reported for nutrients. For instance, Young reported concentration reductions for TSS of 70 percent, nitrate 10 percent, phosphorus 40 percent, and zinc 40 percent.

The load reduction shown in Table 8-5 is the total reduction expected for all three sites in a typical year. Much of the observed load reduction shown, which is greater than the concentration reduction, is a function of the amount of infiltration that occurred in the strips. On average, 30 percent of the runoff that entered the strips infiltrated and was not discharged to surface waters. There were significant differences among the sites in the amount of infiltration, which was highest at the Carlsbad MS, where about 80 percent of the runoff infiltrated. Losses resulting from infiltration were much less at the I-605/SR-91 site (37 percent) and the Altadena MS (14 percent). The low value at the Altadena MS may have been a function of less strip area relative to the size of the drainage area and occasional bypass of the influent control structure during periods of high intensity rainfall. Like swales, the load reduction for many constituents is comparable to that observed in more complex devices such as media filters.

Surprisingly, the concentration reduction for many constituents at the I-605/SR-91 site was less consistent than that observed at the other two sites, despite the fact it had the smallest tributary area relative to the size of the strip (Table 8-3). When the percent reduction in concentration is calculated using the methodology described in the introduction, the high variance results in a prediction of sediment export. This erratic performance may have been caused by wind blown sediment along the highway shoulder and/or dirt from gopher mounds accumulating in the sample collection trench between storms. The percent reduction of the monitored constituents observed at the Carlsbad site was greater than the other two sites, likely because of the much higher influent concentrations.

The percent reduction in constituent concentrations for the individual strips also was calculated using the geometric mean of the influent and effluent EMCs. The results of this analysis and the amount of infiltration at each site are shown in Table 8-6. The data are not sufficient for determining the maximum tributary area for a biofilter strip because of the relatively poor performance of the I-605/SR-91 site. In addition, all the strips had slopes of less than 3 percent, so no new information relative to the impact of slope on pollutant removal was developed.

Table 8-4 Concentration Reduction of Biofiltration Strips

Constituent	Mean EMC Influent mg/L	Mean EMC Effluent mg/L	Removal %	Significance P
TSS	100	31	69	<0.000
NO_3-N	0.44	0.58	-30	0.367
TKN	2.00	2.10	-5	0.542
Total N[a]	2.45	2.68	-10	-
Ortho-Phosphate	0.15	0.46	-216	0.047
Phosphorus	0.42	0.62	-46	0.035
Total Cu	0.058	0.009	85	<0.000
Total Pb	0.046	0.006	88	<0.000
Total Zn	0.240	0.066	72	<0.000
Dissolved Cu	0.019	0.007	65	0.004
Dissolved Pb	0.004	0.002	65	0.006
Dissolved Zn	0.073	0.035	53	<0.000
TPH-Oil [b]	1.7	0.7	59	0.101
TPH-Diesel [b]	0.9	0.3	66	0.138
TPH-Gasoline [b]	<0.05[c]	<0.05[c]	-	-
Fecal Coliform [b]	17,700 MPN/100mL	1,500 MPN/100mL	92	0.061

[a] Sum of NO_3-N and TKN
[b] TPH and Coliform are collected by grab method and may not accurately reflect removal
[c] Equals value of reporting limit

Table 8-5 Load Reduction of Biofiltration Strips

Constituent	Annual Load , kg		Load Reduction %
	Influent	Effluent	
TSS	183	30	83
NO_3-N	1.00	0.60	45
TKN	3.90	2.10	47
Total N	5.00	2.80	44
Ortho-Phosphate	0.25	0.44	-76
Phosphorus	0.70	0.60	7
Total Cu	0.090	0.009	90
Total Pb	0.071	0.005	92
Total Zn	0.377	0.054	86
Dissolved Cu	0.044	0.006	85
Dissolved Pb	0.007	0.001	78
Dissolved Zn	0.152	0.034	78

Table 8-6 Comparison of Individual Sites for Representative Constituents – Biofiltration Strips

Site	TSS Reduction, %	TKN Reduction, %	Dissolved Copper Reduction, %	Infiltration %
Altadena MS	70	-8	20	14
I-605/SR-91	73	-50	12	37
Carlsbad MS	83	46	87	80

A linear regression analysis was also performed on the influent and effluent EMCs aggregated data from all sites and the results are shown in Table 8-7. Of the constituents monitored only the phosphorus effluent concentrations are independent of the influent concentration. In addition, these phosphorus values are significantly higher than those measured in the influent, resulting in an increase for almost all events, similar to that observed in the swales. This suggests that leaching of phosphorus from dormant vegetation results in an effluent concentration that is independent of the influent concentration.

The sediment collected in the spreader ditch of the Altadena biofiltration strip had to be removed in June and December of 1999. All sediment and collected material that accumulated in the spreader ditch was tested for hazardous materials prior to disposal. Testing found the material to be nonhazardous and therefore all material was disposed of at the landfill. Testing results can be found in Appendix F.

8.5.2 Empirical Observations

One of the biggest difficulties with these strips was reestablishing uniform sheet flow once the flow was concentrated for measurement. Although concrete level spreaders were included in the design for this purpose they were not very effective and often continued to hold water long after runoff ceased. This problem would not exist in the general application where flow and water quality monitoring would not be necessary. Strips should be used where sheet flow conditions occur.

Although there is no formal mechanism for litter control in strips, the strips generally retained accumulated litter at the strip pavement interface or within the vegetated area until scheduled maintenance visits. The water depths in the strips were not high enough to transport trash and debris.

The vegetation at the Altadena and Carlsbad MS strips was overrun by weedy species or species from an erosion control mix. At the I-605/SR-91 strip there were fewer weedy species. This is probably due to the fact that seeds from other species are not blown or washed into the strip since it is adjacent to and downwind of the highway. All the sites maintained the required vegetative coverage, if the weedy species are included.

Table 8-7 Predicted Effluent Concentrations – Biofiltration Strips

Constituent	Concentration[a]	Uncertainty, ±
TSS	0.074x +19.2	$29.2\left(\frac{1}{27}+\frac{(x-101)^2}{200{,}000}\right)^{0.5}$
NO_3-N	1.31x – 0.03	$0.59\left(\frac{1}{26}+\frac{(x-0.38)^2}{0.98}\right)^{0.5}$
TKN	1.09x + 0.08	$2.74\left(\frac{1}{28}+\frac{(x-1.78)^2}{23}\right)^{0.5}$
Particulate P	0.36	0.17
Ortho-phosphate	0.50	0.26
Particulate Cu	0.078x + 0.70	$2.69\left(\frac{1}{28}+\frac{(x-16)^2}{6974}\right)^{0.5}$
Particulate Pb	0.083x + 1.7	$5.17\left(\frac{1}{28}+\frac{(x-27)^2}{15780}\right)^{0.5}$
Particulate Zn	0.10x +5	$13.3\left(\frac{1}{28}+\frac{(x-89)^2}{192{,}000}\right)^{0.5}$
Dissolved Cu	0.11x + 4.6	$8.57\left(\frac{1}{28}+\frac{(x-17)^2}{8421}\right)^{0.5}$
Dissolved Pb	0.074x + 1.2	$0.11\left(\frac{1}{28}+\frac{(x-4)^2}{803}\right)^{0.5}$
Dissolved Zn	0.31x + 12.4	$38.8\left(\frac{1}{26}+\frac{(x-68)^2}{35{,}000}\right)^{0.5}$

a Concentration in mg/L except for metals, which are in µg/L; *x* = influent concentration

8.6 Cost

8.6.1 Construction

Table 8-8 shows the actual construction costs with and without monitoring equipment and related appurtenances for each biofiltration strip. The table presents the cost per cubic meter of water treated, using actual cost without monitoring. The construction cost for the Carlsbad MS is for the stand-alone biofiltration strip.

Table 8-8 Actual Construction Costs for Biofiltration Strips (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
Altadena MS	146,400	106,348	618
I-605/SR-91	157,174	85,570	1,646
Carlsbad MS Drain	89,243	80,561	866

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Adjusted construction costs for the strips are presented in Table 8-9. The primary reasons that costs were adjusted include:

- The cost of the associated infiltration trench was estimated and removed.
- Due to the accelerated nature of construction, sod was used for the strips. The cost of using soil preparation and hydroseeding cost in lieu of sod was substituted for the sod cost. Using sod would increase the individual adjusted cost by 0 percent, 6 percent, and 28 percent for the three sites, respectively. The larger the biofilter, the larger the percent change in adjusted cost because the cost of vegetation begins to dominate the total project cost. The additional cost for using sod was excluded from the adjusted construction cost.
- Rebuilding storage bins at one location caused greater than usual facility restoration cost. Including the original facility restoration cost would increase the adjusted construction cost for that location by 23 percent. Instead, the average facility reconstruction cost for similar BMPs was used for estimating the adjusted construction cost.
- At one location, adjustments to cost attributed to the level of contractor experience caused an increase to adjusted cost. Excluding the cost increase for contractor experience would decrease adjusted cost by 8 percent. These cost changes were included in the adjusted cost.

- Miscellaneous site-specific factors caused increased construction cost. This cost would increase the adjusted cost by 14 percent. These costs were excluded from the adjusted cost.

- One location incurred cost due to limited space for construction. Including this cost would increase adjusted cost by 29 percent for that location. This cost was excluded from the adjusted cost.

Table 8-9 Adjusted Construction Costs for Biofiltration Strips (1999 dollars)

Strips	Adjusted Construction Cost, $	Cost / WQV $/m^3
Mean (3)	63,037	748
High	67,099	1,237
Low	58,262	384

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

The construction costs of off-highway (maintenance station) strips are similar to the cost of the on-highway strip. The additional site-specific costs for clearing and grubbing existing AC and facility restoration at maintenance stations are roughly equal to the cost of traffic control incurred at the highway sites.

8.6.2 Operation and Maintenance

Table 8-10 shows the average annual operations and maintenance hours for each strip. The I-605/SR-91 strip had the largest vegetated area and consequently required more maintenance time. Field hours include inspections, maintenance and vector control.

Table 8-10 Actual Operation and Maintenance Hours for Biofiltration Strips

District	Site Name	Average Annual	
		Equipment Hours	Field Hours
7 (Los Angeles)	Altadena MS	14	122
	I-605/SR-91	34	213
11 (San Diego)	Carlsbad MS	0	58
	Average Value	**16**	**131**

Table 8-11 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs.

Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 8-11 Actual Average Annual Maintenance Effort – Biofiltration Strips

Activity	Labor Hours	Equipment & Materials $
Inspections	10	-
Maintenance	96	101
Vector control*	26	-
Administration	101	-
Direct cost	-	1,762
Total	**233**	**$ 1,863**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate a biofiltration strip or reflect the design lessons learned during the course of the study. Table 8-12 presents the expected maintenance costs that would be incurred under the final version of the MID for a strip serving about 2 ha, constructed following the recommendations in Section 8.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Design refinements will eliminate the need for activities such as vector control. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Equipment generally consists of a single truck for the crew and their tools.

Table 8-12 Expected Annual Maintenance Costs for Final Version of MID – Biofiltration Strips

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	47	182	2,250
Vector control	0	0	0
Administration	3	0	132
Materials	-	310	310
Total	**51**	**$492**	**$2,736**

8.7 Criteria, Specifications and Guidelines

Based on the findings of this study, strips are considered technically feasible depending on site specific conditions; however, there are a number of research needs associated with this type of vegetated controls. There is little empirical data on the effect of slope and length on pollutant removal performance. In addition, there was no relationship between the ratio of the strip size and tributary area, and pollutant removal. Consequently, additional information is needed relative to sizing of these devices. This study implemented a monoculture of salt grass at all the biofilter sites, so the effectiveness of other grass species for pollutant removal was not quantified. Finally additional information would be useful on the minimum vegetation density for effective operation and the limit of their deployment for other areas based on rainfall and climate factors. Considerations for siting, design, and operation are described below.

8.7.1 Siting

Based on the results of this study, the primary siting criteria recommended for future installations include the following:

- Consider strips for pretreating runoff before entering devices that are susceptible to clogging such as infiltration trenches and basins and sand filters. Also look for opportunities to direct shoulder sheet flow from highways through a biofiltration strip and then into a biofiltration swale.
- Construct strips on highway shoulders where adequate space is available.
- Verify that the natural vegetation in the climate is dense enough to stabilize surfaces and to provide effective pollutant removal.
- Site in areas where sheet flow predominates.

8.7.2 Design

The general guidelines used for design of the test sites were successful in creating installations that performed effectively. The test sites were similar in many regards to the vegetated shoulders common along highways in many areas of the state. Consequently, one would expect these areas, which were not originally designed as treatment devices, to offer the comparable water quality benefit as these engineered sites. One potential issue was that all strips had the same width even though the size of the tributary areas varied widely; however, these data do not definitely establish a maximum tributary/treatment area ratio. Based on the observations and measurements in this study, the following guidelines are recommended:

- Locate, size, and shape biofiltration BMPs relative to topography and provide extended flow paths to maximize their treatment potential.
- Specify vegetation that occurs naturally in the area to minimize establishment and maintenance costs. (See Section 7.7.2 for specific plant list.)
- If slope stability is an issue in the period immediately following construction, consider the use of matting or other temporary erosion control measures rather than specifying the use of sod.
- Avoid the use of concrete level spreaders to distribute runoff. If the existing flow at a proposed site is concentrated, consider the implementation of a biofiltration swale instead of a strip.
- Specifications should include appropriate fertilizer and soil amendments based on soil properties determined through testing and compared to the needs of the vegetation requirements.
- Install strips at the time of the year when there is a reasonable chance of successful establishment without irrigation; however, it is recognized that rainfall in a given year may not be sufficient and temporary irrigation may be used at the discretion of the Resident Engineer.
- While not tested in this study, consensus guidance recommends slopes less than or equal to 20 percent for filter strips.

8.7.3 Construction

Listed below are guidelines recommended to improve the construction process:

- Soil should be conditioned so that it is sufficient to establish and support the vegetation selected for the site.
- Time biofilter establishment to coincide with periods of greater rainfall and the natural growing season of the selected vegetation.

- If use of sod is unavoidable, place it without gaps and staggered to avoid channelization.
- Use a roller on the sod to ensure that no air pockets form between the sod and the soil.

Physical erosion controls will be necessary on steeper slopes to protect seeds for at least 75 days after the first rainfall of the season. Erosion controls might include the placement of a blanket, mulch, or other biodegradable cover over the seeded portion of the site.

8.7.4 Operation and Maintenance

Based on the level of maintenance required in this study, future maintenance activities should include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes inspection of vegetation, observation of flow across swale invert and sediment and debris accumulation.
- Inspect strips at least twice annually for erosion or damage to vegetation, preferably at the end of the wet season to schedule summer maintenance and before major fall runoff to be sure the strip is ready for winter. However, additional inspection after periods of heavy runoff is most desirable. The strip should be checked for debris and litter, and areas of sediment accumulation.
- Recent research on biofiltration swales but likely also applicable to strips (Colwell et al., 2000) indicates that grass height and mowing frequency have little impact on pollutant removal; consequently, mowing may only be necessary once or twice a year for safety and aesthetics or to suppress weeds and woody vegetation.
- Trash tends to accumulate in strip areas, particularly along highways. The need for litter removal should be determined through periodic inspection, but litter should always be removed prior to mowing.

9 STORM-FILTER™

9.1 Siting

The Storm-Filter™ is a proprietary water quality treatment device that uses cartridges filled with different types of media to filter stormwater runoff. One maintenance station in District 11 (Kearny Mesa) was selected for installation of this technology and the watershed characteristics for this site are summarized in Table 9-1. Siting criteria are similar to those for other media filters and include:

- No bare soil or construction activities up-gradient of the site
- Tributary area of less than 8 ha
- Adequate hydraulic head (about 1 m) to operate by gravity flow

Table 9-1 Summary of Contributing Watershed Characteristics for Storm-Filter™

Site	Land Use	Watershed Area Hectare	Impervious Cover %
Kearny Mesa	Maintenance Station	0.6	100

9.2 Design

The Storm-Filter™ is sized based on the maximum flow rate to be treated as specified by the manufacturer. Design specifications are summarized in Table 9-2 and the hydrologic conditions are listed in Table 9-3. A schematic of the device is presented in Figure 9-1 and pictures of the actual site are shown in Figures 9-2 and 9-3.

Table 9-2 Design Criteria of the Storm-Filter™

Design Criteria	Value	Discussion
Number of canisters	Based on infiltration rate of media canisters	The manufacturer estimates that 30 canisters treat approximately 0.028 m^3/s or 0.0009 m^3/s/canister.
Pretreatment vault volume	2 min at peak flow	The volume of the pretreatment vault should be sized with a volume produced by the peak flow rate for a 2 min period.
Filter media	Media canisters	Canisters are supplied by manufacturer; media type is combination of perlite and zeolite.

Table 9-3 Design Characteristics of the Storm-Filter™

Site	Design Storm mm	Design Storm Discharge L/s	WQV[a] m^3	Number of Canisters	Number of Chambers
Kearny Mesa	36	76	194	86	3

[a] Volume treated during a design storm.

The manufacturer offers various media types. A perlite/zeolite combination was selected for this study based on a recommendation by the manufacturer. Perlite is a puffed volcanic ash. It is porous with rough edges and the manufacturer recommended it for the removal of TSS and oil and grease. Zeolite is a naturally occurring mineral recommended for the removal of soluble metals, ammonium and some organics.

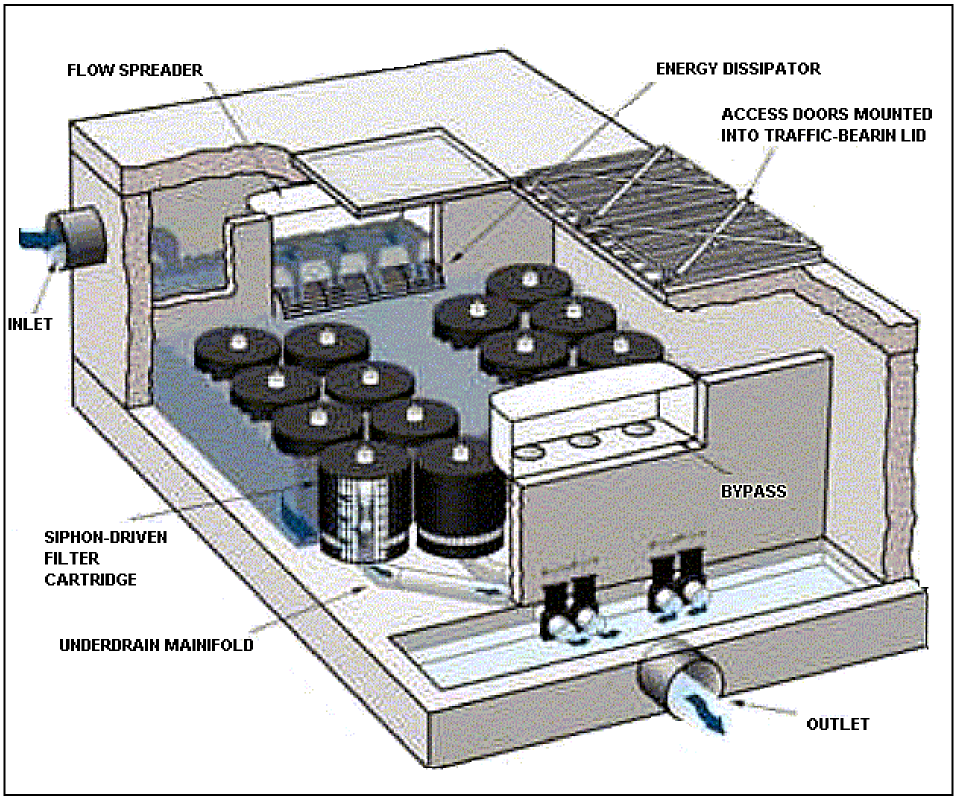


Figure 9-1 Schematic of a Storm-Filter™

(SOURCE: Stormwater Management, Inc.)

Figure 9-2 Surface View at Kearny Mesa

Figure 9-3 Internal View at Kearny Mesa

9.3 Construction

9.3.1 Construc tability

Stormwater Management, Inc. (SMI) provided media cartridge filters in precast vaults as a package system. During the design and construction phase, it was difficult to obtain specific design details on the vaults and appurtenances required to prepare the construction drawings and specifications.

The filter media was changed from CSF® leaf media (compost) to perlite/zeolite during the design phase of the project. The treatment system specifications for this site were developed in February and March of 1998. SMI provided specifications on CSF® leaf media (compost) for incorporation into the *Special Provisions*. Although CSF® leaf media was the standard filter media in use at the time, SMI was conducting research into the use of perlite/zeolite media. By the time of actual construction in early 1999, research had led to the selection of perlite/zeolite as the media of choice for a maintenance station type application and SMI provided it as the filter cartridge media.

9.3.2 Unknown Field Conditions

During excavation for the filter and pretreatment vaults, sandstone was encountered at a depth of approximately 1 m. To remove this material, special excavation equipment (hoe ram) was used to break through the sandstone. The excavated materials were not suitable for backfill and had to be removed from the site at an additional cost. Removing the sandstone at the subgrade produced an uneven surface; thus, it was as necessary to excavate beyond the subgrade and to backfill to the subgrade with imported materials to provide a uniform foundation under the vault.

The contractor began excavation and was informed by the Caltrans permit inspector that the work was in potential conflict with a City of San Diego 900 mm high-pressure water transmission main within an existing easement. The existence of the pipeline and easement were not shown on the plans and were not discovered during utility research for the project. Further research and coordination with the City of San Diego confirmed that the location of this easement was in conflict with the proposed BMP. The contractor was directed to stop construction, while the exact easement location was determined. The plans were revised, and construction staking was rescheduled. The filter vaults were moved approximately 4 m northeast of the original location. This new location required removal and replacement of approximately 30 m of concrete gutter and minor asphalt pavement. The relocation also caused a manhole with a non-traffic-rated lid to be moved into a traffic area, requiring replacement of the lid with a traffic-rated lid. In addition, the contractor incurred expenses due to down time of equipment that had been mobilized to the site and was inactive. This experience reinforces the necessity for site characterization to identify utility conflicts and other unseen potential problems.

Additionally, the existing storm drain outlet for the BMP was located in an easement owned by the City of San Diego. The project was delayed while modification of the storm drain was discussed with the City. The City required an encroachment permit in order for the work to be completed.

9.4 Maintenance

Maintenance items for the Storm-Filter™ included inspection of sediment accumulation and removal of sediment from the pretreatment sedimentation basin when the accumulation exceeded 300 mm. Sediment removal was not required during the course of the study. In addition, weekly inspections for trash accumulation were conducted during the wet season. The design flow rate of 0.0009 m^3/s per canister was evaluated during one storm per month during the wet season. The Storm-Filter™ was inspected for standing water annually at the end of the wet season, and monthly to identify damage to inlet and outlet structures, and evidence of graffiti or vandalism.

The Storm-Filter™ was inspected monthly for minor maintenance in accordance with the manufacturer's guidelines, including flushing of the underdrains. The site was inspected annually in August/September for major maintenance.

An average of only about 23 hr/yr were required for field activities, not including 45 hours for vector control activities. As shown in Figure 9-4, field inspections were the largest field activity. The number of inspections and time spent reflect the requirements of the (MID), which required weekly inspections during the wet season. Seasoning of the Storm-Filter™ at the beginning of the second wet season was the second largest activity. This involved flushing the Storm-Filter™ with water to remove suspended solids from the media. This was done because data from the first year of monitoring indicated significant export of some constituents (TSS, dissolved Pb). It is suggested that seasoning of the media before installation by the manufacturer be required for any future installations.

The Storm-Filter™ holds water in the pretreatment sedimentation chamber and thus is a potential source of vector problems. Table 9-4 shows the number of occurrences of mosquito breeding and number of abatement actions that were taken.

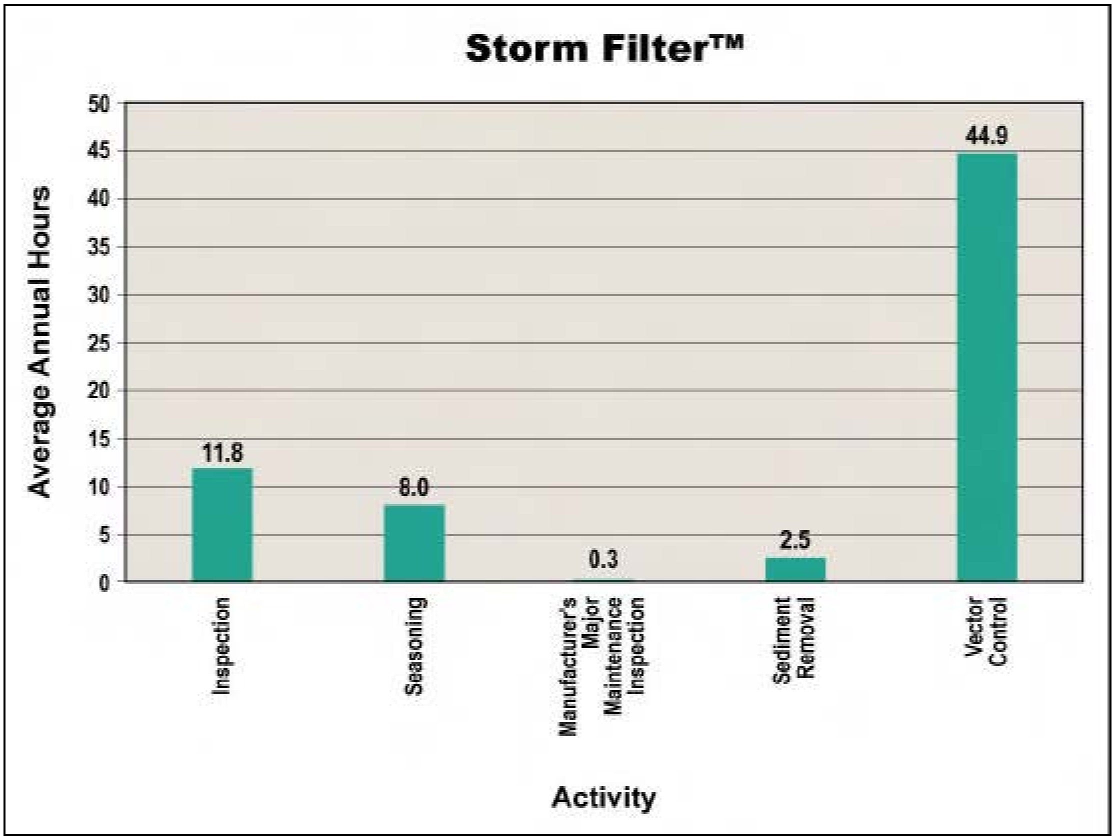


Figure 9-4 Field Maintenance Activities for the Storm-Filter™ (1999-2001)

Table 9-4 Incidences of Mosquito Breeding – Storm-Filter™

Site	Number of Times	
	Breeding Observed	Abatement Performed
Kearny Mesa	14	0

9.5 Performance

9.5.1 Chemical Monitoring

The concentration reductions observed during the monitoring program are shown in Table 9-5. Since this device is constructed of concrete, it was assumed that influent and effluent volumes were equal and consequently the load reduction is equal to the concentration reduction. The column labeled "Significance" is the probability that the influent and effluent concentrations are not significantly different. Statistically significant differences between influent and effluent concentrations at the 90 percent confidence level were observed only for TSS and total metals. In general, the results compare unfavorably to filters that employ sand as the filter medium, such as the Austin and Delaware designs.

The results of the monitoring program shown in Table 9-5 do not include the first year's monitoring data. During this period, the device was a net exporter of almost all constituents. The Storm-Filter™ was "seasoned" during the following summer by flushing the canisters with potable water and performance improved markedly during the following wet seasons.

The generally low removals were surprising in that the average influent concentrations at this site were among the highest measured in this study. For instance, the TSS influent concentration was approximately twice that observed for the Austin-style filter sites. The modest TSS removal resulted in a concentration in the effluent that was still larger than the influent concentrations at many other pilot program sites. Although the selected media (zeolite and perlite) reputedly provide better metals removal than sand, lead and zinc removals were much less than that of the Austin filters. There are no previously published independent studies of the effectiveness of other Storm-Filter™ units utilizing this media with which to compare the performance of this particular installation.

Table 9-6 presents the results of the regression analysis of influent and effluent concentrations. In contrast to the sand filters, the effluent TSS concentration is correlated with the influent concentration, indicating that the effluent quality is not as consistent as that produced by the other types of filters.

Table 9-5 Concentration Reduction of the Storm-Filter™

Constituent	Mean EMC[d] Influent mg/L	Mean EMC[d] Effluent mg/L	Removal %	Significance P
TSS	174	104	40	0.038
NO_3-N	1.03	1.09	-7	0.759
TKN	3.15	2.56	19	0.292
Total N [a]	4.18	3.65	13	-
Ortho-phosphate	0.15	0.14	9	0.659
Phosphorus	0.43	0.36	17	0.318
Total Cu	0.142	0.066	53	0.004
Total Pb	0.070	0.033	52	0.006
Total Zn	0.802	0.389	51	0.001
Dissolved Cu	0.038	0.031	18	0.257
Dissolved Pb	0.003	0.002	15	0.534
Dissolved Zn	0.205	0.167	18	0.296
TPH-Oil [b]	3.3	1.6	52	0.119
TPH-Diesel [b]	3.3	1.1	67	0.281
TPH – Gasoline [b]	< 0.05[c]	< 0.05[c]	-	-
Fecal Coliform [b]	1500 MPN/100mL	800 MPN/100mL	47	0.574

[a] Sum of NO_3-N and TKN
[b] TPH and Coliform are collected by grab method and may not accurately reflect removal
[c] Equals value of reporting limit
[d] Event mean concentration

The sediment collected in the chambers of the Storm-Filter™ had to be removed in October 2000 and October 2001. All sediment and collected material that accumulated in the Storm-Filter™ was tested for hazardous materials prior to disposal. Testing found the material to be nonhazardous and therefore all material was disposed of at the landfill. Testing results can be found in Appendix F.

9.5.2 Empirical Observations

Most of the relevant empirical observations at this site concern standing water in the facility. Standing water was observed repeatedly in the pretreatment vault and cartridge chambers. The Storm-Filter™ is designed such that there is always standing water in the pre-sedimentation chamber and in the basin preceding the energy dissipaters in each chamber. Also, water is always present in the PVC piping that routes water from the filters to the outlet chambers. The vector control district reported minor breeding in these locations.

One potential reason for the modest pollutant removal observed is that the runoff has a very short residence time within the device. Figure 9-5 compares influent and effluent hydrographs for a typical storm. It is clear from this figure that there is little or no attenuation of peak flows in the device and consequently little time for particles to be filtered or to settle out of the runoff. This is in stark contrast to the hydrographs produced by sand filters and illustrated in Figure 2-8.

Table 9-6 Predicted Effluent Concentrations – Storm-Filter™

Constituent	Expected Concentration[a]	Uncertainty, ±
TSS	0.42x + 30.5	$92.9\left(\frac{1}{15}+\frac{(x-174.8)^2}{158959}\right)^{0.5}$
NO_3-N	0.84x + 0.23	$0.567\left(\frac{1}{15}+\frac{(x-1.0)^2}{7.26}\right)^{0.5}$
TKN	0.68x + 0.40	$0.45\left(\frac{1}{15}+\frac{(x-3.14)^2}{41}\right)^{0.5}$
P Particulate	0.19	0.10
Ortho-phosphate	0.78x + 0.02	$0.044\left(\frac{1}{9}+\frac{(x-0.15)^2}{0.04}\right)^{0.5}$
Particulate Cu	35.9	8.0
Particulate Pb	0.34x + 0.06	$35.9\left(\frac{1}{14}+\frac{(x-69)^2}{20346}\right)^{0.5}$
Particulate Zn	224	67
Dissolved Cu	0.81x + 1.06	$17.2\left(\frac{1}{14}+\frac{(x-37.6)^2}{3390}\right)^{0.5}$
Dissolved Pb	0.77x + 0.24	$1.68\left(\frac{1}{14}+\frac{(x-3)^2}{59}\right)^{0.5}$
Dissolved Zn	0.77x + 14.7	$52.9\left(\frac{1}{14}+\frac{(x-204)^2}{148350}\right)^{0.5}$

[a] Concentration in µg/L for metals; x = influent concentration

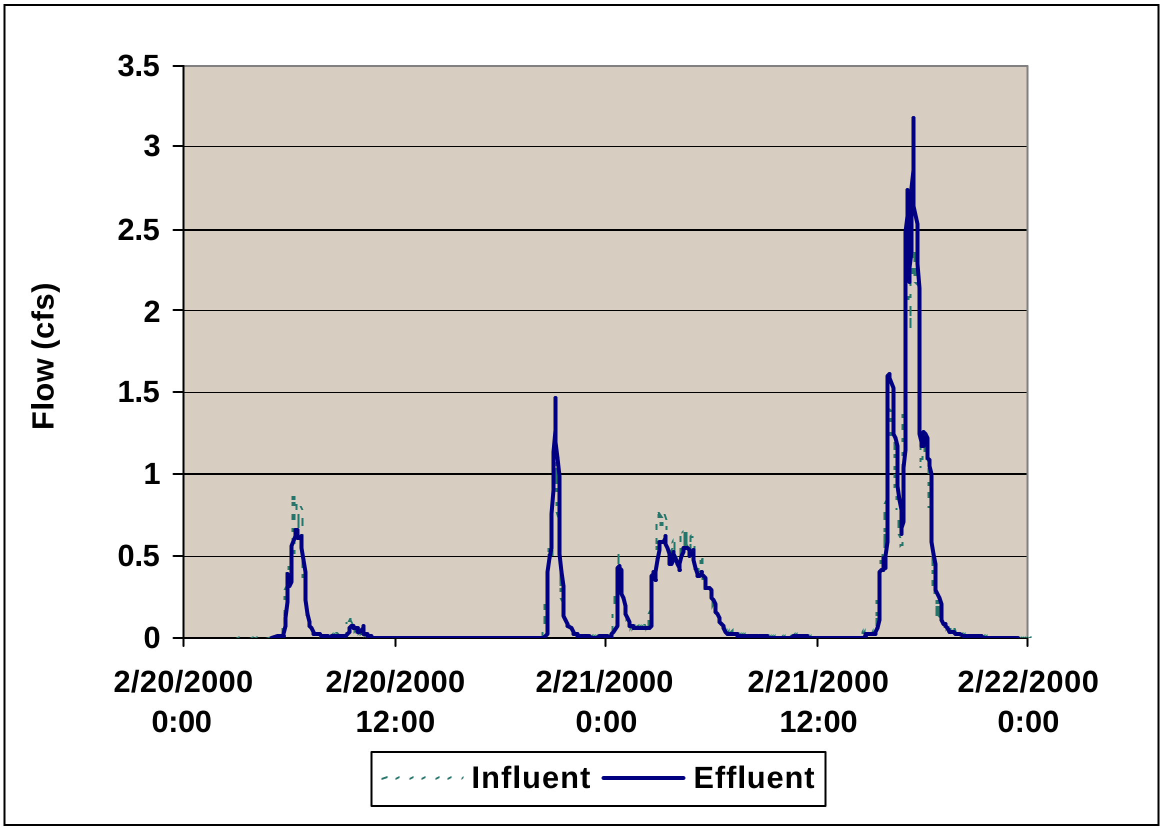


Figure 9-5 Comparison of Storm-Filter™ Influent and Effluent Flow Rates

9.6 Cost

9.6.1 Construction

The construction costs for the Kearny Mesa site are presented in Table 9-7. The cost per unit water quality volume treated was similar to the Austin sand filters that did not include pumps in the design.

The adjusted cost for the Storm-Filter™ is shown in Table 9-8. As in Table 9-7, the only adjustment to the cost was for features associated with monitoring. Including this cost would increase the adjusted cost by 6 percent. This cost was excluded from the analysis for estimating the adjusted cost.

Table 9-7 Actual Construction Costs for Storm-Filter™ (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m³
Kearny Mesa	325,517	305,355	1,575

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Table 9-8 Adjusted Construction Costs for Storm-Filter™ (1999 dollars)

Storm-Filter™	Adjusted Construction Cost, $	Cost/WQV $/m³
One location	305,356	1,572

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

The Storm-Filter™ installation was in a maintenance station and consequently did not incur traffic control costs. If constructed roadside, Storm-Filter™ could incur traffic control cost typical of EDBs, in which traffic control accounted for an average of 9 percent of the adjusted construction cost. Traffic control costs were not used to estimate adjusted construction cost.

9.6.2 Operation and Maintenance

An average of 67 hr/yr was spent on field activities, including inspections, maintenance and vector control activities and no equipment was required. Table 9-9 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 9-9 Actual Average Annual Maintenance Effort – Storm-Filter™

Activity	Labor Hours	Equipment & Materials $
Inspections	12	-
Maintenance	11	0
Vector control*	45	-
Administration	39	-
Direct Cost	-	308
Total	**107**	**$ 308**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate a Storm-Filter™ or reflect the design lessons learned during the course of the study. Table 9-10 presents the expected maintenance costs that would be incurred under the final version of the MID for a Storm-Filter™ serving about 2 ha, constructed following the recommendations in Section 9.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as filter media replacement, were not performed during the relatively short study period. Only one hour is shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. This estimate also assumes that the facility is constructed of concrete and no vegetation maintenance is required. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Vector control hours were converted to cost assuming an hourly rate of $62. Equipment generally consists of a single truck for the crew, their tools, and material removed from the filter.

Table 9-10 Expected Annual Maintenance Costs for Final Version of MID- Storm-Filter™

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	39	131	1,847
Vector control	12	0	744
Administration	3	0	132
Direct Costs	-	2,800	2,800
Total	**55**	**$2,931**	**$5,567**

9.7 Criteria, Specifications and Guidelines

The Storm-Filter™ did not perform as well as other non-proprietary media filters (Austin and Delaware sand filters). The Storm-Filter™ manufacturer continues to refine and develop new filter media; consequently, improvements in this area may support consideration in the future. The Storm-Filter™ is considered technically feasible for use at the piloted location; however, other technologies provide better performance for less capital cost. Should this technology be selected for implementation, the following information may be useful.

9.7.1 Siting

The original siting criteria seem to have been generally successful at locating the Storm-Filter™. Based on the results of this study, the primary siting criteria recommended for future installations include the following:

- Sufficient head to allow operation by gravity flow (about 1.0 m)
- Relatively small, highly impervious ultra-urban contributing watershed
- No construction planned up-gradient of the proposed location
- No installation in areas where vector control is not feasible
- No construction near side slopes where leaks could impact slope stability
- Avoid areas with potentially high sediment load

9.7.2 Design

Since these devices are proprietary, the manufacturer provides sizing and configuration design and all materials. Based on the observations and measurements in this study, the following guidelines are recommended:

- Provide a method to completely drain the facility between storms and during the dry season to address concerns about vector issues.
- Consider alternative media since the zeolite/perlite mixture in the filter cartridges did not provide any improvement in constituent removal as compared to compost.
- When possible, use standardized designs and prefabricated vaults to reduce costs.
- If mosquito breeding is a concern, include vector-restricting covers in the initial design.

9.7.3 Construction

Determining the location of all utilities prior to construction may not be practical due to limited documentation of utility locations. It is suggested that a small (1 to 2 percent) contingency be provided in case unknown utilities are encountered. In addition, unsuitable material was encountered at many of the construction sites. Sufficient borings should be made before going out for bid to avoid the delays and expense of contract change orders.

As noted previously, the Storm-Filter™ exported constituents until flushed with potable water following the first wet season. For future installations, a requirement that the supplier provide cartridges that are pre-washed would improve performance and reduce the short-term impact to receiving waters.

9.7.4 Operation and Maintenance

Several factors contributed to the reduced maintenance requirements for the Storm-Filter™. The chambers were constructed of concrete consequently no vegetation maintenance was required and slope stability was not an issue. Additional reduction in maintenance costs could be expected by reducing the maintenance frequency from weekly to semiannually (assuming vectors are adequately controlled).

Based on the level of maintenance required in this study, recommended future maintenance activities include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes checking for media clogging, replacement of filter media, and inspection for standing water.

- Schedule semiannual inspection for beginning and end of the wet season to identify potential problems.
- Remove accumulated trash and debris in the pretreatment chamber, stilling basin, and the filter chamber during routine inspections.
- Develop guidance to identify the proper interval for removal and replacement of media canisters. Ensure canisters are properly seasoned before start of the wet season.
- Remove accumulated sediment in the pretreatment chamber every 5 years or when the sediment occupies 10 percent of the volume of the filter chamber, whichever occurs first.

10 MULTI-CHAMBERED TREATMENT TRAIN

10.1 Siting

Three Multi-Chambered Treatment Trains (MCTTs) were planned for District 7 for inclusion in this study. The Metro Maintenance station installation was not completed in time for this evaluation; therefore, the following discussion is based on the experience with this technology at the Via Verde and Lakewood Park & Rides.

The MCTT was developed for treatment of stormwater at critical source areas specifically to reduce stormwater toxicity in the ultra-urban environment (Pitt et al., 1999). The target area for use of this particular device includes vehicle service facilities, parking areas, paved storage areas and fueling stations with tributary areas of 0.1 to 1 ha. Similar types of land use areas are common at Caltrans facilities. Characteristics of the contributing watersheds for the two subject sites are shown in Table 10-1.

MCTTs need enough vertical clearance to operate hydraulically, a minimum of about 1.5 m for gravity flow. The elevation difference between the inlet and outlet must include clearance for the depth of the inlet sump, sedimentation chamber, water on top of the filter, the filter media, and the underdrains. The selected sites lacked sufficient head for unit operation and two pumps were installed at each site, one to transfer runoff from the sedimentation chamber to the filter and one to return the treated discharge to the pre-existing drainage system.

Table 10-1 Summary of Contributing Watershed Characteristics for MCTTs

Site	Land Use	Watershed Area Hectare	Impervious Cover %
Via Verde P&R	Park & Ride lot	0.44	100
Lakewood P&R	Park & Ride lot	0.76	100

10.2 Design

The MCTTs were designed as a three-stage device as illustrated in Figure 10-1. Figures 10-2 and 10-3 show internal and external views of the MCTTs, respectively. The first stage consisted of a catch basin with sump and packed column aerators. This was followed by the main settling chamber that included tube settlers to improve particulate removal and sorbent pillows to capture floating hydrocarbons. The sedimentation basin was designed so that the water quality volume is held above the tube settlers, which are nominally 0.6 m deep with about 0.3 m of plenum space underneath. The sorbent pillows are “Oilup Sorbent Blue Booms.” The dimensions of the MCTTs are summarized in Table 10-2.

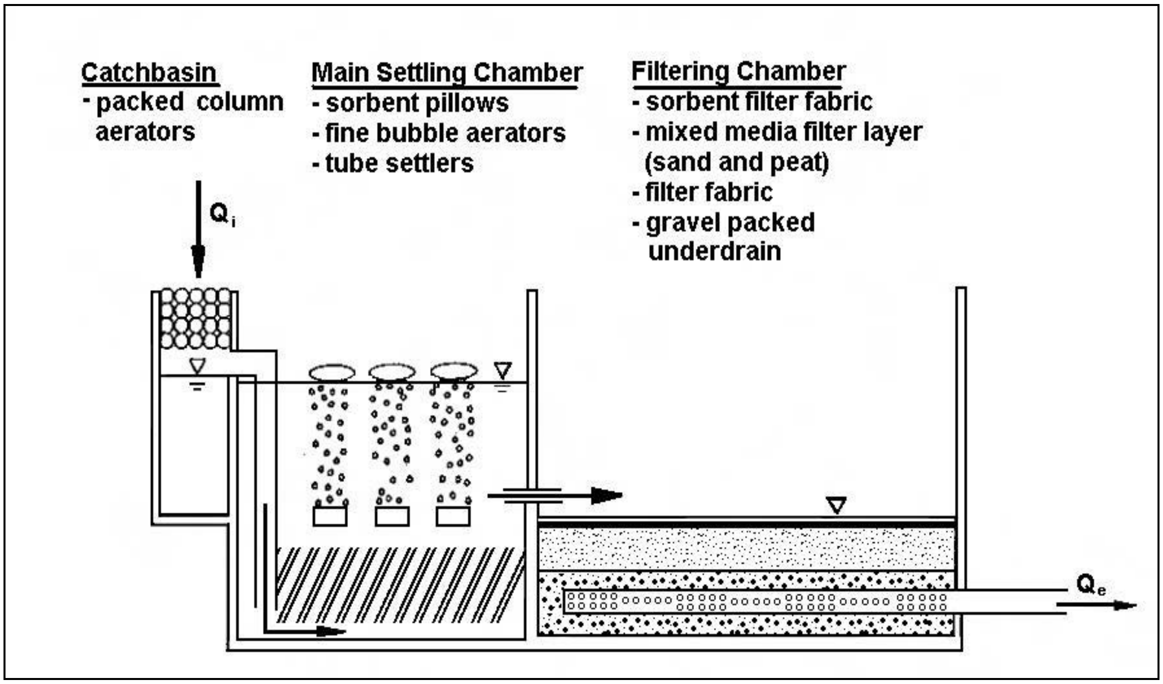


Figure 10-1 Schematic of an MCTT (Source: Pitt, et al., 1999)

Fine bubble aerators were not incorporated in the study designs, because the concentration of volatile organics was expected to be low in runoff from a park-and-ride. As mentioned previously, pumps were included in the design to move the runoff from the sedimentation chamber to the filter chamber. Although the pumps could be triggered automatically, for this study they were activated manually on the day following a storm event to ensure that the runoff remained in the sedimentation basin for at least 24 hours.

The final chamber consisted of a 600 mm thick filter media layer consisting of a 50/50 mixture of sand and peat moss. This layer is separated from a gravel-packed underdrain by a layer of filter fabric. The filter area was determined from the recommended solids loading rate of the peat/sand mixture of 5000 g TSS/m^2/yr (Pitt, et al., 1999). To estimate the solids loading it was assumed that the TSS influent concentration to the device was 100 mg/L, of that half was retained in the settling chamber, and of the remainder, 90 percent was retained on the filter. Pumps were employed to return the filtered runoff to the pre-existing drainage system.

Figure 10-2 Surface View of an MCTT (Via Verde P&R)

Figure 10-3 Internal View of an MCTT (Lakewood P&R)

Table 10-2 Design Characteristics of the MCTTs

Site	Design Storm mm	WQV m^3	Sedimentation Basin Area m^2	Filter Basin Area m^2
Via Verde P&R	25	123	35.5	17.4
Lakewood P&R	25	173	61.2	32.9

10.3 Construction

The lessons learned during the construction of the MCTTs were similar to those described for sand filters and centered on material availability for the filter, excavation of the site for the device, unknown field conditions, and interface with existing activities at the site. The filters were all constructed in park-and-ride facilities that provided a limited work area and the requirement to coordinate with normal facility operations. For additional information, see Section 2.3 in *Sand Filters*.

The tube settler systems and associated stainless steel hardware were special-order items requiring a significant lead-time. The fabrication and delivery time should be considered in the construction schedule, or the items should be pre-purchased. Further, the sand specified in the plans for the filter was a special gradation and required a custom mix with additional time and expense.

Since the MCTTs are designed to maintain a permanent pool covering the tube settlers, it is important that the facilities be made watertight. Leaks were detected at the Via Verde site during operation of the facility and an additional $35,000 was required to waterproof the sedimentation chamber and line the piping between the grit and sedimentation chambers.

Difficult excavation was a problem at the Via Verde site. The MCTT unit requires a significant excavation with a sound subgrade. Large boulders were removed at the site from the excavation, resulting in increased costs and construction time.

Unmapped utilities were encountered at the Lakewood site. Two 100 mm water service lines were damaged as well as a 50 mm electrical conduit. None of these utilities were shown on as-built drawings.

Site layout was also an issue during construction. At the Via Verde site, the City requested that a recently installed electric vehicle charging station not be relocated to avoid conflict with the MCTT. The MCTT design was modified at the City's request. In addition, power was not available at the Via Verde site to operate the pumps, except from the existing lighting system, and additional trenching was required to establish the service.

10.4 Maintenance

Major maintenance items for MCTTs include removal of sediment from the sedimentation basin when the accumulation exceeds 150 mm and removing and replacing the filter media every 3 years. Neither of these activities where required during the course of the study. After two wet seasons, total accumulated sediment depth was less than 25 mm. This indicates that sediment removal may not be required for as many as 10 years or more. The sorbent pillows are scheduled to be replaced annually or sooner if darkened by oily stains.

In addition, weekly inspections for trash accumulation in the inlet and outlet structures were conducted during the wet season. Finally, monthly inspections also were conducted to identify damage to inlet and outlet structures, and evidence of graffiti or vandalism.

MCTTs generally have greater maintenance requirements than many other types of stormwater treatment facilities. An average of about 108 hr/yr was required for field activities, not including the 70 hours needed for vector control activities. This is nearly twice the maintenance required for the Austin and Delaware media filter designs. As shown in Figure 10-4, vector-related issues, including dewatering and mosquito proofing the sites account for a significant amount of the fieldwork. Structural repair of the leaks at Via Verde and pump replacement and repair also contributed substantially to the large total. As with the pumped sand filters, the pumps and associated electrical circuits were a continual source of problems. The number of inspections and time spent reflect the requirements of the MID, which required weekly inspections during the wet season.

Previous MCTT installations in Wisconsin did not use pumps, but used small orifices to control the water flows (Corsi et al., 1999). These installations therefore did not experience these electrical or pumping maintenance problems. In addition, it is expected that underground and fully sealed MCTT installations would have needed much less vector abatement activity.

MCTTs were originally conceived to be small footprint devices that would be covered. Because of the size of the drainage area and required water quality volume, the two constructed devices are much larger than any implemented previously. Consequently, the original designs did not call for covers for the two facilities. Unfortunately, the open design provided easy access for mosquitoes to the permanent pool of water below the tops of the tube settlers in the sedimentation chamber. This standing water required repeated abatement activities, and the tube settlers compromised the ability of the vector control agencies to adequately monitor larval growth. The tube settlers also made abatement difficult since each settler formed, in effect, a separate chamber. Covers were fabricated for both sites and installed in February 2001 to eliminate mosquito access to the areas with standing water.

Maintenance activities at the MCTT sites also were hampered by the lack of adequate access and by the presence of the tube settlers. Each basin was fitted with a rung-type ladders to allow maintenance personnel access; however, these are not sufficient for allowing equipment access for major maintenance activities.

Since the MCTT maintains a permanent pool below the tops of the tube settlers, mosquito breeding was a constant problem at these sites. Table 10-3 shows the number of occurrences of mosquito breeding and the number of abatement actions that were taken. In addition, the presence of the settlers restricted access to the runoff and hampered effective mosquito abatement activities. The operation practices had to be modified to allow 0.3 m of water to remain above the settling tubes to allow for vector inspection and abatement. Both sites were ultimately completely enclosed to prevent mosquito access, which added $35,000 to the cost (excluded from costs shown in Tables 10-6 and 10-7). Litter and other debris also occasionally blew into the basin, and the tube settlers impeded access when removal of this material was necessary.

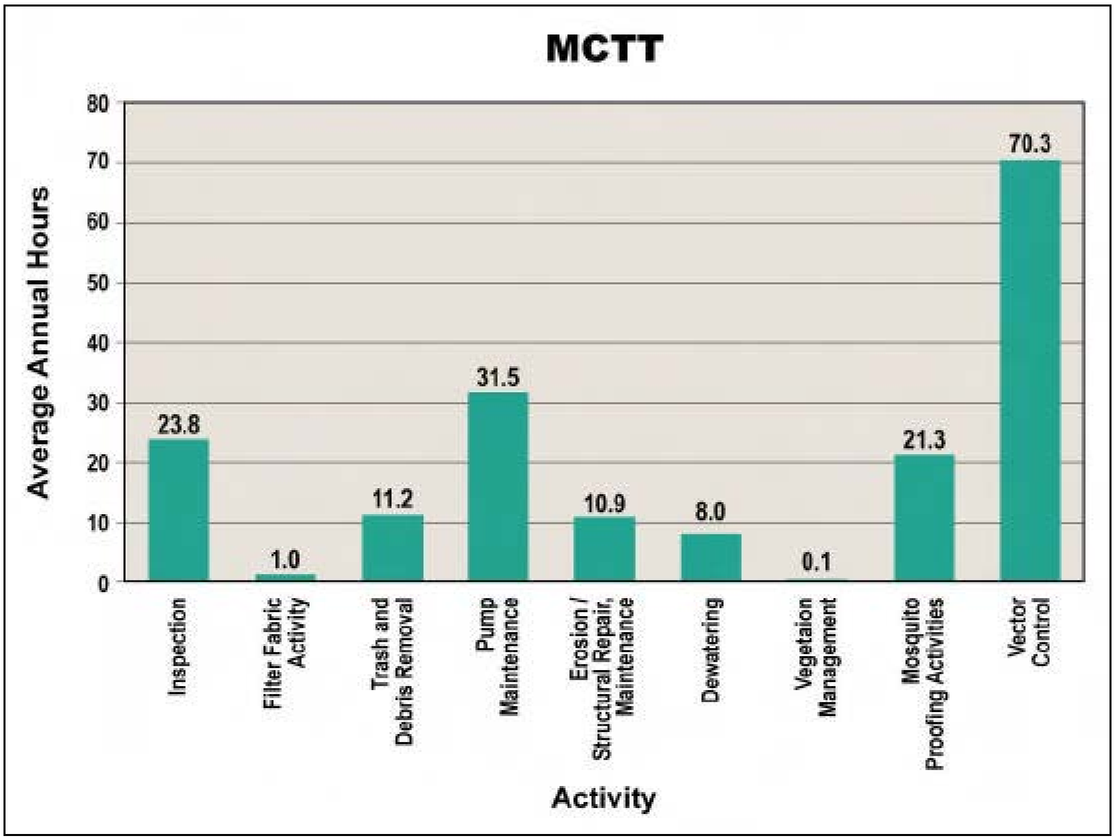


Figure 10-4 Field Maintenance Activities at MCTT Sites (1999-2001)

Table 10-3 Incidences of Mosquito Breeding - MCTTs

Site	Number of Times	
	Breeding Observed	Abatement Performed
Via Verde P&R	7	7
Lakewood P&R	49	43

Draining of the MCTTs at the end of the wet season was also extremely difficult due to the need to remove the settling tubes. In addition, a supplemental pump or relocation of an existing pump was needed to pump the MCTT dry. A method for complete draining of the sedimentation basin should be incorporated in the design of the MCTT.

10.5 Performance

10.5.1 Chemical Monitoring

Data from both of the MCTT sites were combined for calculating performance. Since both of the devices are constructed of concrete, it is assumed that the effluent volume equals the influent volume (i.e., there are no significant infiltration or evaporation losses). Therefore, all constituent mass reduction is reflected by the reduction in concentration between the influent and effluent.

The data shown in Table 10-4 indicate that the observed constituent reduction is generally comparable to that observed in sand filters. As with the sand filters, nitrate increased; however, unlike the sand filters there was no removal of total nitrogen. In addition, there was export of ortho-phosphate indicating that the peat used in the media mixture was exporting nutrients. The column labeled “Significance” is the probability that the influent and effluent concentrations are not significantly different.

The performance for constituents such as TSS is especially good in light of the very low influent concentrations measured. The last column in the table summarizes removal efficiencies reported by Pitt et al. (1999). These data indicate that the devices in this study performed roughly the same as those evaluated previously.

Although the filter media consisted of a mixture of sand and peat, which is intended to provide better performance than filter systems using sand alone, the difference in constituent removal between Austin sand filters and the MCTTs was generally small.

Table 10-4 Concentration Reduction of MCTTs

Constituent	Mean EMC		Removal %	Significance P	Concentration Reduction Previous Work (Pitt et al., 1999)
	Influent mg/L	Effluent mg/L			
TSS	40.8	10.2	75	<0.000	83
NO_3-N	0.47	0.78	-68	0.004	24
TKN	1.93	1.61	17	0.471	NA
Total N [a]	2.40	2.39	0	-	NA
Ortho-phosphate	0.120	0.123	-3	0.972	NA
Phosphorus	0.22	0.18	18	0.302	NA
Total Cu	0.011	0.007	35	0.129	22
Total Pb	0.007	0.002	74	<0.000	93
Total Zn	0.146	0.037	75	0.009	91
Dissolved Cu	0.006	0.005	22	0.408	17
Dissolved Pb	0.002	0.001	32	0.177	42
Dissolved Zn	0.074	0.022	71	<0.000	46
TPH-Oil [b]	1.0	0.3	70	0.161	NA
TPH-Diesel [b]	1.0	0.2	80	0.186	NA
TPH-Gasoline [b]	<0.05[c]	<0.05[c]	-	-	NA
Fecal Coliform [b]	700 MPN/100mL	600 MPN/100mL	14	1.000	NA

[a] Sum of NO_3-N and TKN
[b] TPH and Coliform are collected by grab method and may not accurately reflect removal
[c] Equals value of reporting limit

Table 10-5 summarizes the results of the linear regression analysis of influent and effluent concentrations. The analysis revealed many of the same phenomena observed for the sand filters. The effluent concentrations of most of the particulate constituents were independent of the influent concentration and are best represented as constant values, while the effluent concentrations of dissolved constituents were generally a function of influent concentration.

Table 10-5 Predicted Effluent Concentrations - MCTT

Constituent	Expected Concentration [a]	Uncertainty, ±
TSS	9.8	2.4
NO_3-N	0.52x + 0.57	$0.48\left(\frac{1}{16}+\frac{(x-0.41)^2}{2.69}\right)^{0.5}$
TKN	0.78x + 0.08	$1.61\left(\frac{1}{18}+\frac{(x-1.97)^2}{39}\right)^{0.5}$
P Particulate	0.12	0.04
Ortho-Phosphate	0.55x + 0.05	$0.10\left(\frac{1}{9}+\frac{(x-0.11)^2}{0.04}\right)^{0.5}$
Particulate Cu	1.1	0.5
Particulate Pb	0.7	0.7
Particulate Zn	4.4	2.0
Dissolved Cu	0.39x + 2.4	$5.20\left(\frac{1}{17}+\frac{(x-6.1)^2}{456}\right)^{0.5}$
Dissolved Pb	1.1	0.14
Dissolved Zn	0.19x + 5.2	$17.5\left(\frac{1}{17}+\frac{(x-73)^2}{35565}\right)^{0.5}$

[a] Concentration in mg/L except for metals, which are µg/L.; *x* = influent concentration

10.5.2 Empirical Observations

Empirical observations were recorded during and after storm events. One of the primary concerns at these two sites was the use of pumps for transferring the runoff. As mentioned in the maintenance section, the pumps and associated electrical circuits were a significant source of problems. The pumps were powered by the same electrical circuits as the park-and-ride lights and at the Lakewood site, there was insufficient power at night to operate the pumps. In addition, pumps failed on several occasions, requiring replacement – a situation likely caused or exacerbated by the low voltage condition.

10.6 Cost

10.6.1 Construction

The construction costs for the two sites are presented in Table 10-6. The costs per water quality volume treated were similar to the Austin sand filters that included pumps, although the costs were significantly more than for Austin sand filters that drained by gravity.

Table 10-6 Actual Construction Costs for MCTTs (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
Via Verde P&R	383,793	375,617	3,054
Lakewood P&R	464,743	456,567	2,639

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

The adjusted construction costs for the MCTTs are shown in Table 10-7. Reductions to the actual MCTT costs were made for the following reasons:

- The MCTTs were installed in areas where existing conditions did not allow for gravity drainage and space constraints required extensive shoring. Including the cost of pumps and extensive shoring increases adjusted cost by 41 percent and 52 percent for the two locations. These costs were excluded from the adjusted cost.
- Miscellaneous site-specific factors caused increased construction cost at both locations. This cost would increase the adjusted cost by 1 percent. These costs were excluded from the adjusted cost.

Table 10-7 Adjusted Construction Costs for MCTTs (1999 dollars)

MCTT	Adjusted Construction Cost, $	Cost/WQV $/m^3
Mean	275,616	1,875
High	320,531	1,895
Low	230,701	1,856

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

All MCTT installations were in park-and-ride lots and subsequently did not incur traffic control costs. If constructed roadside, MCTTs could incur traffic control cost typical of EDBs, in which traffic control accounted for an average of 9percent of the adjusted construction cost. Traffic control costs were not used to estimate adjusted construction cost.

In January 2001 the sedimentation chamber and inlet pipe at the Via Verde MCTT had to be repaired and waterproofed when the BMP was found to be leaking. This was done at a cost of $15,000.

10.6.2 Operation and Maintenance

Table 10-8 shows the annual average number of hours required for maintaining the BMP as described above. The operation and maintenance hours are generally higher due to numerous problems encountered with the pumps. Lakewood did not receive enough power during the evening hours when the park-and-ride lights were on, so the site had to be visited after every storm to manually turn on the pump during the daylight hours when there was enough power. Problems encountered with the pumps themselves also resulted in additional maintenance. The higher number of field hours at Via Verde was mainly associated with the work to repair leaks in the facility. Field hours include inspections, maintenance and vector control.

Table 10-8 Actual Operation and Maintenance Hours for MCTTs

District	Site Name	Average Annual Equipment Hours	Average Annual Field Hours
7 (Los Angeles)	Via Verde P&R	44	125
	Lakewood P&R	35	231
	Average Value	**40**	**178**

Table 10-9 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 10-9 Actual Average Annual Maintenance Effort – MCTT

Activity	Labor Hours	Equipment & Materials, $
Inspections	24	-
Maintenance	84	308
Vector control*	70	-
Administration	131	-
Direct cost	-	2,504
Total	**309**	**$ 2,812**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate an MCTT or reflect the design lessons learned during the course of the study. Table 10-10 presents the expected maintenance costs that would be incurred under the final version of the MID for an MCTT serving about 2 ha, constructed following the recommendations in Section 10.7. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Some of the estimated hours are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Only one hour is shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. This estimate also assumes that the facility is constructed of concrete and no vegetation maintenance is required. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Vector control hours were converted to cost assuming an hourly rate of $62. Equipment generally consists of a single truck for the crew, their tools, and material removed from the filter.

Table 10-10 Expected Annual Maintenance Costs for Final Version of MID – MCTT

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	46	216	2,240
Vector control	12	0	744
Administration	3	0	132
Direct costs	-	4,006	4,006
Total	**62**	**$4,222**	**$7,166**

10.7 Criteria, Specifications and Guidelines

MCTTs were originally designed to reduce toxicity in runoff from critical stormwater source areas, including gas stations, oil change facilities, transmission repair shops and other auto repair facilities. The MCTT was designed with enhanced pollutant removal capabilities compared to a conventional sand filter in order to better operate in heavily contaminated areas for longer periods of time. The extra pretreatment capability protects the media from clogging before the filtration media is exhausted and the selection of appropriate filtration/sorption media also allows targeted control of specific pollutants.

In this study, MCTTs were installed at park-and-ride sites where the runoff contained relatively low levels of pollutants. Consequently, the extra pretreatment capabilities were not utilized. In addition, the performance evaluation of MCTTs was based on the removal of a number of conventional stormwater constituents, rather than on toxicity or PAH reduction. Using this measure of performance, the MCTTs provided approximately the same pollutant removal as sand filters. This is not surprising given that the device, in essence, is an enhanced media filter. At the same time, there are a number of areas in which MCTTs were at a disadvantage to the Austin sand filter design relative to maintenance requirements. A permanent pool of water is maintained in the MCTT, which increased vector concerns and hampered maintenance. The presence of tube settlers in the sedimentation basin also impeded maintenance activities.

MCTTs are considered technically feasible depending on site specific conditions. However, given the comparable performance, it is difficult to conceive of a situation within the context of Caltrans operations in which the selection of an Austin sand filter would not be a better choice for implementation where media filtration of stormwater discharges is desired. Nevertheless, should implementation of an MCTT be considered, the following lessons learned, similar to those for sand filters, may be useful.

10.7.1 Siting

The original siting criteria seem to have been generally successful at locating MCTTs where they could operate effectively. The lack of sufficient head to drive these devices with gravity flow was overcome at all sites with the use of pumps. The pumps have not performed well. Based on the results of this study the primary siting criteria for future installations should include:

- Allow sufficient head to operate by gravity flow (about 1.0 m).
- Contributing watershed area should be relatively small and highly impervious.
- Do not plan any construction up-gradient of the proposed location.
- Avoid installing the device in areas where vector propagation may be a concern.

10.7.2 Design

Because these devices have had no implementation history in California, design engineers were unfamiliar with basin configuration, filter sizing and appropriate sources of sand for the filter, tube settlers, and absorbent booms. Consequently, design details would be useful to engineers with limited experience. In addition, there are other media filter configurations not tested in this study, such as under-pavement designs and shallower chambers that may be more economical, less intrusive on work space, and acceptably fulfill other requirements. Based on the observations and measurements in this study, the following guidelines are recommended:

- Provide a method to completely drain the sedimentation basin during the dry season if vector issues are a concern.
- The sand/peat mixture in the filtration chamber showed no improvement in removal of the monitored constituents as compared with a filter system using sand alone. Thus, the simpler medium may be preferred.
- When possible, use standard details and prefabricated vaults, where concrete vaults are needed.
- If mosquito breeding is a concern, include vector-restricting covers in the initial design.

10.7.3 Construction

Determining the location of all utilities before construction may not be practical due to limited documentation of utility locations. It is suggested that a small (1-2 percent) contingency be provided in case unknown utilities are encountered. In addition, unsuitable material was encountered at many of the construction sites. Sufficient borings should be made before going out for bid to avoid the delays and expense of contract change orders.

10.7.4 Operation and Maintenance

The MCTTs required more maintenance than other devices in this study; however, some factors helped control maintenance. The basins were constructed of concrete; consequently, no vegetation maintenance was required and slope stability was not an issue. Of course, the initial construction cost is significantly higher than it would be at a comparable site with earthen walls and floors. Additional reduction in maintenance costs could be expected by reducing the maintenance frequency from weekly to semiannually (assuming vectors are adequately controlled) and not siting the units where pumping is required.

Based on the level of maintenance required in this study, recommended future maintenance activities include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes inspections for trash and debris, sediment accumulation, standing water, and pump operation.
- Schedule semiannual inspections for the beginning and end of wet season to identify potential problems.
- Remove accumulated trash and debris in the sedimentation basin and the filter bed during routine inspections.
- Inspect the facility once during the wet season after a large rain event to determine whether the facility is draining completely within 48 hours.
- Remove and dispose of top 50 mm of media if facility drain time exceeds 72 hours. Restore media depth to 450 mm when overall media depth drops to 300 mm.
- Remove accumulated sediment in the sedimentation basin every 10 years or when the sediment occupies 50 percent of the volume underneath the tube settlers.
- Where there is a long dry season and concern with mosquito breeding, pump MCTTs dry at the end of the wet season.

11 DRAIN INLET INSERTS

11.1 Siting

A total of six drain inlet inserts (DIIs) were sited, installed, and monitored for this study. All were located within District 7. Of the six inserts, three were FossilFilter™ and three were StreamGuard™. One of each type of drain inlet insert was sited at each of three maintenance stations. Initially, six different DII manufacturers were considered. These included Aquafend Filter, FossilFilter™, Gullywasher® Geotextile CB Insert, Hydro-Kleen, StreamGuard™, and Zero Discharge Storm Drain Liner. These candidates use a variety of arrangements (e.g., trays, bags, and baskets) and construction materials (e.g., stainless steel, fiberglass, polypropylene, PVC, and galvanized steel).

The process of selecting two types of DIIs included review of manufacturers' literature and the limited test data available to identify the advantages and constraints of each of the technologies. Two different types of arrangements (bag vs. tray) where selected by the study team to allow for comparison between types of arrangements. FossilFilter™ had over 5,000 installations according to the manufacturer and was the most thoroughly evaluated insert. The StreamGuard™ had over 20,000 installations according to the manufacturer, although data on performance was limited. After the first year of operation, all of the inserts, including some that were introduced since the study began, were again considered for testing; however, the study team elected to continue testing the FossilFilter™ and StreamGuard™.

One of the primary siting criteria that reduced the number of viable sites was that the proposed sites needed to contain at least two drain inlet structures so that a comparison between each DII type could be made under similar conditions. Additional criteria included storage of heavy vehicles and/or equipment in the tributary area, since petroleum hydrocarbons were primary target constituents for the inserts. Initially, the Alameda, Altadena, Central, Eastern Regional, Foothill, Las Flores, Metro and Rosemead Maintenance Stations were considered for drain inlet insert retrofit because they contained drain inlet structures with heavy equipment on site. Reasons for rejection included: the absence of two onsite catch basins, the high cost of site improvements required to direct water to a second inlet, and the cost and feasibility associated with extensive offsite improvements for those sites not containing adequate onsite drainage facilities.

After review, only three sites met the site selection criteria: Foothill, Rosemead, and Las Flores Maintenance Stations. These sites contained multiple drainage inlets and site activities consistent with the criteria for the study. Table 11-1 shows the characteristics of the contributing watersheds for each drain inlet insert.

Since the purpose of the pilot study was to assess the effectiveness of two types of drain inlet inserts, ideally each insert would have treated the same amount of runoff. Since this was not possible, the inserts were rotated over the course of the study placed so that one type did not always treat the larger flow at all sites.

Another important siting criterion for DIIs was that flows should enter the insert from all sides of the inlet. Flow that concentrates on one side or corner of device can cause bypass for even moderate events. This was most relevant for the FossilFilter™, which had a center bypass through the perimeter 'tray.'

Table 11-1 Summary of Contributing Watershed Characteristics for DIIs

Site	Drain Inlet Insert Type	Watershed Area Hectare	Impervious Cover %
Foothill MS	FossilFilter™	0.64	100
	StreamGuard™	0.07	100
Rosemead MS	FossilFilter™	0.10	100
	StreamGuard™	0.49	100
Las Flores MS	FossilFilter™	0.32	70
	StreamGuard™	0.09	62

11.2 Design

The FossilFilter™ DII is a trough structure that is installed under the grate of a drain inlet. The trough contains stainless steel filter cartridges filled with amorphous alumina silicate for the removal of petroleum hydrocarbons and other contaminants. The trough is made of fiberglass and consists of a large center opening for the bypass of water when the flow-through capacity of the filter is exceeded. A schematic of the device is shown in Figure 11-1. An installation is shown in Figure 11-3.

The StreamGuard™ DII is a conical-shaped porous bag made of polypropylene fabric and contains an oil absorbent polymer. As stormwater flows through the insert, the fabric absorbs oil and retains sediment. Floating oil and grease are absorbed by the absorbent polymer. The insert has two overflow cutouts near the top of the cone to allow bypass when the fabric's flow-through capacity is exceeded. A schematic is shown in Figure 11-2. An installation is shown in Figure 11-4.

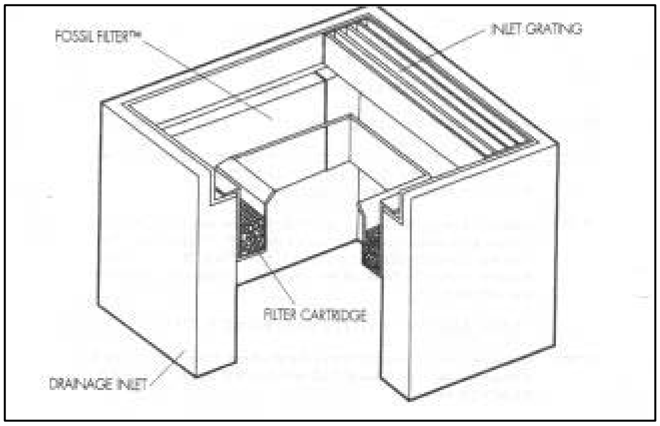


Figure 11-1 Schematic of FossilFilter™
SOURCE: KriStar

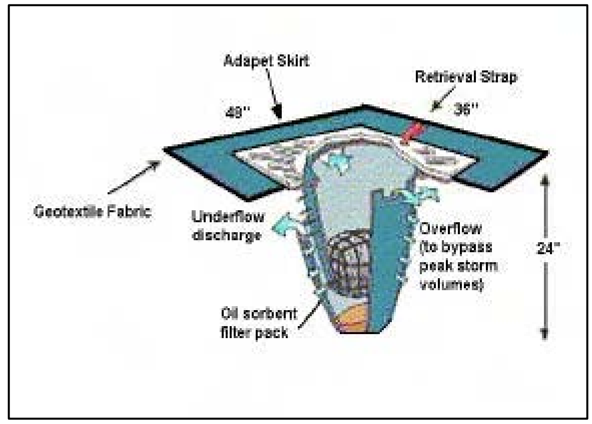


Figure 11-2 Schematic of StreamGuard™
SOURCE: Foss Environmental

Figure 11-3 FossilFilter™

Figure 11-4 StreamGuard™

Each pair of drain inlets at the three maintenance stations originally operated in series, with one drain inlet discharging into the other drain inlet. This situation would distort the monitoring results of the downstream inlet since the effluent sample would contain runoff that did not flow through the insert. Therefore, the design included the diversion of the upstream piping to isolate the retrofitted inlet. For widespread installation of DIIs this would be unnecessary.

The StreamGuard™ fits catch basins up to 0.760 m by 1.02 m. Bypass was observed when the depth of water reached 0.56 m. This occurred at various flow rates depending on the filter fabric, but generally the StreamGuard™ is designed to handle flow rates up to 0.005 m^3/s. It is designed to fill with the heavier sediment particles, and the oil rises to the surface where it is absorbed in the oil-absorbent media. The FossilFilter™ fits a standard Caltrans G1 type inlet using type 450-9X and 600-12X grates. It has a flow capacity of 0.0025 m^3/s/m of filter rail. The design peak flows for the water quality storm are shown in Table 11-2.

Table 11-2 Design Characteristics of the DIIs

Site	Design Storm mm	Design Storm Peak Flow m^3/s	WQV m^3
Foothill MS FF*	25	0.010	160
Foothill MS SG*	25	0.001	12
Rosemead MS FF	25	0.003	25
Rosemead MS SG	25	0.014	123
Las Flores MS FF	25	0.005	86
Las Flores MS SG	25	0.001	25

*FF = FossilFilter™, SG = StreamGuard™

11.3 Construction

Both the StreamGuard™ and FossilFilter™ were installed according to the manufacturer's guidelines. However, the guidelines were insufficient for providing a tight seal between the frame of the drain inlet and the insert. Both DIIs had to be sealed to minimize flow bypass around the insert. For the FossilFilter™, this was done by sealing the DII-inlet interface with foam material. For the StreamGuard™, this was done by inserting wood between the insert and the inlet edge to form a tight seal between the grate, the grate frame and the insert fabric. This is likely to be a consideration for most DII applications.

Most of the other issues that occurred during construction and installation of the drain inlet inserts were caused by construction activities that were associated exclusively with the monitoring equipment and the need to redirect flows as part of the monitoring program. Installation of the inserts themselves had little impact on normal facility operations and was not impacted by unknown field conditions, presence of utilities or lack of accurate as-built plans.

11.4 Maintenance

Maintenance of the drain inlet inserts depended on the rate pollutants and debris accumulated, the storage capacity, and the requirements for proper operation. Inspections for debris and trash were conducted at each DII site before, during and after each storm event, and monthly during the dry season. In general, small amounts of trash, debris, and sediment were removed from the insert. The DIIs were inspected for oil and grease at the end of each target storm, and monthly during the dry season. Monthly inspections of the structural integrity of the insert were conducted and the medium was replaced annually. Additionally, sediment was scheduled for removal when more than 150 mm had accumulated at the StreamGuard™ sites.

The FossilFilter™ inserts were subject to flow bypass because of sediment and debris (leaves, litter, etc.) covering the cartridges. Therefore, sediment and debris had to be removed from the top of the cartridges before a storm event and generally once during the event. This requirement could be a major operation and maintenance burden depending on the DII siting.

The StreamGuard™ inserts at Las Flores and Rosemead had to be refitted into the drain inlet after they had slipped because of the weight of the water and material collected within the filter bag. Pre-storm inspections and maintenance of the inserts were necessary to minimize the slipping of the insert into the drain inlet during the storms. Inspections were conducted prior to and during each storm event, as well as monthly. Figure 11-5 shows the average number of hours spent in the field for maintenance at the DIIs. An average of 40 hours was needed to maintain the FossilFilter™ DII and 32 hours to maintain the StreamGuard™ DII. Of these hours each had approximately 17 hours for vector control related activities.

11.5 Performance

11.5.1 Chemical Monitoring

Removal efficiencies were estimated using a mass-balance approach for each DII, because paired influent and effluent samples were not collected. The effluent pollutant mass was determined through flow weighted monitoring and the influent mass was estimated from the amount of material retained on the insert as described below.

1. Calculate percent efficiency representing the time interval since the last time the insert medium was changed, using the equation:

$$\text{Efficiency (\%)} = \frac{\text{Estimated Influent Pollutant Mass} - \text{Effluent Pollutant Mass}}{\text{Estimated Influent Pollutant Mass}} \times 100$$

2. Estimate the influent pollutant mass for the time interval according to:

$$\text{Estimated Influent Pollutant Mass} = \text{Insert Medium Pollutant Mass} + \text{Total Effluent Pollutant Mass for the Time Interval}$$

3. Estimate the total effluent mass for all storm events in the time interval according to:

$$\text{Estimated Total Effluent Pollutant Mass} = \text{Mean EMC} \times \text{Total Runoff Volume}$$

4. Compute mean efficiencies for each pollutant for the monitoring period.

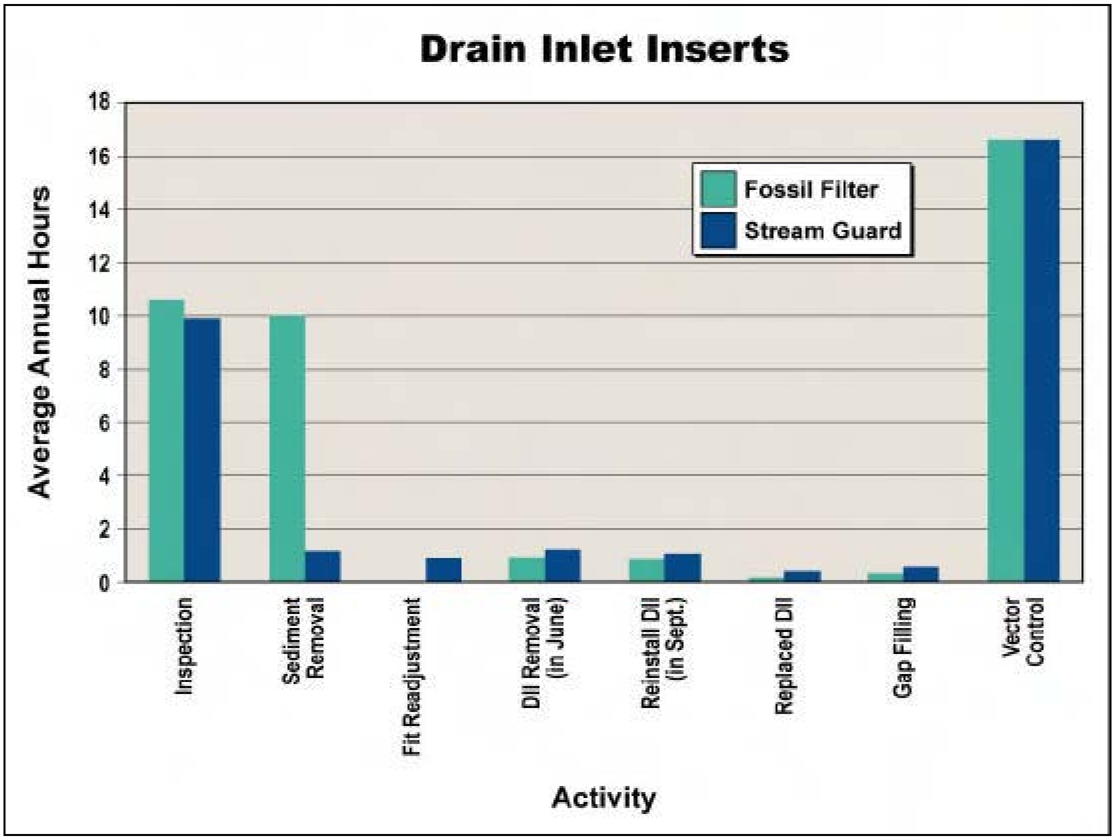


Figure 11-5 Field Maintenance Activities at DII Sites (1999-2001)

Tables 11-3 and 11-4 show the average removal efficiencies for the StreamGuard™ and FossilFilter™. The amount of material retained by the device is the total weight from all the installations of each type of device during the 2000-2001 monitoring period. For most constituents less than a 10 percent reduction in concentration was observed despite a maintenance program that included removal of obstructing material during storm events. Solids removal is slightly higher than that calculated for metals and hydrocarbons.

Solids, metals and hydrocarbon removal efficiency by the FossilFilter™ DII generally decreased with increased flow volume. Solids removal efficiency by the FossilFilter™ at Rosemead MS and the StreamGuard™ DIIs at Foothill and Las Flores MS were comparatively higher than the other DIIs because of the quantity of wind-blown material entrapped by the DIIs. Consequently, these removal efficiencies are not directly comparable to those monitored using automated equipment, since the automated devices do not collect samples of the large debris that was manually removed from the inserts. Therefore, the amount of litter that bypassed the devices could not be measured. Efficiencies of the StreamGuard™ DII at Rosemead MS were especially low, at or near zero, and this was attributed to the large flow volume passing through the DII and the relatively small amount of sediment and debris in its watershed.

Table 11-3 Mass Reduction Efficiencies for StreamGuard™ (excluding litter and debris)

Constituent	Gram Retained Absorbent	Gram Retained Fabric	Gram Effluent	Removal, %
TSS	2,410	6,170	248,930	3
Total Cu	0.03	0.33	98.8	0
Total Pb	0.05	0.68	55.07	1
Total Zn	0.22	4.70	695.88	1
Hydrocarbons	69.94	13.55	3613.05	2

Table 11-4 Mass Reduction Efficiencies for FossilFilter™ (excluding litter and debris)

Constituent	Gram Retained Insert	Gram Effluent	Removal, %
TSS	22,320	131,730	14
Total Cu	0.74	39.64	2
Total Pb	1.08	13.89	7
Total Zn	6.80	417.52	2
Hydrocarbons	7.43	1628.57	0

Note: The manufacturer of FossilFilter™ advises that all models of the FossilFilter™ similar to those used in this study are no longer in production and have been replaced by a product called FloGard™.

11.5.2 Empirical Observations

The hydraulic capacity of the FossilFilter™ DII had an impact on the performance of this insert. The FossilFilter™ DII was designed not to impede flow to prevent flooding from backwater. Therefore, during higher discharge rates, the runoff had sufficient velocity and/or volume to pass over the lip of the cartridges and enter the storm drain directly through the tray bypass area. This occurred during 10 of 18 events at Foothill, five of 18 events at Las Flores and eight of 19 events at Rosemead.

Flow bypass also occurred in the FossilFilter™ DII due to accumulation of trash, debris, and sediment on top of the filter cartridge screens. This blocked the filter cartridge screens so that stormwater could not pass through them. At the Foothill MS FossilFilter™ bypass was observed during 11 events with rainfall intensities as low as

6 mm/hr. At the Rosemead FossilFilter™ bypass was observed during 15 events with rainfall intensities as low as 3.3 mm/hr. At the Las Flores FossilFilter™ bypass was observed during seven events with rainfall intensities starting at 9 mm/hr.

Flow bypass also occurred at the StreamGuard™ DII sites during five of 18 events at Foothill, six of 18 events at Las Flores and eight of 19 events at Rosemead. This was due to runoff filling the cone and flowing through the overflow cut-outs. The cone of the StreamGuard™ is 0.61 m deep; when the standing water in the cone reached a depth of 0.56 m, bypass occurred through the two overflow cut-outs on the sides. It was determined that there were variations in the pore size of the filter fabric and the smaller pore size reduced the flow rate. The manufacturer indicated that the apparent opening size (AOS) of the fabric used to construct the unit was highly variable, resulting in substantial differences in the hydraulic capacity of a specific filter unit.

A secondary failure due to low hydraulic capacity occurred when the weight of the standing water in the cone caused the insert to slip downward into the inlet. This caused a gap in the inlet-insert interface and allowed bypass to occur. During heavy rainfall conditions, the StreamGuard™ did not have sufficient flow bypass capacity; consequently, flooding occurred at the Rosemead MS on three occasions.

Each DII site was monitored for mosquito activity by the local vector control agency. One location, Rosemead MS, had observations of breeding on five occasions; however, this was due to standing water associated with the monitoring equipment and was not related to the performance of the DII. At the Las Flores Maintenance Station, abatement was performed on one occasion when standing water was observed in the monitoring vault, even though no breeding had been detected. The vector control district was subsequently notified to only abate when vector breeding was verified. Table 11-5 lists the incidences of mosquito breeding at the DII sites.

Table 11-5 Incidences of Mosquito Breeding – DIIs

Site	Number of Times	
	Breeding Observed	Abatement Performed
Foothill MS	0	0
Rosemead MS	5	5
Las Flores MS	0	1

11.6 Cost

11.6.1 Construction

Table 11-6 shows the cost for construction and installation of the drain inlet inserts. The actual costs are the costs incurred for the installation of the drain inlet inserts and the associated monitoring facilities needed for the pilot program. This includes the installation of flumes for monitoring and diversion of flows to isolate effluent flow for monitoring. These costs are easily the lowest of any of the BMPs evaluated in this study. Costs were normalized for drain inlet inserts by calculating a water quality volume for the drainage area treated by the device and the amount of rainfall during the design storm. While the size of inlets does vary according to catchment area, the variation is not enough to significantly affect the cost of a DII; in most cases, these types of BMPs would be installed on a unit (per drain inlet) basis and not according to runoff volume or flow.

The adjusted construction costs for the DIIs are shown in Table 11-7. No single item was responsible for the cost adjustment. The majority of the cost for the drain inlet insert pilot was related to monitoring. Since the material cost of the inserts was a minor part of the bid package, the labor to install these could have been incorporated into the larger bid items. Consequently, the adjusted construction cost seems to reflect the purchase price of the inserts and may not accurately include labor cost.

Table 11-6 Actual Construction Costs for DIIs (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
Foothill MS FF	36,879	1,186	7.30
Foothill MS SG	36,879	1,186	66.70
Rosemead MS FF	32,116	1,186	46.69
Rosemead MS SG	32,116	1,186	9.53
Las Flores MS FF	51,696	1,186	14.59
Las Flores MS SG	51,696	1,186	51.88

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

All DII installations were in maintenance stations and subsequently did not incur traffic control costs. If constructed roadside, DII could incur significant traffic control cost. Traffic control costs were not used to estimate adjusted construction cost.

11.6.2 Operation and Maintenance

Table 11-8 shows the average annual operation and maintenance hours for each site and the average annual hours for equipment. Field hours include inspections, maintenance and vector control.

Table 11-7 Adjusted Construction Costs for DIIs (1999 dollars)

DII	Adjusted Construction Cost $	Cost/WQV $/m^3
Mean	370	10.23
High	371	20.81
Low	369	2.28

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

Table 11-8 Actual Operation and Maintenance Hours for DIIs

Site Name	Average Annual	
	Equipment Hours	Field Hours
Foothill MS FF*	0	31
Rosemead MS FF	0	56
Las Flores MS FF	0	31
Foothill MS SG*	0	21
Rosemead MS SG	0	51
Las Flores MS SG	0	24
Average Value	**0**	**36**

*FF = FossilFilter™; SG = StreamGuard™

Slightly more hours were spent at the FossilFilter™ DIIs than at the StreamGuard™ DIIs. This was primarily due to the more frequent cleaning needed by the FossilFilter™ DII to prevent flow bypass during storm events. The actual number of maintenance hours spent in the field for the FossilFilter™ was an average of 36 hr/yr and for the StreamGuard™ an average of 20 hr/yr.

Table 11-9 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 11-9 Actual Average Annual Maintenance Effort - DII

Activity	Labor Hours	Equipment & Materials $
Inspections	11	-
Maintenance	9	0
Vector control*	17	-
Administration	84	-
Direct cost	-	563
Total	**121**	**$ 563**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate a DII or reflect the design lessons learned during the course of the study. Table 11-10 presents the expected maintenance costs that would be incurred under the final version of the MID for a DII at a single inlet. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Only one hour is shown for facility inspection, which is to occur simultaneously with all other inspection requirements for that time period. Hours assume maintenance will occur during business hours. If maintenance is required during non-business hours bypass may occur. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Equipment generally consists of a single truck for the crew and their tools.

Table 11-10 Expected Annual Maintenance Costs for Final Version of MID – DII

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	18	21	813
Vector control	0	0	0
Administration	3	0	132
Direct Costs	-	115	115
Total	**22**	**$136**	**$1,104**

11.7 Criteria, Specifications and Guidelines

The DII devices selected for the pilot program appeared to be the best available at the time for the intended use. The most appropriate application for DII is probably an area where source controls can prevent most but not all pollutant releases to the drainage system, and with personnel in attendance to provide the level of maintenance needed. However, the devices proved to be more maintenance-intensive and less effective than expected. The main maintenance issue was that personnel had to be available during storms to remove material causing bypass of the devices.

This technology is continually evolving and new configurations may be developed that are better suited for Caltrans facilities and that should be considered. However, they are not considered technically feasible for use at the piloted locations at this time due to poor constituent removal, and required level of maintenance. It also would be beneficial to have a test site for DII devices, where manufacturers could install their devices and have them operated and tested at their expense to facilitate rapid adoption of those devices that prove successful.

11.7.1 Siting

Based on the results of this study, the primary siting criteria recommended for future installations include the following:

- Implement DIIs where the drainage area is less than 0.8 ha.
- DII should be installed in maintenance yards or other facilities where there are personnel available to do regular maintenance and monitor operation.
- Source control should be the primary means to prevent pollutants from coming in contact with stormwater.

- DIIs may be more appropriate for temporary conditions (e.g., a construction project or a special operation that may release pollutants), than for installation as a primary treatment BMP.
- Avoid installation of DIIs in areas with overhanging vegetation and other sources of material that could potentially clog the filters, or where wind-blown debris from off-site is a problem.

11.7.2 Design

Based on the observations and measurements in this study, the following guidelines are recommended:

- Avoid installing perimeter-type drain inlet inserts where runoff enters the insert as concentrated flow.
- If flows do not enter the insert along all sides of the inlet, determine the maximum flow rate allowed considering only the sides the flows enter.

11.7.3 Construction

Listed below are guidelines that should improve the construction process:

- To prevent flow bypass seal all gaps between the inlet and the drain inlet insert.
- Be aware of mesh-size variation in “sock” type DIIs.

11.7.4 Operation and Maintenance

Based on the level of maintenance required in this study, recommended future maintenance activities include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes inspections for trash and debris, structural integrity and sediment accumulation.
- Inspect the insert for debris and trash weekly during the wet season and remove accumulated material.
- Inspect the structural integrity at the beginning and end of the wet season.
- Renew the insert or medium annually at the end of the wet season or per manufacturer’s direction.
- For the StreamGuard™, remove sediment when it accumulates to more than 150 mm, and inspect weekly during the wet season.

12 OIL-WATER SEPARATOR

12.1 Siting

One Oil-Water Separator (OWS) was sited, installed, and monitored for this study. It was located in District 7 at the Alameda Maintenance Station.

The primary siting criteria for an OWS were:

- Presence of heavy equipment, light-duty vehicles and cars
- Presence of liquid asphalt crack sealant and solids
- Quality of oil waste storage area
- Type of runoff flow paths (concentrated for sampling purposes)
- Site exposure to rain
- Existence of drain inlets on site
- Accessibility of site for sampling
- Safety with respect to vehicular traffic

Initially, 22 sites were investigated within District 7 and District 11; the 10 sites with the most potential were then subject to further investigations. Those sites were Alameda, Altadena, Eastern Regional, Escondido, Foothill, Kearny Mesa, Metro, San Fernando, Tarzana and Westdale Maintenance Stations. Sites with concentrations of free oil and grease in runoff of greater than 10 mg/L were preferred since this is about the lowest concentration the coalescing plate separator technology can achieve. Stormwater runoff was sampled during the site screening process at the four maintenance stations that had the most potential for high levels of oil and grease. The results are shown in Table 12-1.

Table 12-1 Oil/Grease Sampling Results

Location Maintenance Station	Average Oil/Grease Concentration mg/L
Alameda	34.7
Altadena	20.3
Metro	8.6
Escondido	9.4

Alameda MS was selected for implementation of the oil-water separator because it had the highest oil and grease concentration. More than 25 heavy vehicles were located in areas of the site exposed to stormwater. There was also onsite petroleum-based material storage, such as oil waste, asphalt crack sealant, and solid asphalt. Tables 12-2 and 12-3 show the characteristics of the selected contributing watershed for the oil-water separator.

Table 12-2 Summary of Contributing Watershed Characteristics for Oil-Water Separator

Site	Watershed Area Hectare	Impervious Cover %
Alameda MS	0.3	100

12.2 Design

The oil-water separator selected for this study was an Areo-Power® 500 gallon ST1-P3. The OWS separates oil and water by allowing the oil droplets to collide and coalesce to become larger globules that are then captured in the separator. There are three compartments in the separator, a forebay, an oil separation chamber, and an afterbay. The forebay traps and collects sediments. The oil separation chamber contains a parallel, corrugated plate coalescer and a removable oleophilic fiber coalescer that promote the separation of oil and water. The oil is captured and held in this cell (second chamber). The afterbay discharges treated stormwater with a free oil and grease concentrations of about 10 mg/L or less. A schematic of the device, shown in Figure 12-1, summarizes the design characteristics for the oil water separator. The actual OWS installed is shown in Figure 12-2.

Table 12-3 Design Characteristics of the OWS

Site	Design Storm mm	Design Storm Peak Flow m^3/s	WQV m^3
Alameda MS	25	0.03	65

12.3 Construction

Construction problems centered primarily on conflict with existing utilities. The site is also somewhat constrained with relatively limited space for maintenance station activities. Consequently, some conflicts with the ongoing operation of the station were also encountered.

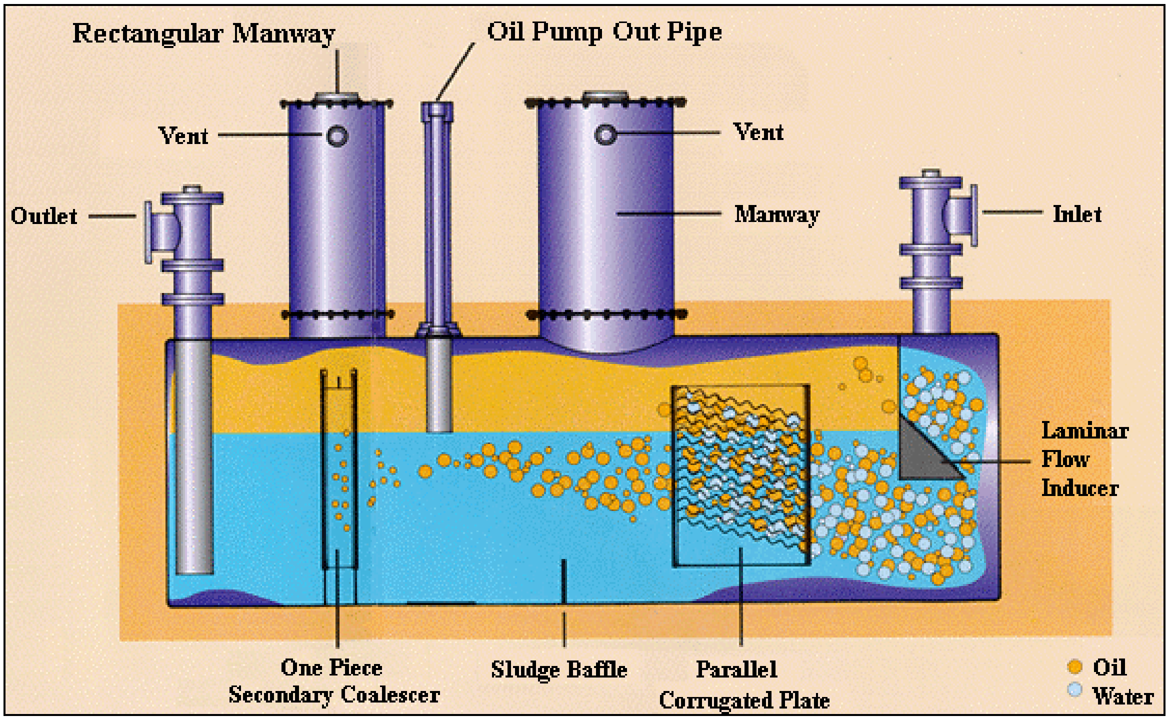


Figure 12-1 Schematic of an OWS (Source: Highland Tank and Manufacturing Company)

Figure 12-2 Alameda OWS

12.3.1 Unknown Field Conditions

The final location of the oil-water separator was changed twice during construction because of conflicts with a fire water line, irrigation line, and electrical conduit. These utilities were in locations different than shown on as-built drawings. The re-excavation resulted in additional labor and equipment costs as well as increased costs for soil and asphalt disposal and backfill. Additional design work was required to re-calculate the system elevations in order to ensure proper drainage of the BMP in the new location. These changes resulted in increased costs and schedule delays.

12.3.2 Interface with Existing Activities

The maintenance station supervisor identified the need for improved access to an existing building entrance. The perimeter fence length was increased to provide better access.

12.4 Maintenance

Initially, there were monthly inspections for sediment accumulation in the pre-separator and separator chamber and inspections for oil accumulation in the oil chamber. The MID requires removal of the accumulated oil when it occupies more than 50 percent of the chamber volume. Because little or no accumulation was observed, the inspection frequency was reduced to quarterly after the first monitoring season.

Additional maintenance included inspection of the coalescer for debris and gummy deposits at the beginning and end of the wet season. On a monthly basis, the water level of the tank was measured to ensure it was at the operating level. The general mechanical integrity of the oil-water separator was assessed monthly before the beginning of and during the wet season.

The annual number of maintenance field hours, 74 hours, by activity is shown in Figure 12-3. Because of the small amount of oil and grease in the runoff, little actual maintenance of the facility was required. Inspections required under the MID and by the vector control agencies constituted almost all of the activities at the site, 14 hours and 57 hours, respectively.

12.5 Performance

12.5.1 Chemical Monitoring

Removal efficiencies were estimated for the oil-water separator based on grab samples collected at the influent and effluent. TSS, TPH-gasoline, TPH-diesel, TPH-oil and oil and grease removal efficiencies were analyzed and the results are shown in Table 12-4. TPH-diesel exhibited the highest removal efficiency, followed closely by TSS. Despite the relatively high concentrations of oil and grease measured during the siting phase at this location, most events after installation of the device had no detectable amounts of oil and grease. During one event (10/26/00) a concentration of 216 mg/L of oil and grease was reported; however, this far exceeds the concentrations of TPH gasoline and diesel (both below reporting limits) and TPH oil (3.1 mg/L) measured for the same event. This single high value is mainly responsible for the average oil and grease concentration of 30 mg/L shown in Table 12-4. Only low levels of other hydrocarbons were observed.

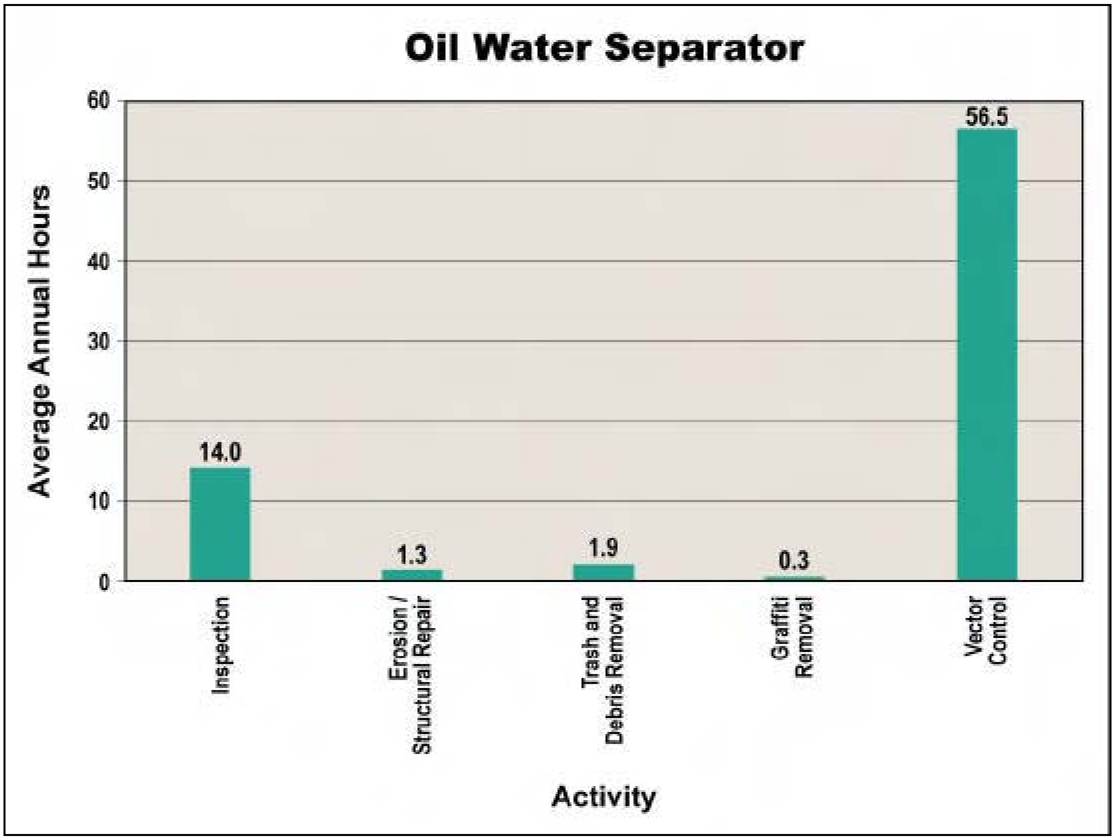


Figure 12-3 Field Maintenance Activities at OWS (1999-2001)

Table 12-4 Concentration Reduction for the OWS

Constituent	Mean of Grab Samples Influent mg/L	Mean of Grab Samples Effluent mg/L	Removal %
TSS	144.7	74.3	49
TPH – Oil [b]	0.83	0.71	14
TPH – Diesel [b]	0.83	0.40	52
TPH – Gasoline [b]	<0.050[a]	<0.050[a]	-
Oil & Grease [b]	30	<5[a]	89

[a] Equals value of reporting limit
[b] TPH was collected by grab method and may not accurately reflect removal

12.5.2 Empirical Observations

The observations of the OWS indicated there was no bypass or short-circuiting of the unit during design level storms. The influent water generally appeared brown with suspended solids and a slight oily sheen. The effluent discharged was clear with black suspended solids and a hydrocarbon odor; however, as noted previously, oil accumulation in the device was never observed.

The OWS was monitored for mosquito activity by the local vector control agency. As shown in Table 12-5, mosquito breeding was observed and abatement was performed on two occasions.

Table 12-5 Incidences of Mosquito Breeding – OWS

Site	Number of Times	
	Breeding Observed	Abatement Performed
Alameda MS	2	2

12.6 Cost

12.6.1 Construction

Table 12-6 shows the cost for construction and installation of the oil-water separator. The actual costs are the costs incurred for the installation of the oil-water separator and the associated monitoring facilities needed for the pilot program. Construction costs without monitoring related equipment are also shown.

Table 12-6 Actual Construction Costs for OWS (1999 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m³
Alameda MS	179,437	165,043	2,540

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

The adjusted construction costs for the OWS are presented in Table 12-7. Reductions to the actual OWS costs were made for the following reasons:

- Limited head and space caused construction cost that would increase the adjusted cost by 23 percent. This cost was excluded from the adjusted cost.
- Miscellaneous site-specific factors caused increased construction cost. This cost would increase the adjusted cost by 4 percent. These costs were excluded from the adjusted cost.

The oil-water separator installation was at a maintenance station and subsequently did not incur traffic control costs. If constructed roadside, an OWS could incur traffic control cost typical of EDBs, in which traffic control accounted for an average of 9 percent of the adjusted construction cost. Traffic control costs were not used to estimate adjusted construction cost.

Table 12-7 Adjusted Construction Costs for OWS (1999 dollars)

Oil-Water Separator	Adjusted Construction Cost $	Cost/WQV $/m^3
One Location	128,305	1,970

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

12.6.2 Operation and Maintenance

Approximately 74 man-hr/yr were required for inspections, maintenance and vector control activities and no special equipment was required. Table 12-8 presents the cost of the average annual requirements for operation and maintenance performed by consultants in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 12-8 Actual Average Annual Maintenance Effort – OWS

Activity	Labor Hours	Equipment & Materials $
Inspections	14	-
Maintenance	3	0
Vector control*	57	-
Administration	65	-
Direct cost	-	1,066
Total	**139**	**$1,066**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate an OWS or reflect the design lessons learned during the course of the study. Table 12-9 presents the expected maintenance costs that would be incurred under the final version of the MID for an OWS serving about 2 ha. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Table 12-9 Expected Annual Maintenance Costs for Final Version of MID – OWS

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	0	44
Maintenance	10	0	440
Vector Control	12	0	744
Administration	3	0	132
Direct Costs	-	180	180
Total	**26**	**$180**	**$1,540**

Some of the estimated hours are higher than those documented during the study because certain activities, such as oil and sediment removal, were not performed during the relatively short study period. Only one hour is shown for facility inspection, which is to occur simultaneously with all other inspection requirements for that time period. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Vector control hours were converted to cost assuming an hourly rate of $62. Equipment generally consists of a single truck for the crew and their tools.

12.7 Criteria, Specifications and Guidelines

Oil-water separators have generally been thought to be applicable for treatment of stormwater from "gasoline stations, and truck, car, and equipment maintenance and washing enterprises and other commercial and industrial facilities" (WEF and ASCE, 1998). Although Caltrans maintenance stations fit this profile, the initial site screening and subsequent monitoring at the Alameda Maintenance Station and other MS locations indicate that the concentrations of free oil and grease in runoff from these types of facilities is normally very low. This is primarily due to source-control measures in effect at all Caltrans maintenance station facilities.

Manufacturers indicate that free oil and grease concentrations in the influent must routinely be at 50 mg/L or higher for the units to be considered applicable for the site. Other conventional controls, such as extended detention basins, biofilters or sand filters, could be expected to provide better removal of other constituents, while providing comparable reduction in oil and grease at the concentrations observed in this study. A simple baffle box may be appropriate under certain circumstances for spill control; however, treatment of stormwater runoff would not be an objective. An oil-water separator should not be considered the first choice for a stormwater BMP. However, they may be appropriate in certain non-stormwater situations (e.g., where source controls cannot ensure low oil and grease concentrations).

13 CONTINUOUS DEFLECTIVE SEPARATORS (CDS®)

13.1 Siting

Continuous Deflective Separators (CDS®) are a proprietary water quality treatment device originally developed in Australia and marketed through CDS Technologies in the United States. They are hydrodynamic devices designed primarily as gross pollutant traps to capture trash, debris and floatables in stormwater runoff. A secondary objective is removal of sediment and associated pollutants. Two CDS® units were sited and constructed for this study, both located in District 7. Table 13-1 presents the watershed characteristics for the two sites. Siting criteria for the CDS® units included:

- Maintenance access
- Equipment security
- Sampling safety and access
- Absence of median drains
- Minimum of four and maximum of ten drain inlets contributing to the unit
- No offsite tributary area
- Sufficient space at the storm drain outfall to construct the unit and appurtenances

Table 13-1 Summary of Contributing Watershed Characteristics for CDS®

Site Location	Land Use	Watershed Area Hectare	Impervious Cover %
I-210 WB east of Orcas	Highway	0.44	100
I-210 WB east of Filmore	Highway	1.02	100

13.2 Design

The CDS® units work by diverting flow from the storm drain system via a weir into the unit separation chamber and sump. Flow must be subcritical in the storm drain system for the diversion weir to function effectively. These hydrodynamic units are designed to introduce the flow in a direction tangent to the arc of the separation chamber. Using this approach, the dominant velocity vector is parallel to the unit screen, which tends to keep the screen from blocking with debris. Water passes through the screen to an outer peripheral chamber where it reverses direction and flows back into the storm drain system. The screen retains gross pollutants from the diverted flow except for material smaller than the openings in the screen. Figures 13-1 and 13-2 show a plan and elevation view of the device.

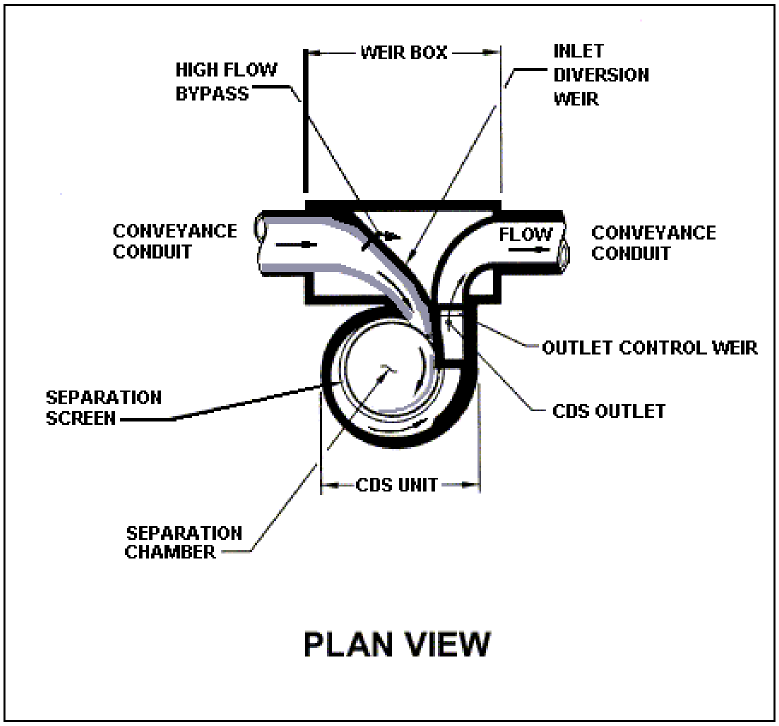


Figure 13-1 Plan View of CDS®

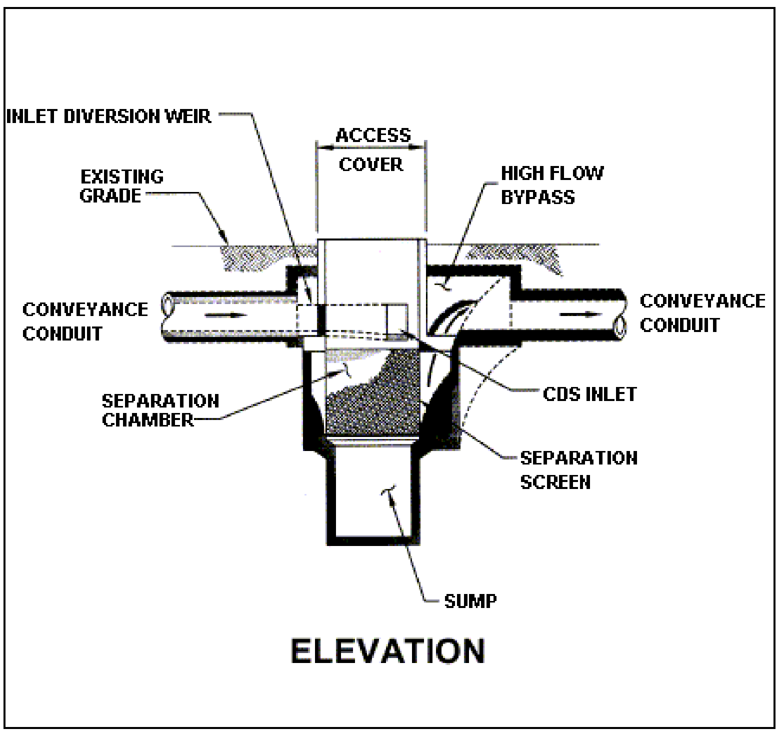


Figure 13-2 Elevation View of CDS®

Table 13-2 presents the storm characteristics used for design of the CDS® units. The units installed were the smallest manufactured, and have a sump diameter of 864 mm; sump depth of 610 mm and sump volume of 0.358 m^3. The separation chamber has a depth of 686 mm. The flow capacity of the units is 0.03 m^3/s. Figure 13-3 shows one of the CDS® installations at I-210 east of Filmore.

Table 13-2 Design Characteristics of the CDS®

Site Location	Design Storm (mm)	Peak Flow (m^3/s)	WQV[a] m^3
I-210 WB east of Orcas	25	0.007	107
I-210 WB east of Filmore	25	0.017	246

[a] Volume treated during a design storm

Figure 13-3 CDS® Unit (I-210 / Filmore)

During the early part of the 2000 wet season modifications to the units were completed. In early October 2000, CDS Technologies replaced the original 1.2 mm screen at Orcas with a 2.4 mm opening screen and replaced the 1.2 mm screen at Filmore with a 4.7 mm opening screen. The 1.2 mm screen was the smallest available at the time of installation; however, due to clogging problems experienced by the manufacturer at other locations, resulting in unreasonably high maintenance requirements, the original screen size was no longer recommended.

13.3 Construction

The CDS® units were installed with only one minor change order required. The existing drainage system at the I-210 / Orcas Avenue site is a concrete v-ditch channel that runs along the bottom of the embankment parallel to the roadway. The first 5 m of the channel was removed as part of the construction for the device. Following preliminary site clearing and grubbing, the contractor informed Caltrans that the v-ditch downstream of the pilot site was blocked with debris, which caused a backwater condition at the construction site during runoff events. This prevented the contractor from proceeding with construction until the v-ditch was cleaned. Caltrans maintenance forces subsequently cleaned the v-ditch and the contractor was able to resume construction. No schedule delays resulted from this action.

Site access at the I-210 / Filmore Street CDS® unit was from an existing gate at the end of the cul-de-sac on Filmore Street. During an initial progress meeting, the contractor informed Caltrans that there was not enough room between the gate and the toe-of-slope for vehicles to access the site. Caltrans concluded that although there was enough room when the freeway was originally constructed, the toe-of-slope had migrated closer to the gate over time. The contractor was instructed to remove the gate to facilitate site access. Near the end of construction, a Contract Change Order was issued for the installation of a new 3-m wide chain link gate.

13.4 Maintenance

Routine inspections of the CDS® units were conducted on a monthly basis and weekly during extended periods of wet weather, in accordance with the MID. Major maintenance items for the CDS® units included removal of trash and debris from the site area, clearing of the weir box of sediment and debris, and cleaning out gross pollutants (litter and vegetation) from the unit sump. Some unscheduled maintenance also had to be performed at each site. In July 2000 the manufacturer placed concrete in each unit's weir box so the invert elevation matched the pipe inlet/outlet inverts and CDS® unit invert. The manufacturer made this modification to improve the system hydraulics and eliminate standing water at the weir.

The maintenance threshold for gross pollutant removal in the sump was set at 85 percent full. During the 2000-2001 wet season, this threshold was reached in January and March 2001 at the Orcas site, and in January 2001 at the Filmore site. Neither site had been cleaned since units were placed in service in October 2000. Both units were also cleaned in May 2001, in accordance with the MID.

During the 2001-2002 wet season floatables were cleaned out of the Orcas site on November 19 and January 9. Settlables and floatables were both removed on November 28 and January 30. No cleanouts were required during the wet season at the Filmore site. At the end of the wet season both Orcas and Filmore were cleaned. Figure 13-4 shows the accumulation with respect to time of floatable and settable material in the sump at each CDS® site.

Figure 13-5 shows the amount of time spent on each identified maintenance activity. A measuring stick was inserted into the sump to determine the depth of trash and debris to assess the need for maintenance. A measuring tape was inserted into the top portion of the CDS® unit to measure the floating trash and debris.

13.5 Performance

13.5.1 Chemical Monitoring

There was some concern among the participants in the study that the protocol for estimating removal efficiencies for the other pilot BMPs would understate the performance of the CDS® units. This concern arose over potential problems of collecting a representative influent sample that included the full range of particle sizes present in the runoff. Consequently, an additional mass balance procedure was used to confirm the efficiencies determined from data collected by the automatic samplers. The manufacturer commented critically on the protocol for estimating removal efficiencies used in this study. A copy of this correspondence is included in Appendix F.

BMP constituent removal performance presented in Table 13-3 was calculated using the standard analysis procedure for the Pilot Program based upon EMCs measured at the influent and effluent points of each BMP. Since influent and effluent volumes are equal, the constituent load reduction is the same as the concentration reduction (e.g., no loss due to infiltration). The average concentrations of the influent and effluent were not significantly different for any of the conventional constituents monitored.

The mass balance approach was initiated in the second year of monitoring and consisted of quantifying the amount of sediment retained in each device as well as the amount discharged. Knowing the amount of sediment captured in the unit and the amount discharged allowed computation of the influent load and the load removal efficiency. The CDS® device targets larger sediment size fractions (greater than about 1 mm) of suspended solids. There was concern that the automatic samplers and TSS laboratory analysis procedure biased the results towards smaller size fractions. Automatic samples collected of the CDS® effluent may be more representative since the larger grain sized material would have been captured by the device and the smaller material would be captured by the sampler. Consequently, the efficiency could be calculated as:

Removal Efficiency = (Load Captured)/(Load Discharged + Load Captured)

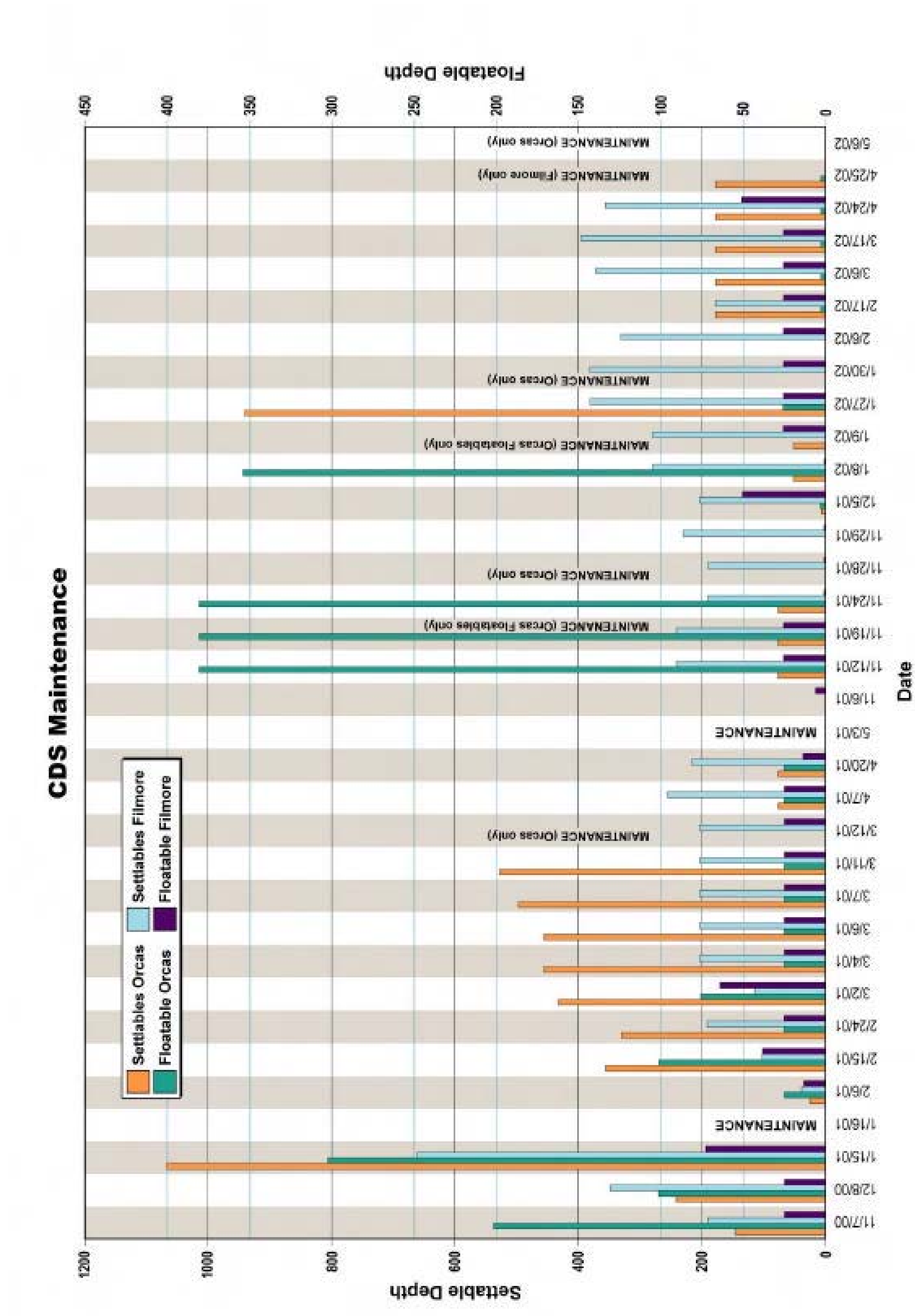


Figure 13-4 Depth of Settlables and Floatable Gross Pollutants in CDS® Units

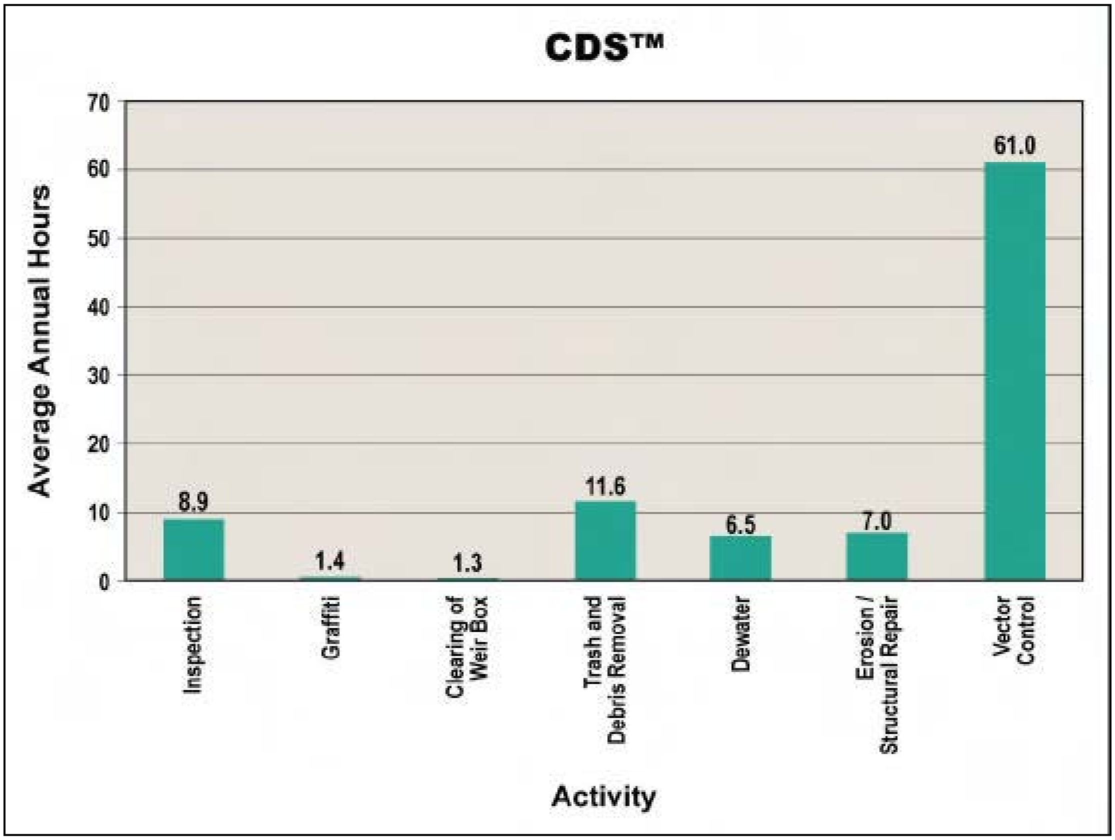


Figure 13-5 Field Maintenance Activities (Average Annual) at CDS® Units (2000-2002)

During the second year of monitoring 0.06 kg and 1.33 kg of TSS were removed from the separation chamber of the Orcas and Filmore sites, respectively, while 12.1 kg and 67.3 kg bypassed, based on the average concentration measured in the effluent and the total volume of runoff treated by the unit during the same time period. The resulting TSS removal efficiencies for each location using a mass balance approach were 0.75 percent for Orcas and 3.56 percent for Filmore. The mass balance approach for sediment removal and the comparison of influent and effluent TSS concentrations (Table 13-3) both show similar results – little or no TSS reduction.

Table 13-3 Constituent Removal Performance of CDS® (Scoping Study Method)

Constituent	Mean EMC Influent mg/L[a]	Mean EMC Effluent mg/L[a]	Removal %	Significance P
TSS	45.3	45.4	0	0.190
NO_3-N	1.46	1.24	15	0.581
TKN	2.67	2.67	0	0.962
Total N	4.13	3.91	5	-
Ortho-Phosphate	0.08	0.08	0	0.863
Phosphorus	0.29	0.25	15	0.351
Total Cu	24.6	22.6	8	0.612
Total Pb	9.5	8.5	11	0.610
Total Zn	244.2	203.9	17	0.637
Dissolved Cu	16.7	14.1	16	0.339
Dissolved Pb	4.7	4.4	6	0.889
Dissolved Zn	178.5	153.9	14	0.779
TPH-Oil [c]	2900	1900	34	0.331
TPH-Diesel [c]	250[b]	250[b]	0	-
TPH-Gasoline [c]	50[b]	50[b]	0	-
Fecal Coliform [c]	8600 MPN/100mL	19000 MPN/100mL	-121	0.365

a Concentration in µg/L for metals
b Equals value of reporting limit
c TPH and Coliform are collected by grab method and may not accurately reflect removal

Table 13-4 shows the expected concentration and the amount of uncertainty at the 90 percent confidence level for each constituent for both lined and unlined basins. The regression analysis was less effective at identifying an association between influent and effluent concentrations. This was primarily the result of highly variable effluent quality, with effluent concentrations higher than influent concentrations for a number of events.

Table 13-4 Predicted Effluent Concentrations –CDS®

Constituent	Concentration[a]	Uncertainty, ±
TSS	0.66x + 12.4	$39.9\left(\frac{1}{28}+\frac{(x-45.7)^2}{77{,}200}\right)^{0.5}$
NO_3-N	0.72x + 0.11	$1.7\left(\frac{1}{28}+\frac{(x-1.47)^2}{203}\right)^{0.5}$
TKN	1.01x – 0.08	$2.44\left(\frac{1}{28}+\frac{(x-2.66)^2}{531}\right)^{0.5}$
Particulate P	0.26x + 0.09	$0.32\left(\frac{1}{28}+\frac{(x-0.2)^2}{2.48}\right)^{0.5}$
Ortho-phosphate	0.79x + 0.01	$0.9\left(\frac{1}{28}+\frac{(x-0.09)^2}{0.64}\right)^{0.5}$
Particulate Cu	0.92x + 1.29	$9.28\left(\frac{1}{28}+\frac{(x-8.0)^2}{2{,}880}\right)^{0.5}$
Particulate Pb	0.34x + 2.32	$10.0\left(\frac{1}{28}+\frac{(x-4.98)^2}{2{,}096}\right)^{0.5}$
Particulate Zn	0.57x + 12.0	$76.4\left(\frac{1}{28}+\frac{(x-65.6)^2}{216{,}000}\right)^{0.5}$
Dissolved Cu	0.76x + 1.61	$16.4\left(\frac{1}{28}+\frac{(x-16.8)^2}{12{,}100}\right)^{0.5}$
Dissolved Pb	0.95x + 0.0	$2.18\left(\frac{1}{28}+\frac{(x-4.94)^2}{1{,}890}\right)^{0.5}$
Dissolved Zn	0.91x –1.18	$133.8\left(\frac{1}{28}+\frac{(x-186.3)^2}{2{,}649{,}200}\right)^{0.5}$

[a] Concentration in mg/L except for metals, which are in µg/L; *x* = influent concentration

13.5.2 Gross Pollutant Monitoring

Table 13-5 shows the gross pollutant removal efficiencies. Gross pollutants are defined by Caltrans Litter Study as solids greater than about 4 mm (Caltrans, August 2001). Gross pollutant removal efficiencies were calculated as the amount of material captured by the device divided by the total amount of material captured and bypassed. Removal efficiency was substantial at each site and was mainly affected by the amount of flow bypassing the devices. Overall, the Filmore site performed better than the Orcas site, with better constituent removal and less gross pollutant bypass. The Orcas site required more frequent cleanout due to the greater number of trees in the tributary watershed and the resulting leaf litter. Bypass may also have occurred more frequently at Orcas due to clogging of the smaller screen size.

The total wet and dry weight and volume of floatables, settlables, material contained in the weir box and bypass material were measured following each clean out. The material contained in the weir box consisted of small amounts of sediment. The litter and vegetation were separated and measured. The material was then left to dry on separate drying racks for a minimum period of 24 hours. Dry weights and volumes of the collected and bypassed material were analyzed for litter and vegetation. Approximately 93 percent of the gross pollutants retained was vegetated material with the remainder being litter. Figure 13-6 shows the percentage of the different types of material making up the litter component. The amount of litter bypass at Orcas is largely due to the January 2001 event, when debris filled the mosquito-proofing bags. This January 2001 event produced more than 100 mm of rain in a 42 hr period. However the measured peak flow rate was only 0.013 m^3/s, less than half of the capacity of the unit.

Table 13-5 Performances of CDS® (Gross Pollutant Removal 2000-2002)

Site	Gross Pollutant	Captured Gross Solids, kg	Bypassed Gross Solids, kg	Total Gross Solids, kg	Removal Efficiency %
Orcas	Dry Mass	252	45	298	85
Filmore	Dry Mass	98	9	107	92

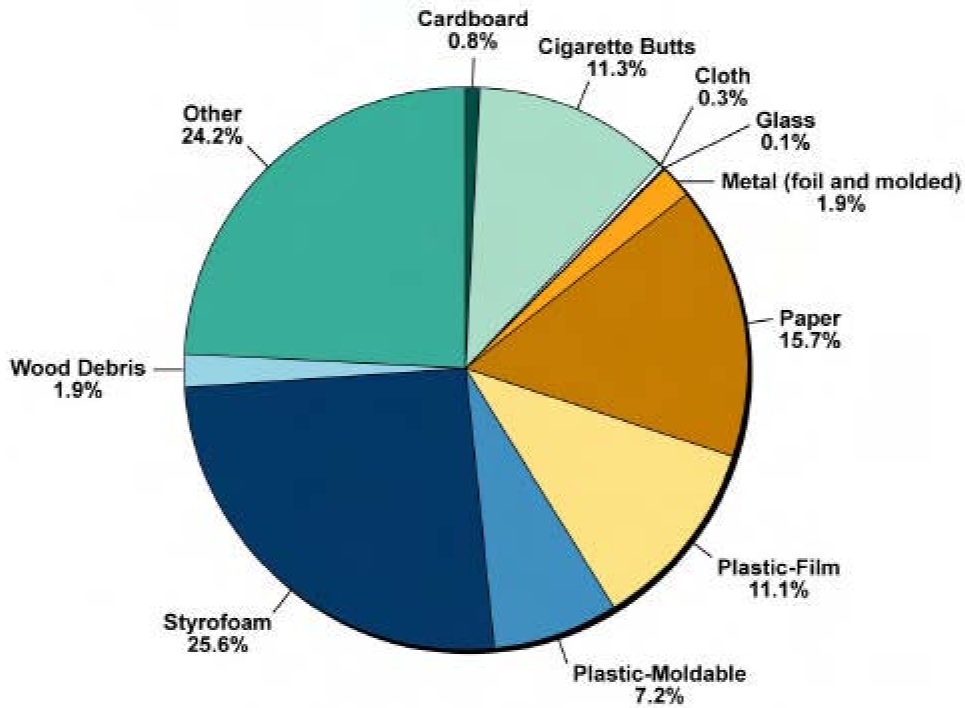


Figure 13-6 Characterization of the Litter Captured (Based on Count, Both Study Sites Over Entire Study Period)

The characteristics of the material, based on count, captured by the CDS® units are shown in Table 13-6. The majority of the debris captured by the CDS® unit at both sites was vegetation. Even though both sites are located on elevated sections of highway, there are numerous trees in the area and windblown vegetation was present in the watershed.

Table 13-6 Characteristics of Gross Pollutants Captured by the CDS® units (2000-2002)

Site	Dry Mass Captured	Dry Mass (Vegetation)	Dry Mass (Litter)
Orcas	252 kg	241 kg	11 kg
Filmore	98 kg	89 kg	10 kg

Material collected in the final cleanout of the CDS® units at the end of the 2001-2002 monitoring season was analyzed using a third approach as well. The litter and debris collected within the unit was burned to remove the volatile organic portion of the material in an attempt to provide another estimate the suspended solids concentration. The results are shown in Table 13-7.

Table 13-7 Summary on Non-Volatile Inorganic Solids Captured

Site	Settlables and Sump Sediment Dry Mass	Settlables and Sump Sediment Inorganic Mass (Incinerated)
Orcas	9,076 g	4,266 g
Filmore	63,432 g	31,081 g

At the Orcas site the entire mass of the sump material was burned and approximately 4.3 kg of non-volatile solids resulted. This was the amount of non-volatile solids that accumulated within the basket since the previous cleanout (3 months prior) and within the unit's sump since the previous cleanout (12 months prior). At the Filmore site, a representative sample was incinerated and approximately 31.1 kg of non-volatile solids remained. This was the amount of non-volatile solids that accumulated within the basket and within the sump since the previous cleanout (both 12 months prior).

Table 13-8 shows the calculations of removal efficiency based on the incinerated mass. The inorganic mass for the entire season was calculated (see 4th Year Annual Report in Appendix F). The mean event mean concentration was used, along with the volume of runoff treated by the unit during the wet season, to determine the mass of TSS that passed through the unit. Using the mass remaining in the unit and the mass passing through the unit the removal efficiency was calculated.

$$\textit{Removal Efficiency (\%)} = \frac{\textit{(Mass retained)}}{\textit{(Mass retained + Mass passing)}} * 100$$

Table 13-8 Summary of Incineration Based Calculation of Removal Efficiency (2001-2002)

Site	Settlables and Sump Sediment Inorganic Mass (entire season), kg	Volume of Water Passing through Unit, L	TSS Effluent EMC, mg/L	Effluent TSS Mass, kg	Removal Efficiency, %
Orcas	6.366	309,528	41.21	12.8	33
Filmore	31.164	789,366	78.73	62.1	33

The material remaining after incineration included not only sediment associated with the gross solids, but ash remaining from the incineration of the captured trash. Therefore, the mass remaining after incineration is not equivalent to the suspended solids and suspended solids attached to the gross solids. In addition, there were likely solids attached to the debris and trash bypassed at each site (about 45 kg at Orcas), which were not quantified. Consequently, calculations based on these results are not viewed as representative of the performance of these devices.

13.5.3 Empirical Observations

Because the CDS® unit is designed to retain water in the sump, standing water was always present in each unit. During the early part of the storm monitoring season, mosquito breeding was observed in both CDS® units. To prevent mosquitoes from entering the CDS® units, the bypass litterbags were changed to a finer mesh and the lids of each CDS® unit were sealed with foam. Bolt holes and other openings were sealed with silicon. During one large storm event in January 2001, debris filled the mosquito-proofing bags, which caused each CDS® unit to overflow through the top of the weir box. The ends of the mosquito-proofing bags were subsequently cut out to prevent flow impedance, and litter bypass baskets were installed at the discharge ends of the H-flumes. Figure 13-7 shows a typical mosquito-proofing bag installation. Following these changes, mosquito breeding was observed within the CDS® units about 20 percent of the time (per inspection), which was much less frequently than before the modifications were made. Table 13-9 presents the number of incidents of observed mosquito breeding.

During each monitored event, the CDS® units generally operated according to design. However, there were more trees in and near the Orcas watershed; thus, more organic debris entered the Orcas unit than the Filmore unit, resulting in the need for more frequent maintenance.

It was noted that some sediment was retained in the corners of the weir box. Most sediment passed into the CDS® units and settled in the sump litter basket. Finer sediment passed through the CDS® units. In general, from visual observation, the water quality appearance (clarity) of the effluent was improved. When oil and grease sheen was observed in the influent, it was generally observed to a lesser extent in the effluent.

Figure 13-7 CDS® Mosquito-Proofing Bag

Table 13-9 Incidences of Mosquito Breeding – CDS® (2000-01)

Site	Number of Times		Inspections Performed following installation of Mosquito bags
	Breeding Observed	Abatement Performed	
I-210 WB east of Orcas	15	15	75
I-210 WB east of Filmore	9	9	75

Bypass was observed during five storms at Filmore and three storms at Orcas. Occasionally, flows greater than the design flows would overflow the weir in the weir box and at times pop the lid off the weir box and flow out of the top. The internal riser was raised during the first season to reduce the amount of bypass occurring. Bypass also occurred due to debris such as foam plates blocking the entrance to the CDS® units. The weir opening to the CDS® unit is 204 mm x 305 mm. During several monitoring visits at each site, it was noticed that the weir box top was missing and water had evidently bypassed the unit during the storm. This was likely due to debris blocking the unit entrance at the diversion weir.

13.6 Cost

13.6.1 Construction

Actual construction costs for the CDS® units are shown in Table 13-10. Costs are shown with and without monitoring equipment and related appurtenances for each CDS® site. The table also presents the cost per cubic meter of water quality volume, using actual cost without monitoring.

Table 13-10 Actual Construction Costs for CDS® (2000 dollars)

Site	Actual Cost, $	Actual Cost w/o Monitoring, $	Cost[a]/WQV $/m^3
I-210 WB east of Orcas	39,736	31,684	296
I-210 WB east of Filmore	45,024	35,681	145

[a] Actual cost w/o monitoring.

SOURCE: *Caltrans Cost Summary Report* CTSW-RT-01-003.

Adjusted construction costs for the CDS® units are presented in Table 13-11. Additions to the actual CDS® unit costs without monitoring were made for the following reasons:

- The low bid for construction of these two units was 40 percent lower than the engineer's estimate. Due to problems with the low bidder, the construction management team felt the low bid was not representative of the true project cost. For this reason, the second low bid was used to estimate retrofit cost. The second low bid was 30 percent lower than the engineer's estimate. Using the original bid numbers would decrease the Adjusted Construction Cost by 16 to 17 percent.

Table 13-11 Adjusted Construction Costs for CDS® (2000 dollars)

Site	Adjusted Construction Cost $	Cost/WQV $/m³
Mean (2)	40,328	264
High	42,875	353
Low	37,782	174

SOURCE: Adjusted Retrofit Construction Cost Tables, Appendix C.

13.6.2 Operation and Maint enance

Table 13-12 shows the average annual operations and maintenance field hours experienced for each CDS® unit during the course of the study. Field hours include inspections, maintenance and vector control.

Table 13-12 Actual Operation and Maintenance Hours for CDS®

Site Name	Average Annual	
	Equipment Hours	Field Hours
I-210 WB east of Orcas	15	167
I-210 WB east of Filmore	10	134

Table 13-13 presents the average annual requirements by task for operation and maintenance performed in accordance with earlier versions of the MID. The operation and maintenance efforts are based on the following task components: administration, inspection, maintenance, vector control, equipment use, and direct costs. Included in administration was office time required to support the operation and maintenance of the BMP. Inspections include wet and dry season inspections and unscheduled inspections of the BMPs. Maintenance included time spent maintaining the BMPs for scheduled and unscheduled maintenance, vandalism, and acts of nature. Vector control included maintenance effort by the vector control districts and time required to perform vector prevention maintenance. Equipment time included the time equipment was allocated to the BMP for maintenance.

Table 13-13 Actual Average Annual Maintenance Effort – CDS®

Activity	Labor Hours	Equipment & Material ($)
Inspection	11	-
Maintenance	89	63
Vector Control*	51	-
Administration	103	-
Direct Cost	-	722
Total	**254**	**785**

* Includes hours spent by consultant vector control activities and hours by Vector Control District for inspections

The hours shown above do not correspond to the effort that would routinely be required to operate a CDS® unit since they do not reflect the modifications made to the maintenance protocol during the study. Table 13-14 presents the expected maintenance costs that would be incurred under the final version of the MID for a CDS® unit serving about 2 ha, constructed following the recommendations in Section 0. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

There is some trade off between maintenance cost and construction cost for a CDS® unit. A larger unit can be installed at a higher construction cost that will require less frequent maintenance due to the larger capacity of the sump.

Only one hour is shown for facility inspection, which is assumed to occur simultaneously with all other inspection requirements for that time period. Labor hours have been converted to cost assuming a burdened hourly rate of $44 (see Appendix D for documentation). Vector control hours were converted to a cost assuming an hourly rate of $62. Equipment generally consists of a single truck for the crew and their equipment.

Table 13-14 Expected Annual Maintenance Costs for Final Version of MID – CDS®

Activity	Labor Hours	Equipment and Materials, $	Cost, $
Inspections	1	-	44
Maintenance	40	1,037	2,797
Vector Control	12	-	744
Administration	3	-	132
Materials	-	-	0
Total	**56**	**1,037**	**3,717**

13.7 Criteria, Specifications and Guidelines

The CDS® units performed effectively for removal of litter and debris, but were not as effective for removing conventional stormwater constituents. The permanent pool of water maintained in the device was a breeding area for mosquitoes, even though the frequency was much reduced by attaching nets to the outlet and sealing the unit. Consequently, other non-proprietary devices developed by Caltrans for litter control (such as gross solids removal devices, GSRDs, Caltrans 2001), which do not maintain a permanent pool may be preferred to this technology. Should a CDS® unit be selected for implementation, the following information may be useful.

13.7.1 Application

CDS® units are a below grade 'end-of-pipe' device that have a relatively small footprint. As a result, they are especially suited to locations where surface use must be maintained, and in locations where space to accommodate a BMP is limited. CDS® devices are also best designed to incorporate multiple drain inlets to centralize maintenance activities and provide access in a location that may be more conducive from a personnel safety or site operation perspective. The design of the unit is flow-based; the manufacturer makes several standard unit sizes that can accommodate a wide range of subcritical discharges.

13.7.2 Siting

The original siting criteria seem to have been generally successful at locating CDS® units where they could operate effectively. Based on the results of this study, the primary siting criteria for future installations should include the following:

- Provide adequate space for safe construction, operation and maintenance.

- Locate where flow is subcritical, or modifications can be made to the storm drain system to achieve subcritical flow conditions upstream of the unit.

13.7.3 Design

Based on the observations and measurements in this study, the following guidelines are recommended:

- Use a screen size opening of 4.7 mm.
- Provide a method to completely drain the facility between storms and during the dry season to address concerns about vector issues.
- When possible, use standardized designs to reduce costs.
- If mosquito breeding is a concern, include vector-restricting covers in the initial design.
- Provide adequate head to avoid adversely impacting the hydraulic grade line in the upstream storm drain system.
- Avoid the use of 90^{o} bends in the inlet pipes. When a 90^{o} bend is needed, ensure there is maintenance access for cleanout of debris.
- Size CDS® unit sump to capture gross solids and sediment for the entire wet season.

13.7.4 Construction

Listed below are guidelines that should improve the construction process:

- Avoid above-ground structures near the roadway that will require a setback or guardrail protection.

13.7.5 Operation and Maintenance

Based on the level of maintenance required in this study, recommendations for future maintenance activities include:

- Perform inspections and maintenance as recommended in MID (Version 17) in Appendix D, which includes inspections for structural integrity, vectors and sediment accumulation.
- Empty CDS® unit annually or when needed based on watershed characteristics.
- Remove trash and debris from weir box on a monthly basis.
- Inspect the screen for damage annually.
- Inspect the structural integrity of the device annually.

14 CAPITAL, OPERATION, AND MAINTENANCE COSTS

14.1 Introduction

An important objective of this study was to establish design, construction, and maintenance costs for retrofit of structural BMP devices in existing highway infrastructure. The actual cost data developed through this study have been analyzed for two purposes: 1) to develop a relative ranking with respect to water quality volume treated in order to assist in selecting the most cost-effective BMP technology for a given set of conditions, and 2) to provide general guidance for future BMP retrofit applications by itemizing the significant independent cost items unique to retrofit construction and operation. Project delivery costs such as siting, design and construction management are excluded from the costs reported in this study. Procedures for cost estimation are presented in Appendix C.

The pilot program construction cost figures represented throughout this report are directly applicable only to Caltrans and its operations. The unique environment and constraints associated with retrofitting BMPs into the California Highway system makes comparisons to other possible applications of the same BMPs difficult. Furthermore, even within the Caltrans system, information on construction costs will undoubtedly increase greatly as BMPs continue to be developed and implemented, such that the construction cost information in this report will be of limited value over time. It should be recognized that the Operations and Maintenance cost information was based partly upon estimates and projections of future needs.

It is also recognized that the construction costs compiled as a part of the program represent stand-alone retrofit projects that, with some exceptions, do not take advantage of potential economies that would occur if the devices were constructed as a part of a new highway, or a highway undergoing substantial reconstruction. During the process of reviewing the costs incurred for this study, additional cost data from other programs throughout the country were compiled. In the interest of providing a complete record, these additional cost data also are provided.

14.2 Pilot Program Construction Cost

The costs incurred for constructing the BMPs in this pilot study have been documented in detail in the Caltrans *Construction Cost Data Summary Districts 7 and 11*, report no. CTSW-RT-01-003, included in Appendix C of this report. The *Construction Cost Data Summary Districts 7 and 11* provides cost breakdown by site, differentiates between those items constructed as a part of the original bid and those constructed by change order, and distributes the actual cost into 'site-specific' cost categories. The *Construction Cost Data Summary Districts 7 and 11* report makes no estimate of costs that might be incurred in a future retrofit program, or what steps might be taken to reduce future implementation costs.

14.2.1 Actual Construction Cost

The construction costs for each of the BMPs have been normalized by the WQV rather than tributary area to account for the significant differences in design storm depth used for sizing the controls in different parts of the study area and the differences in the runoff coefficient at each site. For the flow-through devices, such as swales, the water quality volume was calculated as if a capture and treat type device (e.g., detention basin) were implemented at the site. Where more than one facility of the same type was constructed, the mean cost per unit WQV is reported.

The capital cost of the BMP types (in cost per unit WQV) is shown in Table 14-1. The costs shown are based on the actual construction cost incurred at each site, less the cost of monitoring and sampling equipment. No site-specific cost reductions or other allowances were made for the costs shown in Table 14-1.

Table 14-1 Actual Construction Cost of BMP Technologies (1999 dollars)

BMP Type	Cost/m^3 of the Design Storm $
Delaware Sand Filter	3,472
Multi-chambered Treatment Train	847
Wet Basin	2,670
Oil-Water Separator	2,540
Austin Sand Filter	2,009
Infiltration Trench	1,954
Storm-Filter™	1,575
Swales	951
Unlined Extended Detention Basin	877
Strips	835
Infiltration Basins	639
Lined Extended Detention Basin	348
Continuous Deflective Separator	220
Drain Inlet Inserts	33

14.2.2 General Cost Guidance – BMP Retrofit Construction Cost

The site-specific costs shown in the *Construction Cost Data Summary Districts 7 and 11* were further reviewed on a site-by-site basis by a technical work group comprised of water quality specialists, construction managers and design engineers. The goal of the work group was to develop 'generic' retrofit costs that could reasonably be applied to other BMP retrofit projects. The costs were developed by reviewing the specific construction items for each site, eliminating those that were atypical and reducing the costs that were considered to be in excess of what would 'routinely' be encountered in a retrofit situation. Where there is not complete flexibility in selecting a BMP for a specific site, the cost reduction strategies (Section 14.2.4) are not sufficient in preventing cost from exceeding the costs used for planning (i.e. the 'adjusted' construction cost). Specific construction items that were reduced or eliminated from the actual costs are discussed in the individual device chapters. The results of the adjusted cost are summarized in Table 14-2.

14.2.3 Considerations for Future Projects

The technical work group that reviewed the construction cost data also identified fundamental approaches and strategies to reduce the capital cost of BMP retrofit. Many of the identified cost reduction strategies are consistent with normal evolutionary economies realized as technology and application methods mature over the course of more intensive implementation. Other strategies summarize some of the lessons learned associated with the implementation of the pilot program. The identified cost reduction strategies presented below may be useful for implementation on future projects.

In addition to the recommendations enumerated below for reducing costs of installing structural BMPs, it is generally assumed that source control is the most cost-effective stormwater best management practice. Many source control practices applicable to maintenance stations avoid contact between polluting agents and rainfall or runoff. These practices include covering materials and wastes; maintaining, fueling, and cleaning vehicles where rain and surface runoff will not contact contaminating residues; spill and leak prevention and clean-up; stabilizing bare ground; and general good housekeeping. Pollutants in runoff can be decreased on highways and in park-and-ride lots through designs that reduce impervious surfaces and retain natural soil and vegetation. However, source controls alone may not be sufficient to protect water bodies and their beneficial uses fully, and stormwater treatment BMPs may also be needed. The following cost reduction strategies can save substantially in implementing structural BMPs.

Table 14-2 Adjusted Construction Costs by BMP Type (1999 dollars)

BMP Type		Adjusted Construction Cost $	Adjusted BMP Cost per WQV, $/m^3
EDB (4)	Avg	172,737	590
	High	356,300	1,307
	Low	91,035	303
IB (2)	Avg	155,110	369
	High	171,707	397
	Low	138,512	340
WB		448,412	1,731
MFSTF		305,356	1,572
MFSD		230,145	1,912
MFSA (5)	Avg	242,799	1,447
	High	314,346	2,118
	Low	203,484	746
MCTT (2)	Avg	275,616	1,875
	High	320,531	1,895
	Low	230,701	1,856
BSW (6)	Avg	57,818	752
	High	100,488	2,005
	Low	24,546	182
BSTRP (3) [a]	Avg	63,037	748
	High	67,099	1,237
	Low	58,262	384
IT/STRP (2)	Avg	146,154	733
	High	156,975	775
	Low	135,333	691
OWS		128,305	1,970
CDS® (2)	Avg	40,328	264
	High	42,875	353
	Low	37,782	174
DII (6) [b]	Avg	370	10
	High	371	21
	Low	369	2

[a] Unit costs for strips varied widely because the unit loading ratio, or tributary area/treatment area, varied significantly in the study, ranging from 4 at the I-605/SR-91 biofilter strip in District 7 to 43 at the Altadena Maintenance Station in District 7.

[b] Unit cost for drain inlet inserts varied widely because the treatment area varied significantly.

14.2.4 Cost Reduction Strategies

1. Integration of stormwater BMP projects with larger construction projects is one of the keys to reducing costs over the long term. This principle applies to both retrofits and new construction. Long-range, integrated planning will almost always result in the most cost-effective project. Based on the experience of other state transportation agencies, including the Maryland State Highway Administration, incorporating stormwater management as an integral part of highway construction and operation and maintenance programs offers a variety of benefits, including:

   a) More opportunities to locate BMPs in conjunction with other features (e.g., drainage systems, interchanges)

   b) Enhanced experience of engineering staff with respect to stormwater BMP design, construction, operation, and maintenance

   c) Reduction of mobilization, traffic-control, and equipment costs, as well as economies of scale during the construction process

   d) Regulatory compliance cost savings through the use of single permits for the entire project

   An example from the BMP Pilot Retrofit Program of this strategy was the construction of the biofiltration swale at Palomar Road in District 11. This site was built as a part of a larger project to construct an auxiliary lane in the same vicinity as the pilot swale. The Palomar Road site had the smallest unit construction cost ($246/$m^3$) of any swale in the program, with unit costs for swales ranging as high as $2,192/$m^3$ at I-605/SR-91 in District 7. It is reasonable to assume that some of the economy realized at the Palomar Road site was achieved by integrating the swale into a larger construction project.

2. There is an economy of scale in treating runoff from the largest possible drainage catchment. The unit costs for many of the BMPs evaluated in this study declined sharply as the water quality volume approached 400 m^3. There are insufficient data beyond that point to determine whether there is additional advantage with greater size.

   The unit cost of Austin sand filters decreased at the rate of approximately $6.60 per m^3 of additional water quality volume up to about 300 m^3, the largest volume treated. Unit costs of extended-detention basins and biofiltration swales also declined substantially in a similar range, although not as uniformly as the unit costs of Austin sand filters. The units costs of an extended-detention basin and a biofilter each treating approximately 400 m^3 were lower than the unit costs of the smallest devices of each type by factors of about four and ten, respectively.

Figure 14-1 provides a graph of unit cost vs. water quality volume for three of the pilot technologies to illustrate this point. The graphed data clearly indicate that as the water quality volume increases, the cost per unit volume for the device decreases. While it is likely that the curves shown in Figure 14-1 cannot be accurately extrapolated, it is apparent from the data that economies of scale can be realized.

3. The various BMP types do differ in the amount of runoff, and therefore catchment size, they can serve. For example, biofiltration swales cannot practically serve drainage areas as large as extended-detention basins can. Treating a larger area, and gaining the consequent economy of scale, should be considered in selection and siting of the BMP. Economies may also be gained by simultaneously constructing several BMPs of the same type to treat runoff from neighboring catchments or implementing even larger numbers of BMPs across wider geographic areas as part of a large-scale implementation program. It is probable that the significance of economy of scale is amplified for devices that serve relatively small watersheds, such as in a retrofit situation. This is because the fixed costs account for a relatively greater portion of the overall cost as compared to a site serving a relatively larger watershed.

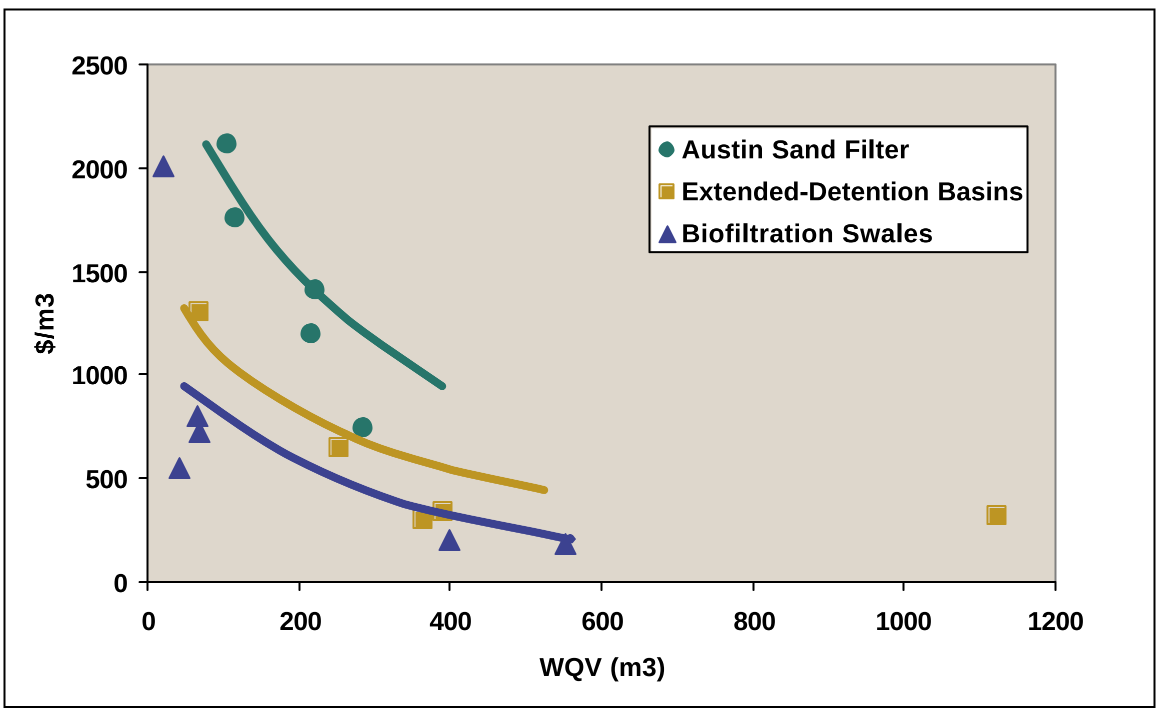


Figure 14-1 Unit Cost vs. Water Quality Volume for Selected Technologies

Two examples from the BMP Pilot program can serve to illustrate this point. The extended detention basin at I-15/SR-78 in District 7 served a tributary area of 5.42 ha and had an adjusted unit cost of $317/m^3. The extended detention basin at I-605/SR-91 in District 7 served a watershed of 0.4 hectares and had an adjusted unit cost of $1,307/m^3. Similarly, for biofilter swales, the site at Melrose Drive in District 11 served 0.96 ha (the largest tributary watershed for swales in the study) and had an adjusted unit cost of $204/m^3, and the biofilter swale at I-605/SR-91 in District 7 served a tributary watershed of only 0.08 ha and had an adjusted unit cost of $2,005/ha.

4. The BMP sizing criterion (e.g., water quality volume) also plays a role in determining BMP costs. The criterion can be set based on hydrologic analysis for the climatological setting and is normally prescribed by regulation. Where space constraints or other factors make capture of the entire WQV infeasible, BMP implementation should still be pursued consistent with the efforts to maximize pollution reduction.

5. Engineering design and construction experience is a major cost-savings factor for state and local transportation and stormwater agencies throughout the United States. In common with most engineering programs, as the experience level of an agency increases, so does the cost effectiveness of highway stormwater projects. Contributing to higher costs, before personnel gain experience, are lack of familiarity with BMP technologies; inexperience with their selection, siting, and design; and modification of existing standard operating procedures.

6. Cross-jurisdictional partnerships within watersheds where highways are located have the potential for creating significant cost savings and water quality improvements. They must, however, be implemented in a way that ensures receiving water protection. Cost sharing and cooperation between Caltrans and other agencies in constructing joint stormwater treatment facilities should result in greater cost effectiveness for several reasons:

   a) Economies of scale associated with construction of BMP facilities that serve large drainage areas, reducing the percentage influence of fixed costs;

   b) Sharing design, construction, and operation and maintenance costs;

   c) Avoidance of traffic-control costs where jurisdictional cooperation allows for constructing BMPs outside the highway right-of-way;

   d) Other opportunities for locating BMPs, with possible avoidance of costs associated with construction of BMPs at sites constrained by space limitations within the right-of-way;

e) More hydraulic flexibility, with possible avoidance of costs associated with construction of BMPs at sites where extensive drainage system modifications are required; and

f) More flexibility in BMP design and opportunities for BMP "treatment trains," where multiple BMPs are shared by several jurisdictions.

7. The development of standardized BMP designs has the potential to reduce the costs of materials needed for building BMPs. Standardizing BMP components (e.g., inlet and outlet structures, pre-cast vaults, etc.) have resulted in substantial cost savings in other parts of the country. Continued improvement in BMP selection guidance should lead to reduced costs and better BMP performance in the field. Particular highway-related facilities often have common water quality problems. If a standard BMP suite can be developed for specific types of highway facilities or locations (e.g., maintenance stations, clover leafs, center medians, highway shoulders, etc.), there can be cost savings realized throughout the planning, design, and implementation processes.

8. BMP design complexity should be minimized. In general, non-structural (vegetation-based) BMPs are less costly than structural devices. These types of BMPs (biofiltration swales and filter strips) also tend to have pollutant removal efficiencies comparable to more expensive structural BMP devices like extended-detention ponds or sand filters. Experience in other locations in the nation supports emphasizing vegetative controls where appropriate based on site conditions. The use of distributed biofiltration and bioretention was found to be a significant component of several state transportation agency stormwater programs. Biofiltration systems can also be integrated more easily into the highway landscape (medians, shoulders, intersections, etc.), thus requiring less right-of-way space. In addition, potentially expensive piping modifications are usually minimal with these types of treatment devices.

9. Specialized BMP devices, such as the oil-water separator, multi-chamber treatment train (MCTT), and Storm-Filter™, may not be as cost-effective as other BMPs for highway installation due to the unique aspects of that environment. They do have potential application, however, in site-specific situations (such as a unique site or specific pollutant of concern), or when the benefits of installation outweigh the costs (such as for protection of a sensitive water body or endangered species). There are situations where proprietary devices are merited, but they are generally not the most cost-effective selection for widespread highway deployment and should be lower priority choices than the other BMPs covered in the pilot program. These technologies are constantly improving, so this observation applies strictly to the experience with the BMPs evaluated in this study.

10. While all BMP categories are amenable to cost reductions through the strategies recommended herein, the type offering the greatest potential for savings is

probably biofiltration (i.e., swales and filter strips). These BMP facilities can frequently do double duty as both drainage conveyances and runoff treatment devices. To the extent they can replace single-purpose conveyance conduits, they can ameliorate the costs normally expended for conveyance while fulfilling water quality objectives. Since structural conveyance elements (e.g., pipes) are more costly than vegetated channels and slopes, there is great potential to lower the costs exclusive to complying with stormwater management requirements through building vegetated drainage systems as part of reconstruction or new construction.

11. The following general guidelines also have potential to improve overall BMP cost effectiveness for retrofits and new construction. Generally, these guidelines are recommended when their use would not otherwise delay the implementation of structural BMPs.

    a) Utilize the natural topography and terrain to maximize BMP performance and to achieve an aesthetic balance in design and siting.

    b) Use natural landscape features and materials instead of concrete and other structural components.

    c) Perform adequate site and geotechnical surveys to avoid unexpected costs and ensure post-construction BMP effectiveness, especially for infiltration BMPs and wet basins.

    d) Select BMPs that do not require pumping, extensive shoring, or both to overcome constraints imposed by available space and head.

    e) Minimize support features such as fencing, access roads, and gates to those necessary for safety and O&M purposes.

    f) Minimize access road surfaces to what is necessary for O&M and use permeable materials for access roads where feasible. It should be noted that permeable materials for access roads may have a higher capital and O&M cost as compared to AC.

    g) Include vector-control features in design and O&M plans.

    h) Utilize prefabricated components as much as possible.

    i) Purchase common BMP components in bulk to save on shipping and other related costs.

    j) A site selection and assessment process should help to avoid hidden costs associated with obstructions like utility conflicts and buried objects.

    k) Cost savings can be realized by integrating BMPs with future flood-control systems. Certain tasks would be performed if a BMP or flood control project were constructed alone, such as mobilization, clearing and grubbing, and some excavation, piping, and concrete work. Both projects would benefit from the efficiency of sharing these costs.

l) During long-range planning and integration, some BMP retrofits will be identified that are critical to improving water quality at ecologically significant or environmentally sensitive sites. Many potential cost savings would be lost if these projects were constructed as stand-alone retrofits. In these cases future highway repair and upgrade needs should be evaluated. If potential reconstruction projects are identified, they should be considered for early installation along with BMPs for greatest overall efficiency.

In summary, analysis of the program cost data indicates that the cost to retrofit structural BMPs is highly site-specific and does not readily lend itself to normalization for application to other studies or projects. The finding itself is a valuable conclusion, and it must be stressed that accurate BMP retrofit costs may best be determined with a complete unit cost estimate based on design plans for the site.

14.2.5 BMP Construction Costs from Other Projects

A review of BMP installation costs in other jurisdictions indicates the potential for lower unit prices ($/WQV) than were realized in this study, for BMPs constructed in a non-project-specific retrofit environment. Table 14-3 presents mean unit costs ($\$/m^3$ of water quality volume) calculated by the Third Party cost workgroup from data collected in a nationwide survey (see Appendix C). One set of columns lists the statistics from the Caltrans Pilot Study, a second set lists statistics of all nationwide data (excluding Caltrans), and a third set gives statistics only from BMP construction by the Maryland State Highway Administration (MD SHA). The MD SHA projects were singled out because they were BMP retrofits installed under a policy that limited cost in conjunction with broader highway reconstructions, therefore representing a potentially more efficient and less costly approach to BMP retrofit compared to other retrofit programs. The survey was not able to obtain specific line-item costs for these BMPs, because their costs were combined with those of other features of the overall projects. As a result, the authors of this study were unable to independently verify the accuracy of the data through review of the bid tabulations. The database is small, containing between one and three examples of each BMP type, except for wet ponds (five). Site-specific anomalies have a strong effect on a small data set, which can be seen where, contrary to expectation, the average cost of extended-detention basins exceeds the costs of wet ponds and wetlands.

Despite the limitations of the Maryland database, it is worth considering as an example of costs that could be realized with the application of cost-saving strategies like those listed in section 14.2.4. In addition to cost savings associated with integrating BMP retrofits with larger projects as was done in Maryland, a second likely reason for the costs being relatively low is the larger water quality volumes generally treated. This observation supports the finding that it is important to treat the largest watershed possible to maximize economies of scale of the device.

14.3 Pilot Program Operation Cost

An important element in selecting the most appropriate BMP for a site is an understanding of the amount and type of maintenance required. BMPs that require less maintenance are preferred, other factors being equal. Table 14-4 summarizes the annual maintenance performed for each of the tested devices. This level of effort is related to the requirements of the earlier versions of the MID. Vector control district hours were high for all devices. Unless constructed of concrete, the largest maintenance item for each of the BMPs was vegetation management. Details on the type of activity at each site are contained in the relevant BMP chapter.

The hours shown in Table 14-4 do not correspond to the effort that would routinely be required to operate the piloted BMPs or reflect the design lessons learned during the course of the study. Table 14-5 summarizes the expected maintenance costs that would be incurred under the final version of the MID for a device serving about 2 ha, and constructed following the recommendations in each chapter. A detailed breakdown of the hours associated with each maintenance activity is included in Appendix D.

Table 14-3 Comparison of Mean Unit Costs and Water Quality Volumes from Nationwide Survey to Adjusted Mean Unit Costs and Water Quality Volumes in Caltrans Retrofit Pilot Program (1999 dollars)

	Pilot Study		Nationwide[a]		MD SHA[b,e]	
BMP	**Adjusted Cost $/m^3$**	**WQ Volume m^3**	**Cost $/m^3$**	**WQ Volume m^3**	**Cost $/m^3$**	**WQ Volume m^3**
Austin sand filter	1,447	168	82	12,123	32.81[c]	1,140[c]
Delaware sand filter	1,912	120	200	1,836		
Extended-detention basin	590	293	5.25	99,537	18.37	32,279
Infiltration trench	733	199	46	2,485	11.48	4,304
Biofiltration swale	752	748	8.86[c]	2,066[c]		
Wet pond	1,731	259	7.55	44,833	9.19	20,391
Wetland			4.59	416,695	3.94	4,877
Storm-Filter™	1,572	194	19[d]	2,350[d]		

[a] Means for all entries in the Third Party Cost nationwide survey where water quality volume is available.

[b] Means for all Maryland State Highway Administration BMPs where water quality volume is available.

[c] Based on a single installation.

[d] Based on compost filters in nationwide survey

[e] MD SHA had a retrofit policy that capped retrofit costs at $12,000 per acre

Table 14-4 BMP Actual Annual Maintenance Effort for Caltrans BMP Retrofit Pilot Program

BMP	Equipment & Materials, $	Average Labor Hours
Sand Filters	872	157
Extended Detention Basin	958	188
Wet Basin	2,148	485
Infiltration Basin	3,126	238
Infiltration Trench	723	98
Biofiltration Swales	2,236	246
Biofiltration Strips	1,864	233
Storm-Filter™	308	106
Multi-Chambered Treatment Train	2,812	299
Drain Inlet Inserts	563	121
Oil-water Separator	1,066	139
Continuous Deflective Separator	785	254

Some of the estimated hours in Table 14-5 are higher than those documented during the study because certain activities, such as sediment removal, were not performed during the relatively short study period. Design refinements may eliminate the need for activities such as vector control. Equipment generally consists of a single truck for the crew and their tools.

The relative ranking of BMP types with known life-cycle costs is shown in Table 14-6. The table includes the adjusted annualized capital cost and total annualized maintenance cost based on a 20 yr life-cycle and a 4 percent discount rate.

Table 14-5 Projected Future Annual Maintenance Requirements for Caltrans BMP Retrofit Pilot Program

BMP	Equipment & Materials, $	Average Labor Hours
Sand Filters	1,013	43
Extended Detention Basin	668	56
Wet Basin	4,875	273
Infiltration Basin	562	56
Infiltration Trench	251	27
Biofiltration Swales	492	51
Biofiltration Strips	492	51
Storm-Filter™	5,731	55
Multi-Chambered Treatment Train	4,222	62
Drain Inlet Inserts	136	22
Oil-Water Separator	180	26
Continuous Deflective Separator	1,037	56

Table 14-6 Projected Present Worth of BMP Capital, Maintenance and Total Cost Requirements for Caltrans BMP Retrofit Pilot Program

BMP	Present Worth Adjusted Capital Cost /m^3 - $	Present Worth Maintenance Cost /m^3 [a] - $	Present Worth Total Cost /m^3 $
Wet Basin	1,731	452	2,183
MCTT	1,875	171	2,046
OWS	1,970	21	1,991
Delaware Sand Filter	1,912	78	1,990
Storm-Filter™	1,572	204	1,776
Austin Sand Filter	1,447	78	1,525
Biofiltration Swale	752	74	826
Biofiltration Strip	748	74	822
Infiltration Trench	733	71	804
Extended Detention Basin	590	83	673
Infiltration Basin	369	81	450
Continuous Deflective Separator	264	99	363
Drain Inlet Inserts	10	29	39

[a] Total maintenance cost based on life cycle of 20 years and 4% discount rate.

15 PERFORMANCE SUMMARY

The objective of this section is to summarize the performance data of the tested BMPs. The relative benefits of each of the subject technologies are based on a comparison of the expected discharge quality and load reduction from each of the devices. Regression analyses were performed on the data from each of the sites with paired influent and effluent composite samples. This allows the prediction of effluent quality from each of the BMPs based on any influent concentration of interest and selection of a BMP based on a comparison between the different technologies for specific constituents of interest.

15.1 Methodology and Results

The first step in this comparison process is to select the concentration in the untreated runoff for each constituent of interest for the watershed in which the BMP will be sited. This could be the average concentration expected at a site or potentially the highest concentration that one might expect to observe. In this example, concentrations were estimated for the influent for selected constituents by calculating the arithmetic mean of all the event mean concentrations observed at the highway and maintenance station monitoring sites. The park-and-rides were excluded because of their relatively low concentrations of constituents of concern. These mean concentrations, shown in Table 15-1, are the calculated water quality design storm concentrations, which will be used to compare the performance of all the BMPs.

Table 15-1 Water Quality Design Storm Concentrations (Mean EMC for Pilot Study)

Constituent	Concentration[a]	USEPA NURP
TSS	114 mg/L	100 mg/L
NO_3-N	0.97 mg/L	0.68 mg/L
TKN	2.36 mg/L	NA
Ortho-phosphate	0.12 mg/L	0.12 mg/L
Particulate Phosphorus	0.26 mg/L	0.21 mg/L
Dissolved Copper	18 ug/L	NA
Dissolved Zinc	122 ug/L	NA
Dissolved Lead	8 ug/L	NA
Particulate Copper	76 ug/L	34 [b] ug/L
Particulate Zinc	233 ug/L	160 [b] ug/L
Particulate Lead	79 ug/L	144[b] ug/L

[a] Park-and-ride sites not included.
[b] Total metal concentration

In general, the pollutant removal effectiveness of the tested BMPs was consistent with previously reported values (see Table 15-1). Analysis of the water quality data collected during the study indicated that in many cases the traditional method of reporting performance as a percent reduction in the influent concentration did not correctly convey the relative performance of the BMPs. The problem was primarily the result of differences in influent runoff quality among the various sites and was especially noticeable for the MCTTs. These devices were installed at park-and-rides, where the untreated runoff had relatively low constituent concentrations. This resulted in low calculated removal efficiencies even though the quality of the effluent was equal to that achieved in the best of the other BMPs. Consequently, a methodology was developed using linear regression to predict the expected effluent quality for each of the BMPs as if they were subject to identical influent quality. The study found that a comparison on this basis resulted in a more valid assessment of the relative performance of the technologies as compared to the more traditional percent removal approach. Table 15-2 presents the expected effluent quality for total suspended solids (TSS), total phosphorus, and total zinc that would be achieved if each of the BMPs were subject to runoff with influent concentrations equal to that observed on average for highway and maintenance stations during the study. Effective concentrations of zero are shown for the infiltration devices, since there is no discharge to surface waters.

Table 15-3 provides performance removal for selected constituents by percent removal across the device. As can be seen from Table 15-3, comparison between some of the devices for TSS shows counterintuitive results. For example, the MCTT has a lower percent removal for TSS than the Austin Sand Filter, even though the filter beds for each device are nearly identical. This is the result of low influent concentration of TSS at the MCTT locations. Other devices, such as the wet basin, also do not lend themselves to performance assessment using percent removal since the effluent quality from the type of wet basin used in this study is a function of the stored dry weather flow influent in the pond, not the influent wet weather runoff. For these reasons, the values shown in Table 15-3 were not used for the performance comparisons in this study and are provided here only as an illustration of the technical difficulties of this type of analysis.

Table 15-2 Effluent Expected Concentrations for BMP types

Device	TSS (Influent 114 mg/L)	Total Phosphorus (Influent 0.38 mg/L)	Total Zn (Influent 355 ug/L)
Austin Sand Filter	7.8	0.16	50
Delaware Sand Filter	16.2	0.34	24
EDB unlined	36.1	0.24	139
EDB lined	57.1	0.31	132
Wet Basin	11.8	0.54	37
Infiltration Basin	0	0	0
Infiltration Trench	0	0	0
Biofiltration Swale	58.9	0.62	96
Biofiltration Strip	27.6	0.86	79
Storm-Filter™	78.4	0.30	333
MCTT	9.8	0.24	33
CDS®	68.6	0.28	197

Table 15-3 Representative Pollutant Removal Efficiencies (Percent) for Pilot Study BMPs

BMP Type	TSS	TN	TP	TZn	TCu	TPb
Infiltration Basin	N/A	N/A	N/A	N/A	N/A	N/A
Infiltration Trench	N/A	N/A	N/A	N/A	N/A	N/A
Extended Detention Basin (Lined)	40	14	15	54	27	30
Extended Detention Basin (Unlined)	72	14	39	73	58	72
Wet Basin	94	51	5	91	89	98
Austin Sand Filter	90	32	39	80	50	87
Delaware Sand Filter	81	9	44	92	66	85
Multi-Chambered Treatment Train (MCTT)	75	0	18	75	35	74
Storm-Filter™	40	13	17	51	53	52
Biofiltration Strip	69	10	N/A	72	65	65
Biofiltration Swale	49	30	N/A	77	63	68
Drain Inlet Insert	N/A	N/A	N/A	N/A	N/A	N/A
Oil-Water Separator	N/A	N/A	N/A	N/A	N/A	N/A

The following graphs compare the discharge concentration and load reduction (including the effects of infiltration) for the technologies for treatment up to the design capacity (design storm). Infiltration basins are assumed to have 100 percent load reduction, and no constituent effluent concentration for the water quality design storm. Effectively, the discharge concentration is always zero and the load reduction 100 percent of the design storm volume. The drain inlet inserts are included in these comparisons but the monitoring strategy did not include paired samples for the inserts; the average of the actual observed effluent quality and load reduction was used in the comparison analysis.

Figure 15-1(a) compares the expected effluent concentration for TSS for each of the BMPs. A detailed explanation of how this graph was developed can be used as an example of how the other figures were created. For the Delaware sand filter the average TSS concentration in the effluent is a constant 16.2 mg/L (from Table 2-11) with an uncertainty of 5.6 mg/L; consequently, the 90 percent confidence interval in Figure 15-1(a) ranges from 10.6 to 21.8 mg/L. Since the TSS effluent concentration for Delaware sand filters is independent of the influent concentration, these values are not affected by the selected influent concentration.

In contrast, the TSS effluent concentration for swales is dependent on influent concentration and is represented by the sum (from Table 7-5):

$$0.42x + 11.0$$

Substituting the selected influent concentration of 114 mg/L, gives a predicted effluent concentration of about 59 mg/L. The uncertainty in this estimate is given by (from Table 7-5):

$$54.6\left(\frac{1}{39}+\frac{(x-84.5)^2}{139{,}000}\right)^{0.5}$$

Substituting the influent concentration of 114 mg/L into this relation, gives a calculated uncertainty of 9.8 mg/L. Consequently, the confidence interval ranges from about 49 to 69 mg/L in Figure 15-1(a). Expected concentrations and confidence intervals for the other BMPs are, likewise, obtained from the tabulated values and/or relations presented in the appropriate BMP chapters.

The load reductions presented in Figure 15-1(b) for TSS are calculated based on the concentration reduction displayed in Figure 15-1(a) and the amount of infiltration observed for each of the BMP types. For biofiltration strips and unlined extended detention basins, approximately 30 percent of the runoff infiltrated, while for biofiltration swales the reduction was about 50 percent. The following equation describes the load reduction:

$$L_r = \left(1-\left(\frac{C_{eff}}{C_{\inf}}(1-I)\right)\right)\times 100$$

where:

L_r = Load reduction

I = Fraction of runoff which infiltrates

Concentration and load reductions for other constituents were calculated similarly.

Figure 15-1 demonstrates the comparatively low TSS concentrations produced by the sand filters (Delaware, Austin, and MCTT) and the wet basin. The small error bars for these devices reflect the consistent effluent created. The Storm-Filter™ and concrete-lined extended detention basin typically have higher concentrations of TSS in the effluent. The large error bars are a result of a highly variable effluent quality (the concrete lined EDB exported TSS on four occasions) and the relatively fewer storms for these devices that consisted of only a single site each. The graph of TSS load reduction shows that the overall difference among the devices is not large, all with load reduction of about 80 percent or more, when the Storm-Filter™, CDS®, DII and lined EDB are excluded.

Figure 15-2 compares the expected performance of the devices for nitrate removal. The wet basin is the only device in this study with an effluent concentration statistically less than the influent concentration of interest (0.97 mg/L) for nitrate (excluding infiltration devices). Media filters are consistent exporters of nitrate according to every published study, presumably the result of nitrification of ammonia in the filter. The quality of the effluent of the EDBs is not significantly different from the influent concentration (90 percent confidence level), while the swales and strips are predicted to have higher effluent than influent concentrations. The nitrate export observed in this study in the strips was during the first year of monitoring and may be related to fertilization of the grass when installed and from hydroseed maintenance. Export of nitrate occurred consistently from the swales and may be related to export of nutrients during the dormant season of the vegetation. Despite the higher concentrations in the effluent from the biofilters, there is a net load reduction of nitrate when infiltration is accounted for.

The relative performance of the various BMPs for reducing TKN in runoff is shown in Figure 15-3. Filter strips are predicted to have effluent concentrations that are higher than influent concentrations; however, a net load reduction should occur due to infiltration in this type of BMP. The concentration increase may be related to the fertilizer used to establish the salt grass at the beginning of the study.

Predicted effluent concentrations and load reduction for dissolved phosphorus are presented in Figure 15-4. Swales, strips, and the wet basin all exhibit much higher effluent than influent concentrations. For the biofilters, this may be related to export of phosphorus from the dormant vegetation. The effluent quality of the wet basin is related primarily to the quality of the wet season baseflow that is displaced from the permanent pool during storms. Consequently, these data should be used with care in estimating the performance of a wet basin relative to other BMPs if implemented at a site with higher or lower quality perennial flow.

Figure 15-5 demonstrates the highly variable performance among the BMPs for particulate phosphorus removal. As with dissolved phosphorus, strips are predicted to have higher effluent than influent concentrations. Highest load reduction was observed for Austin sand filters and unlined extended detention basins.

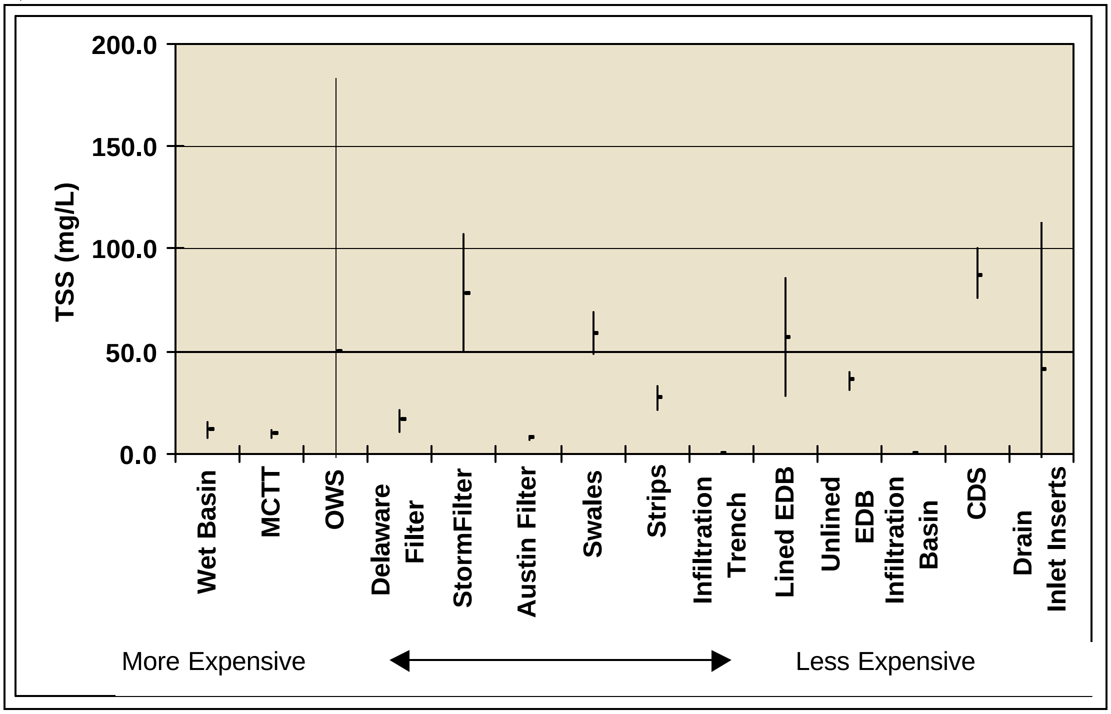
The relative performance of the various BMPs for particulate metals (total minus dissolved) is presented in Figures 15-6 through 15-8. In general, the Storm-Filter™ produced the highest effluent concentration, although the drain inlet inserts and the lined and unlined extended detention basin also did not perform well for these constituents. Most of the other technologies reduce the load of particulate metals by 80 percent or more.

Figures 15-9 through 15-11 compare the removal of dissolved metals for the subject BMPs. For these constituents, the load reductions associated with the swales and strips is among the best of all the technologies, often exceeding that associated with sand filters.

In each of the graphs (Figure 15-1 through Figure 15-11) the technologies are ranked by life-cycle cost from most to least expensive and graphed against constituent concentration and load reduction. The life-cycle costs include expected maintenance cost, rather than actual maintenance cost incurred during the study. One would therefore expect that those devices on the left side of the graph would have lower effluent concentrations and greater load reduction. One can easily see that this is not always the case, however. Error bars on the graphs indicate the reliability of the estimated effluent concentrations and load reductions. This uncertainty indicates the 90 percent confidence interval of the estimate of the mean effluent concentration.

Because of the influence of infiltration on load reduction estimates for the extended detention basins, biofiltration strips and biofiltration swales load reduction estimates are particularly site specific for these BMPs. The load reductions are less certain than concentrations reduction estimates due to the reliance on flow measurements (and inherent error) used to determine total volume. For the extended detention basins 30 percent infiltration was used, for the biofiltration strips 30 percent infiltration was used and for the biofiltration swales 47 percent infiltration was used. The load estimates for these devices will be site specific depending on the soil characteristics and infiltration rates. Caution should be used when using these load reduction estimates for other locations.

a)



b)

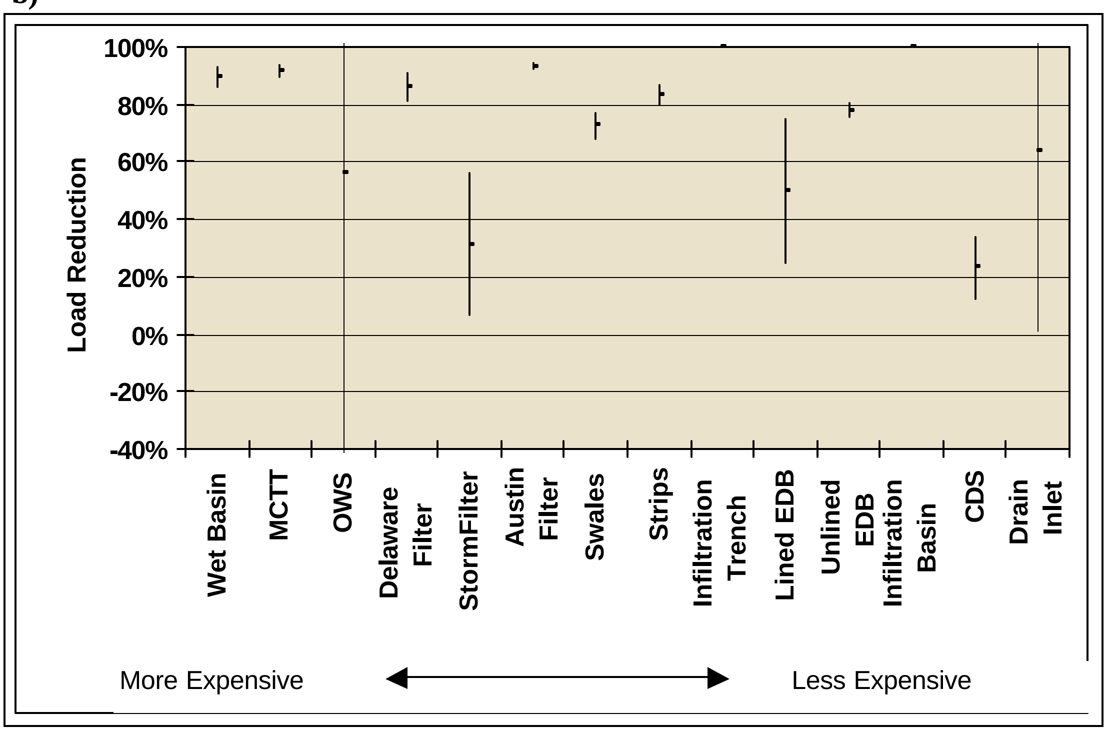
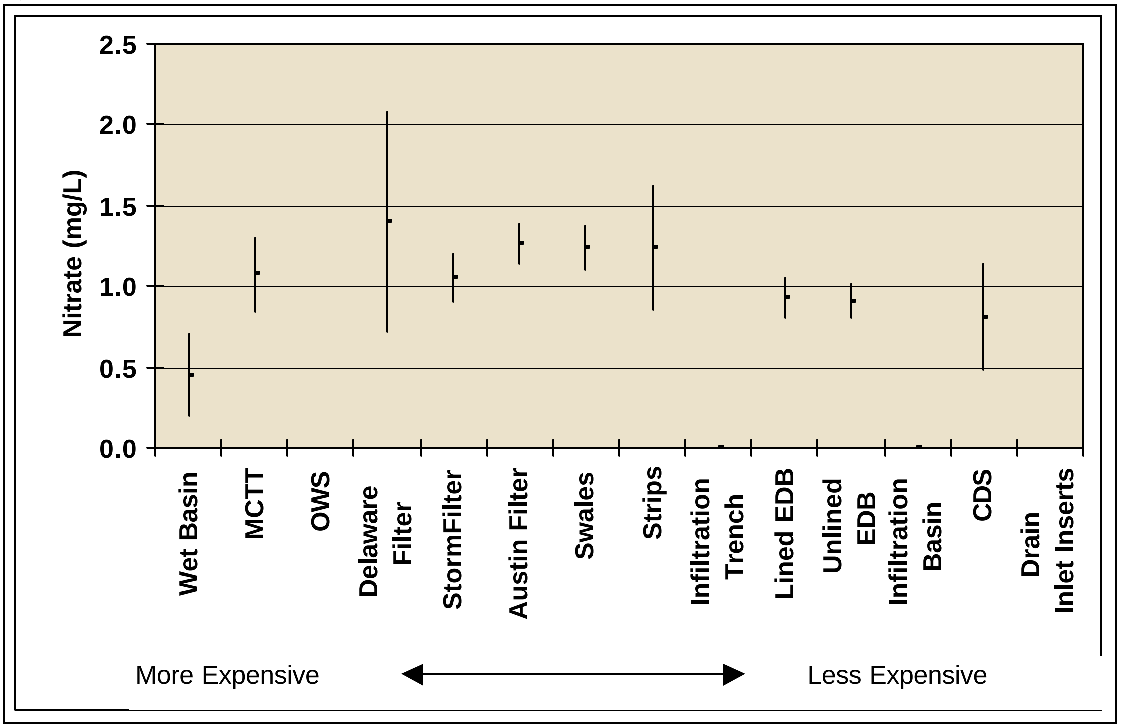


Figure 15-1 Predicted TSS Effluent Concentration (a) and Load Reduction (b)

a)



b)

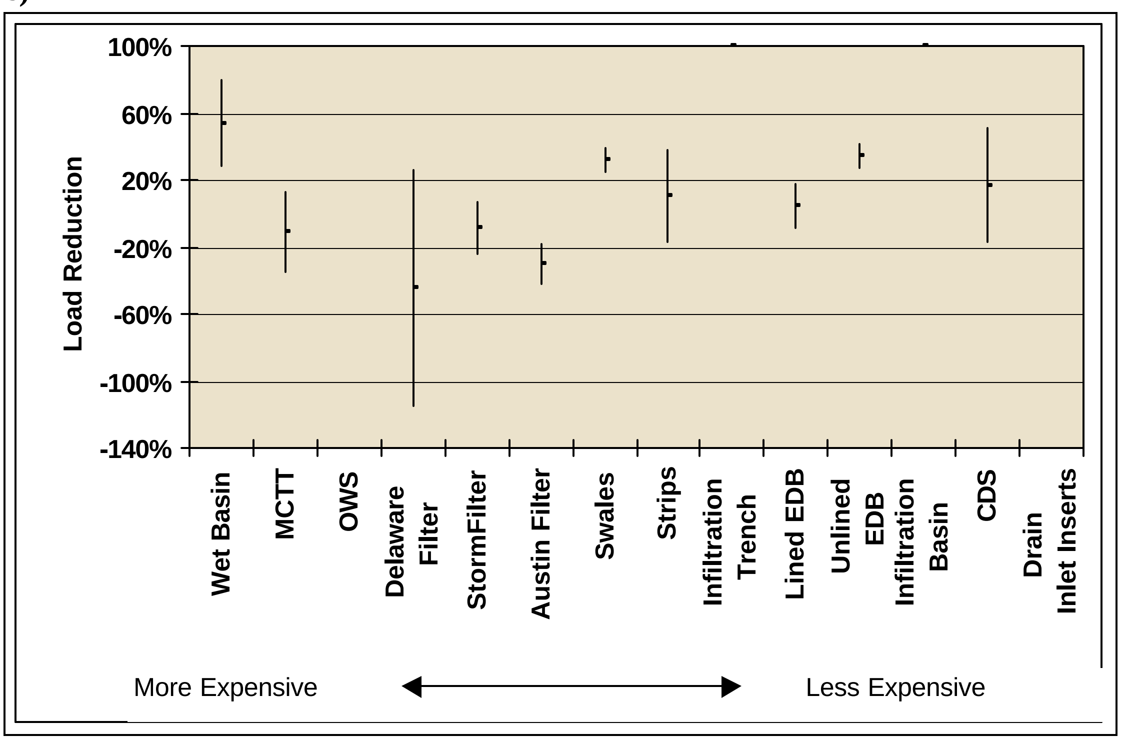
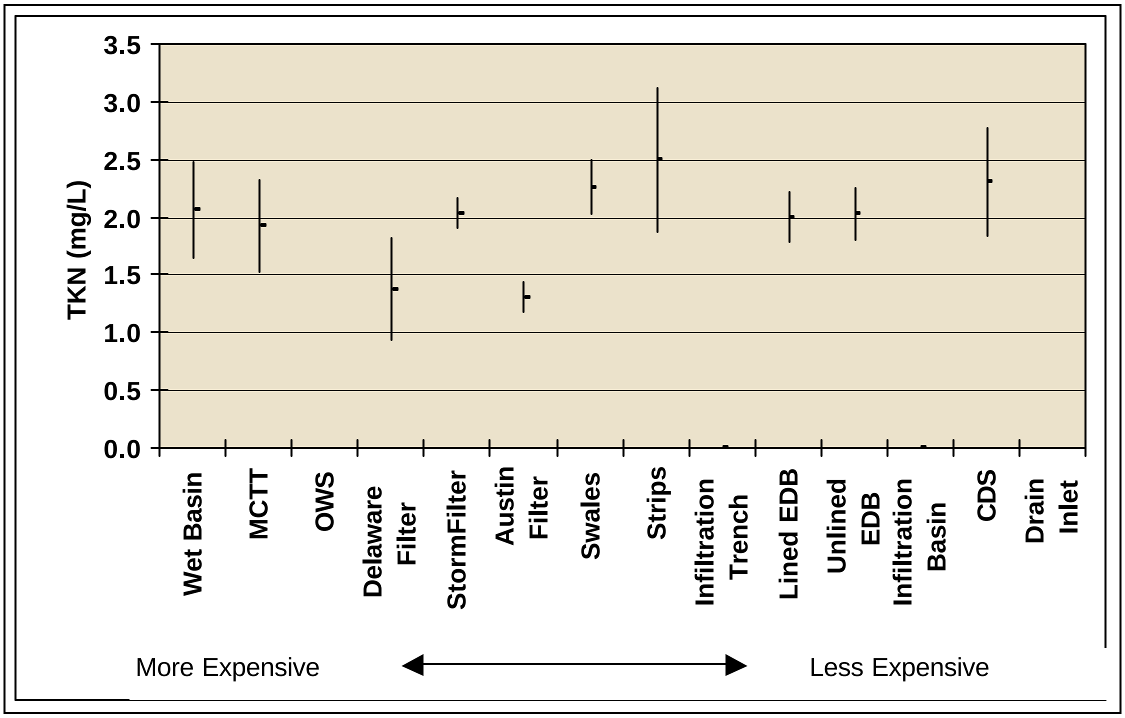


Figure 15-2 Predicted Nitrate Effluent Concentration (a) and Load Reduction (b)

a)



b)

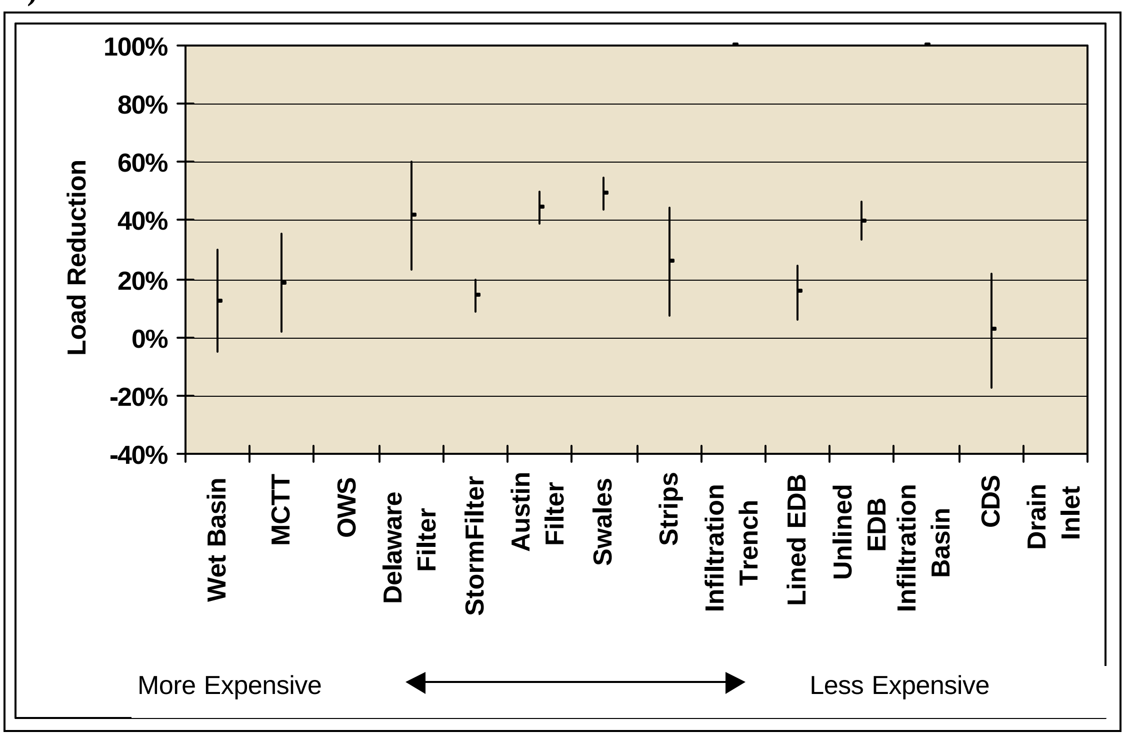
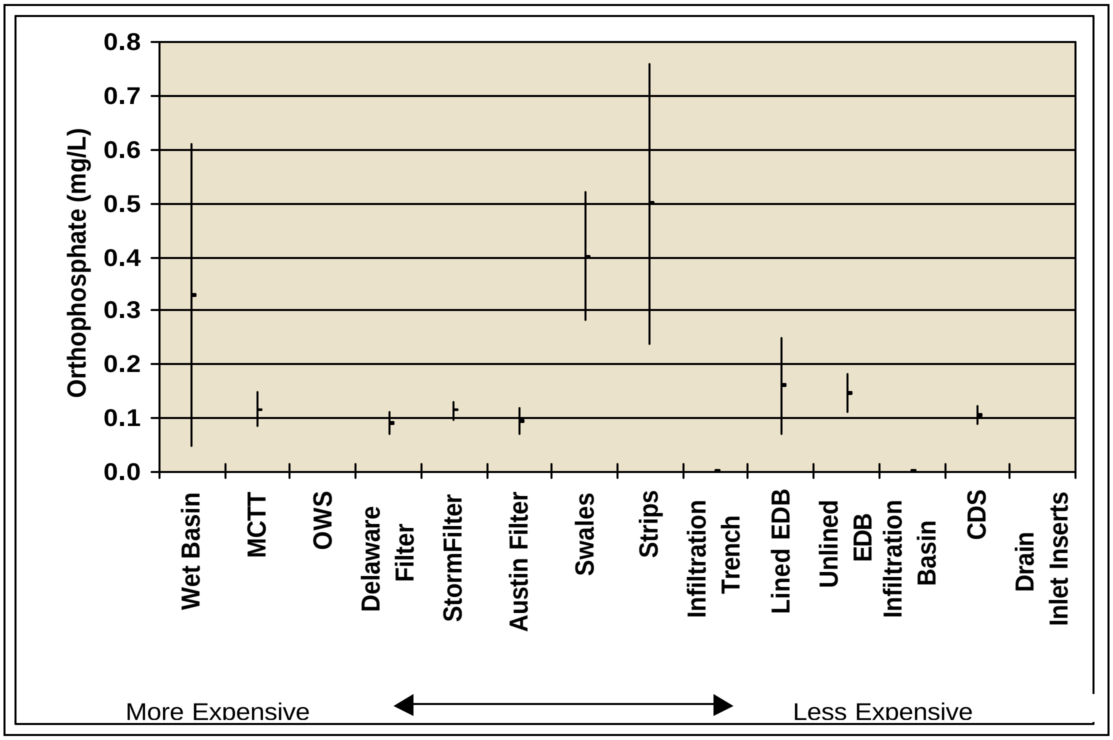


Figure 15-3 Predicted TKN Effluent Concentration (a) and Load Reduction (b)

a)



b)

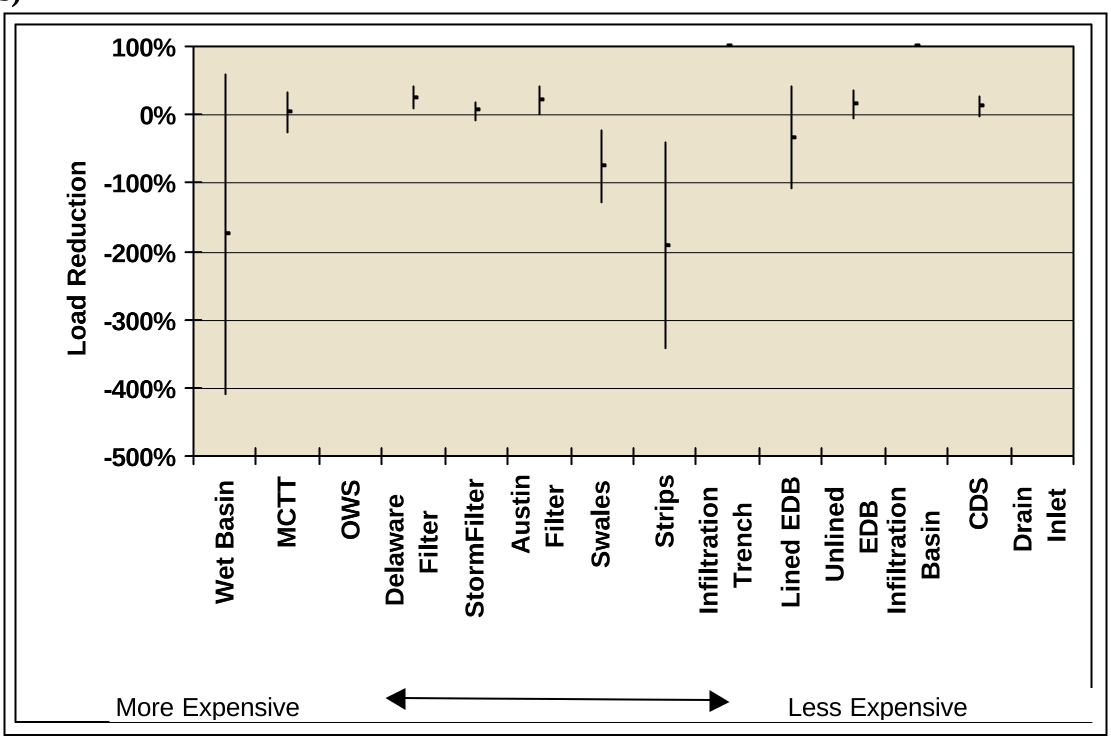
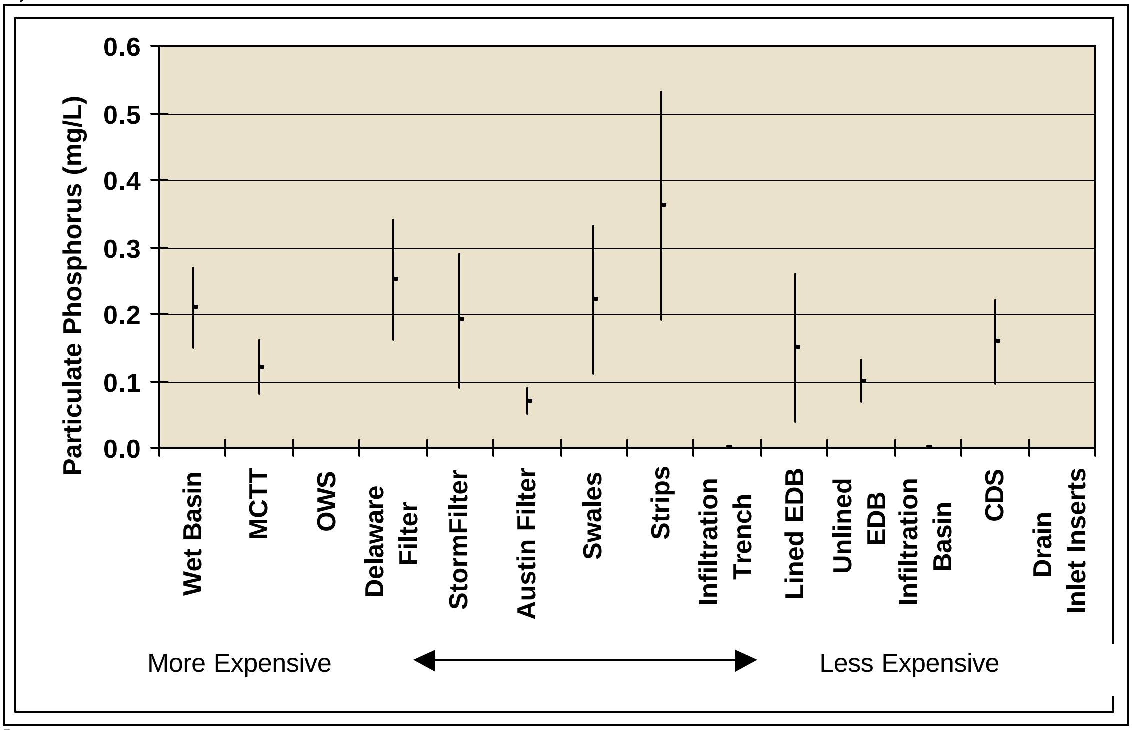


Figure 15-4 Predicted Dissolved P Effluent Concentration (a) and Load Reduction (b)

a)



b)

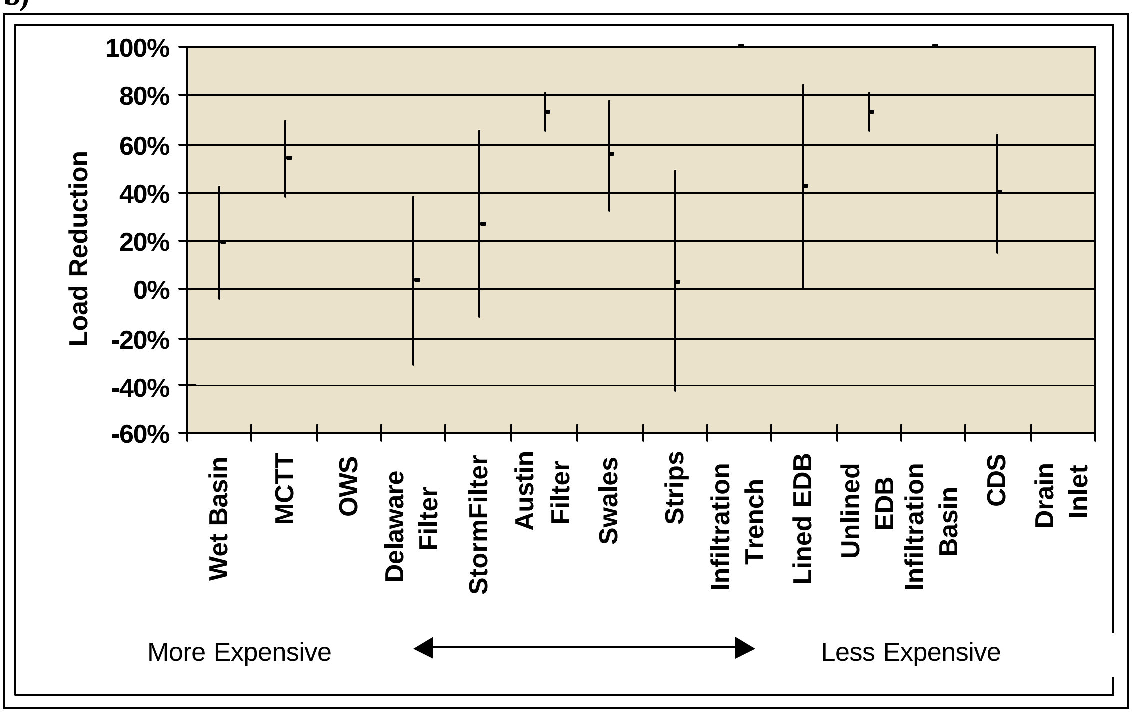
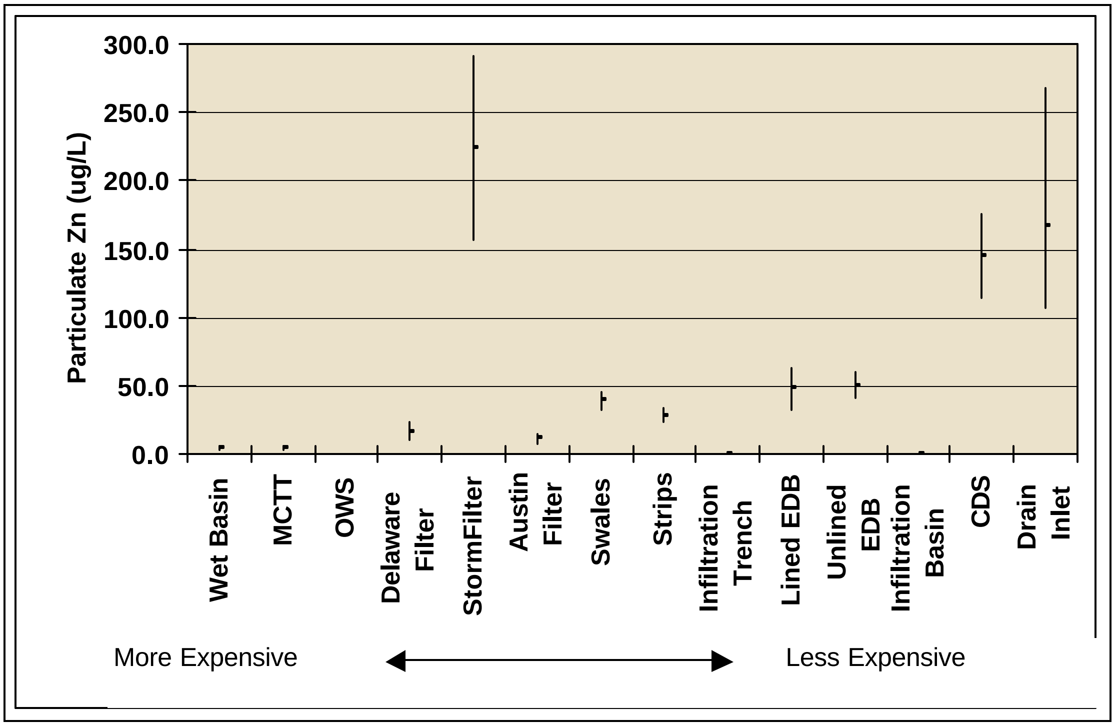


Figure 15-5 Predicted Particulate P Effluent Concentration (a) and Load Reduction (b)

a)



b)

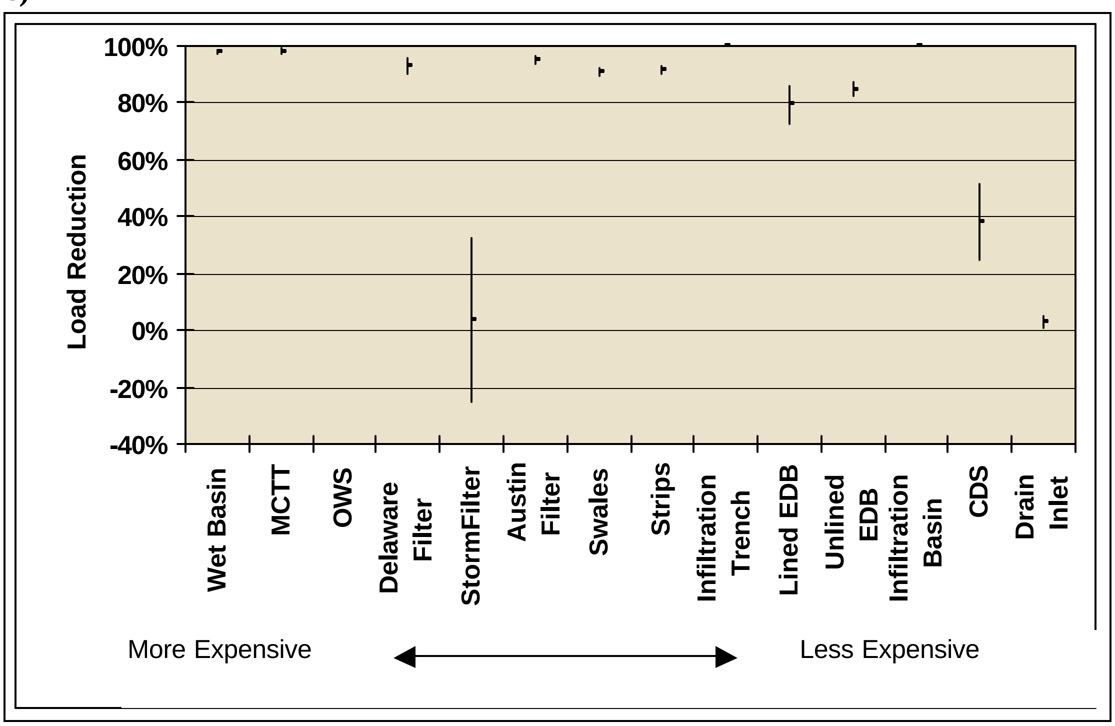
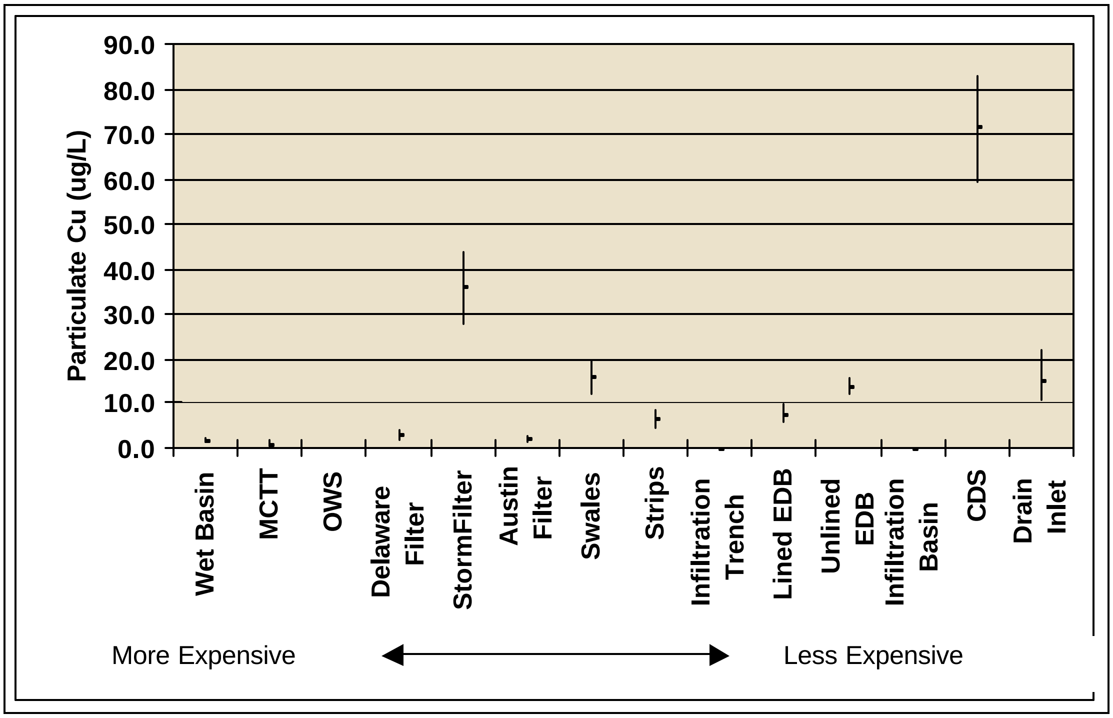


Figure 15-6 Predicted Particulate Zn Effluent Concentration (a) and Load Reduction (b)

a)



b)

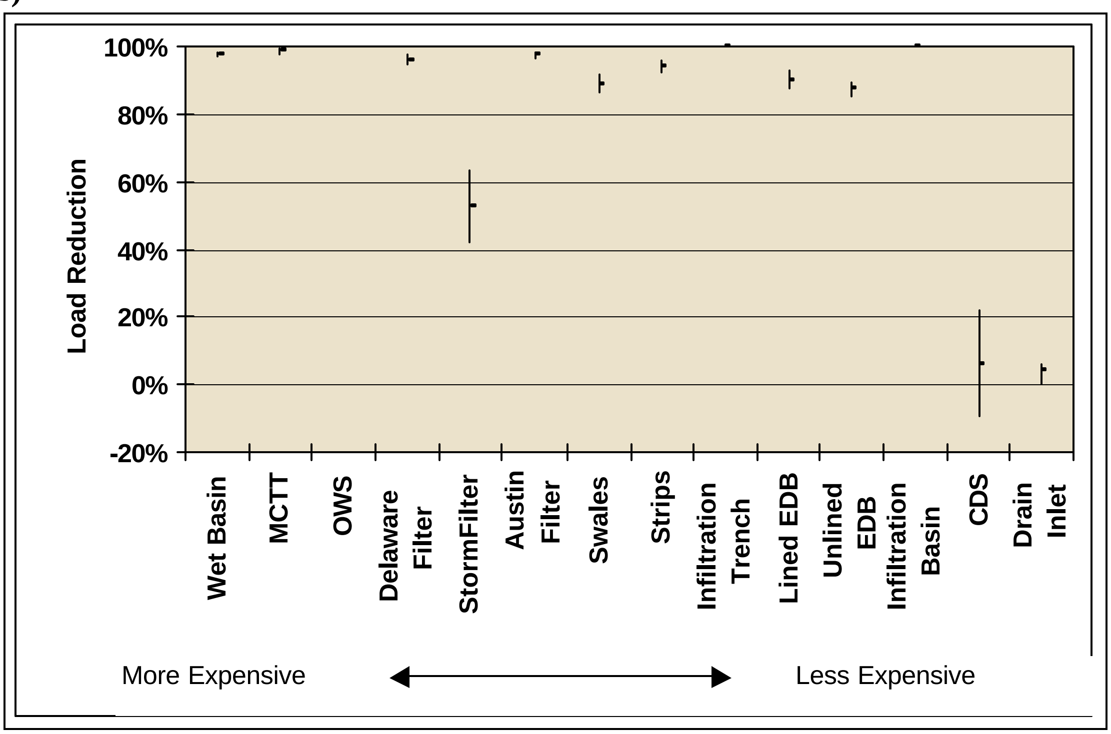
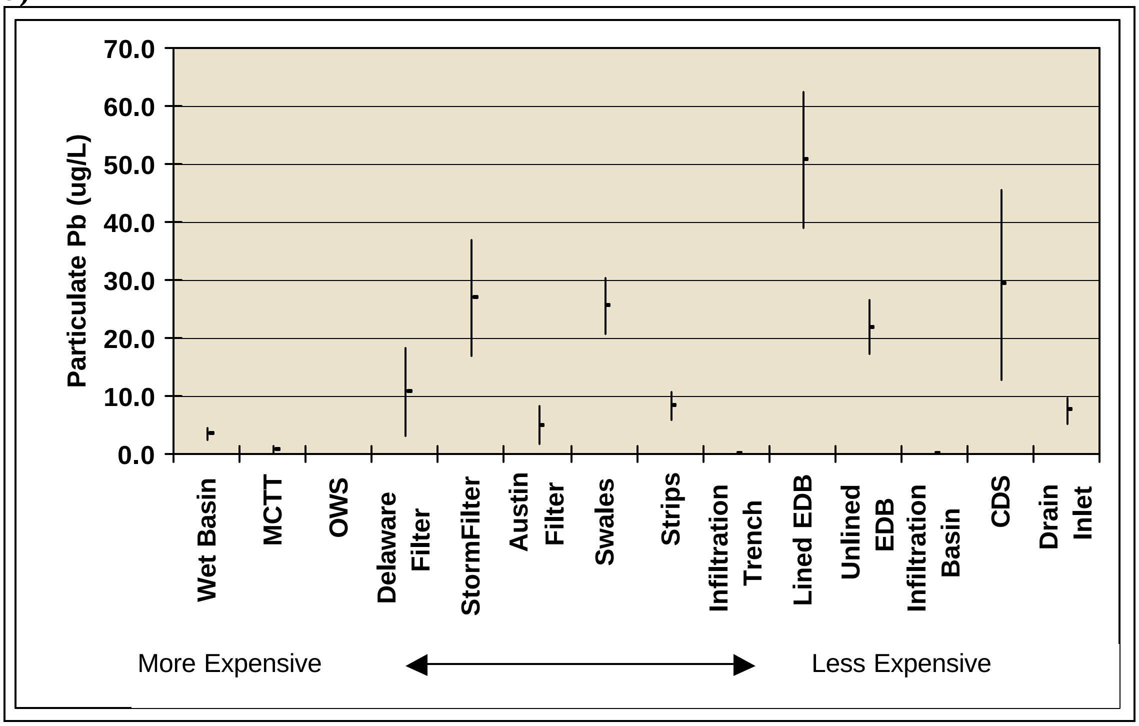


Figure 15-7 Predicted Particulate Cu Effluent Concentration (a) and Load Reduction (b)

a)



b)

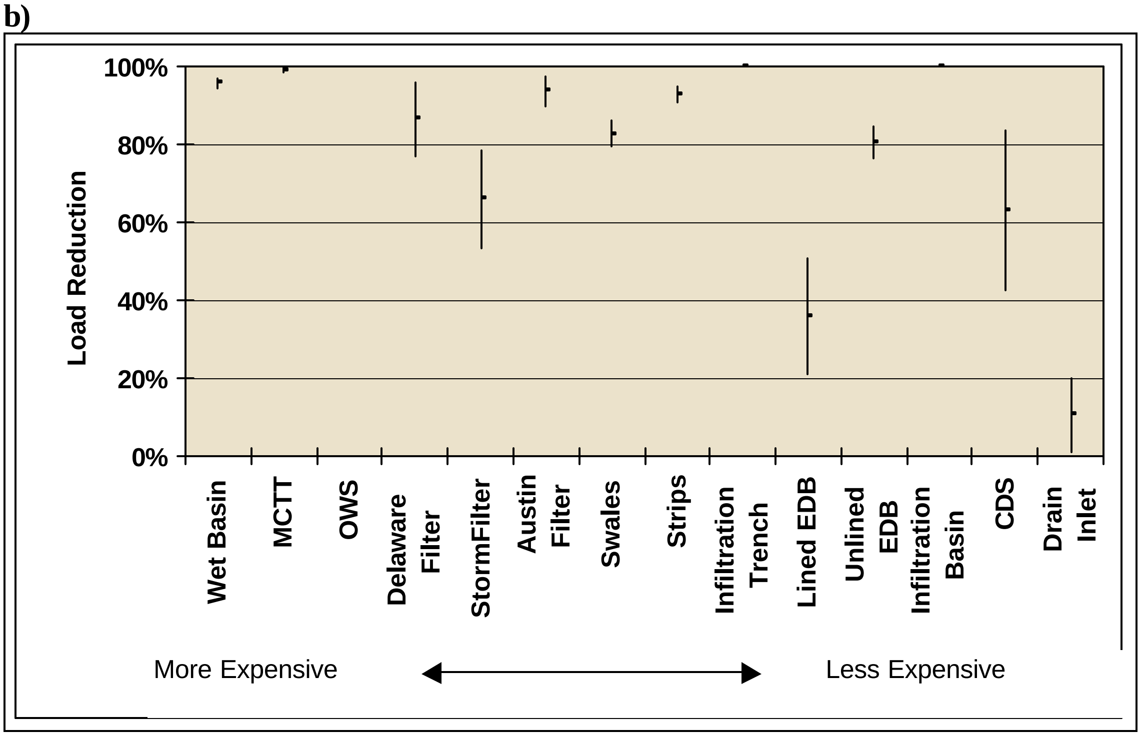


Figure 15-8 Predicted Particulate Pb Effluent Concentration (a) and Load Reduction (b)

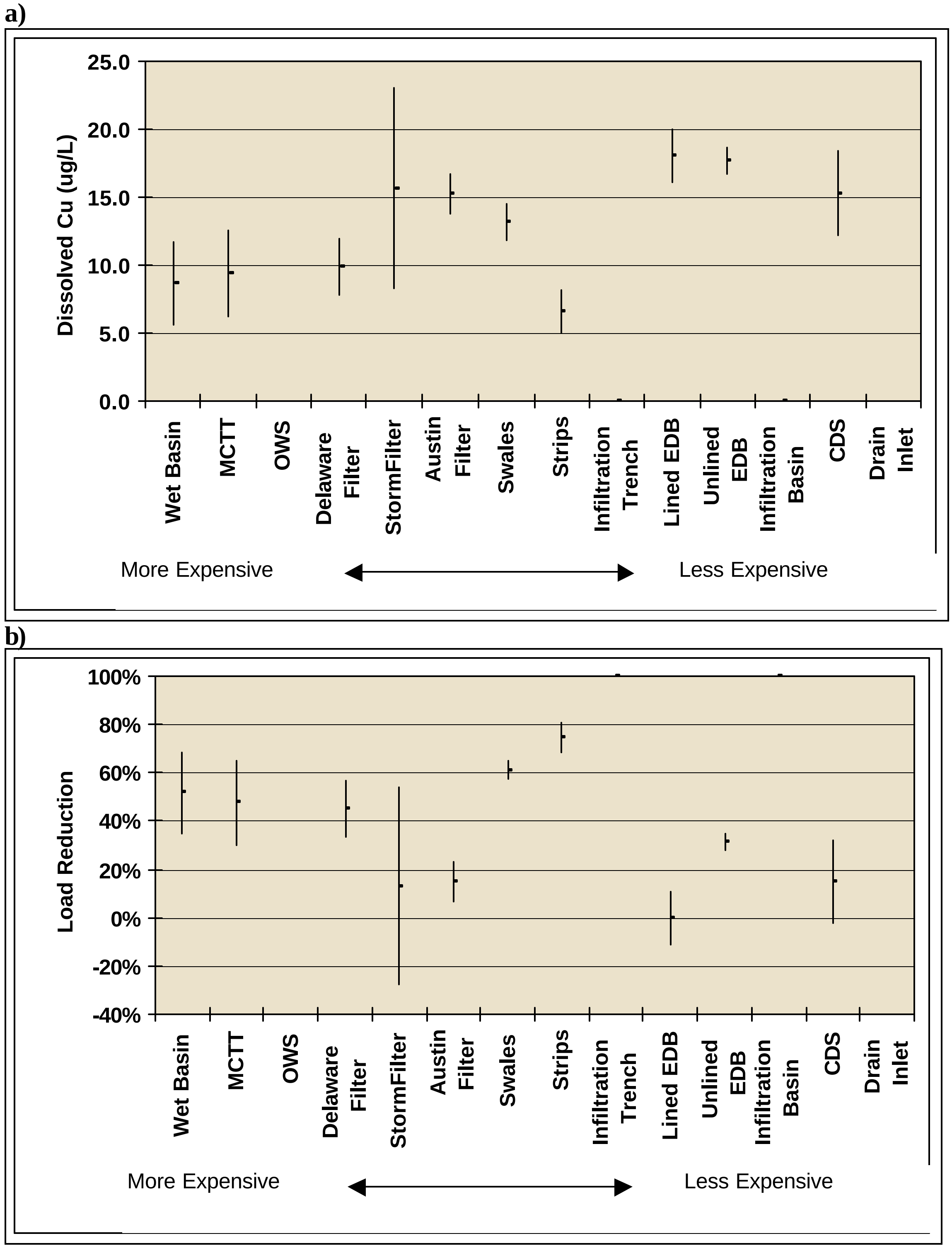
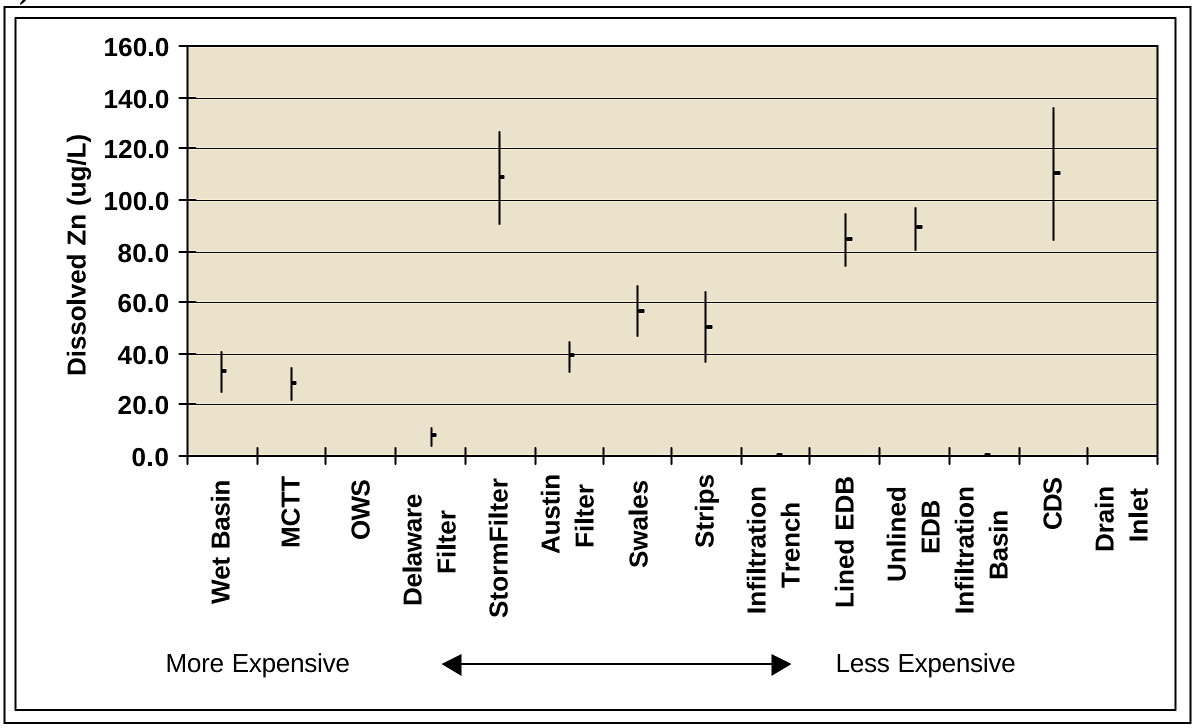


Figure 15-9 Predicted Dissolved Cu Effluent Concentration (a) and Load Reduction (b)

a)



b)

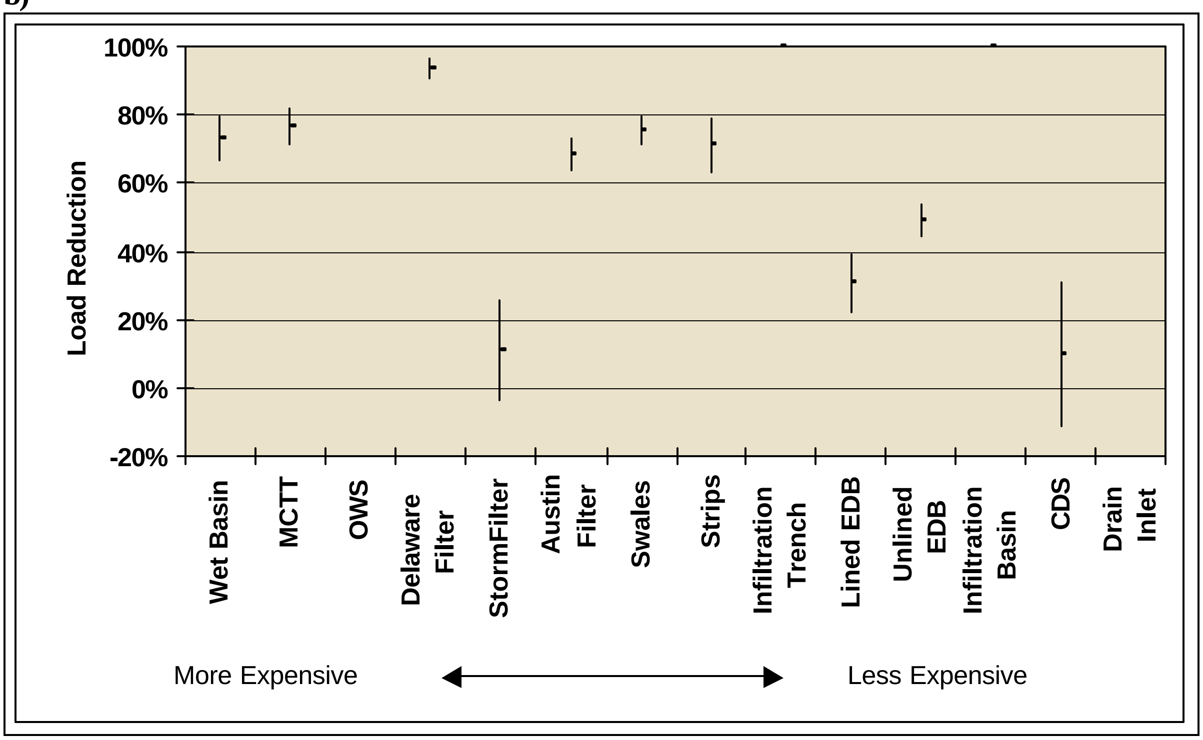


Figure 15-10 Predicted Dissolved Zn Effluent Concentration (a) and Load Reduction (b)

a)

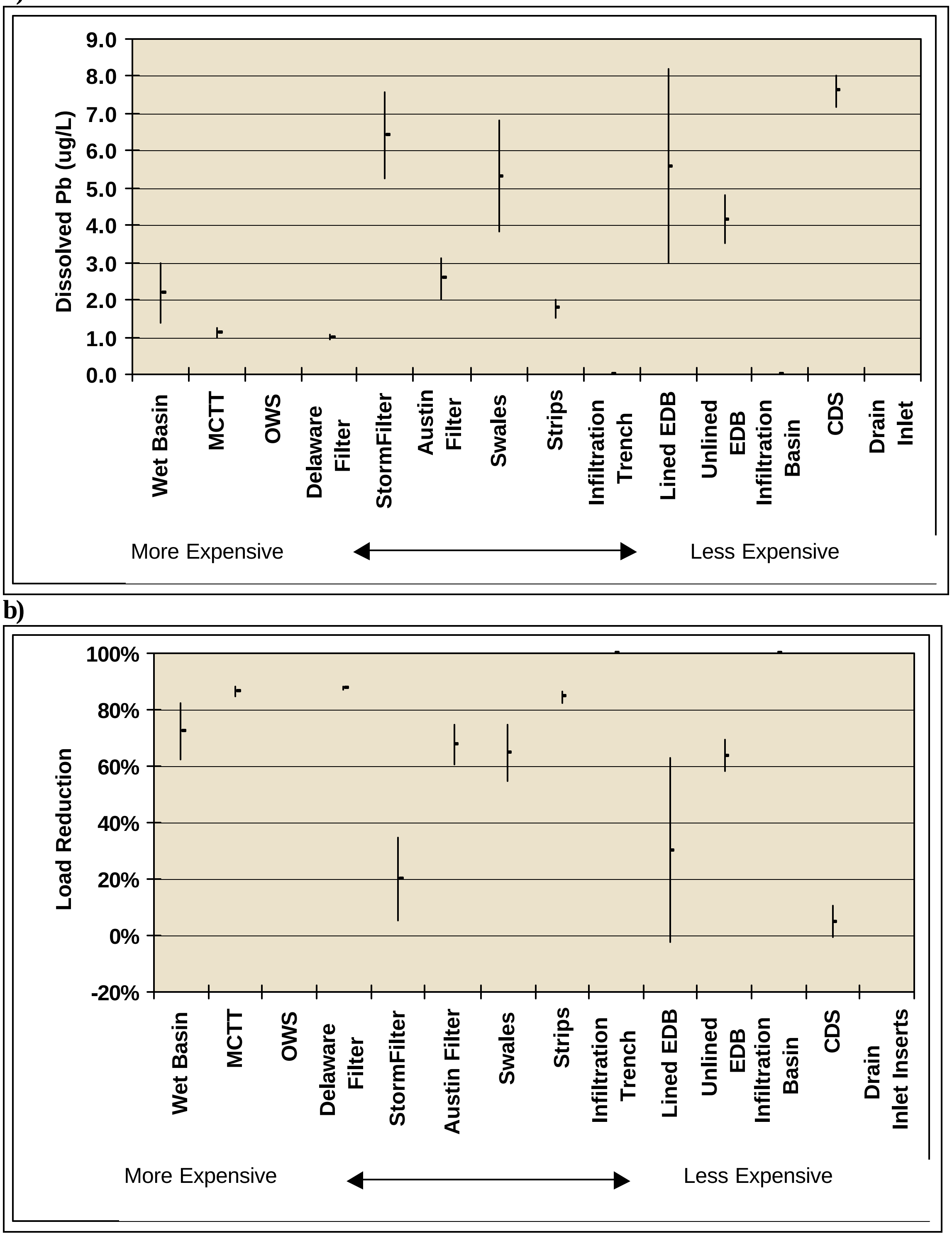


Figure 15-11 Predicted Dissolved Pb Effluent Concentration (a) and Load Reduction (b)

15.2 Implications of the Methodology

One of the primary products of this pilot program has been the development of this BMP selection methodology that allows a direct comparison of many BMP types based on life-cycle cost, removal efficiency for specific constituents of concern, and the concentration predicted for the untreated runoff at the proposed location. The graphs previously presented display the results based on the average runoff concentrations observed in highway runoff in southern California; however, the tabulated results allow one to make this comparison based on any runoff concentration of interest. This calculation of the expected concentration discharged from the BMPs evaluated allows a direct comparison with receiving water quality standards and a determination of the extent to which these standards can be met with conventional structural controls. Care should be taken when using this method to estimate the performance of BMPs installed in significantly different site conditions.

This methodology attempts to correct for biases introduced by the fact that many of the BMPs were evaluated at sites with very different runoff quality. For instance, the conventional analysis of removal efficiency indicates that the TSS reduction expected in an MCTT would be only 75 percent, while the very similar Austin sand filter had a calculated reduction of 90 percent. However, Figure 15-1(a) indicates that the predicted effluent TSS concentration of the two devices is not significantly different. It was only because the untreated runoff at the two MCTT sites had generally low concentrations (P&R sites) that the performance appeared to be worse. Consequently, the technique developed for performance comparison in this study may have widespread application for assessing the relative performance of BMPs nationwide.

16 CONCLUSIONS AND RECOMMENDATIONS

The objectives of this section are to compare and summarize the study findings of the technical feasibility and applicability for Caltrans facilities of the tested BMPs. In addition, recommendations are made for future research. Technical feasibility was assessed through detailed records kept during the installation and operation of each retrofit device. The technical feasibility considers siting, construction, operation, performance, maintenance, safety, and public health issues as described in Section 1.11.

The retrofit pilot program required Caltrans to install and implement a range of BMPs in one of the most challenging settings in the country – freeways. Despite these challenges, and despite several difficulties along the way, the program proved a large success, and several successful BMPs are now operating throughout many portions of urban southern California.

All of the tested devices were successfully sited without compromising the safety of the traveling public or Caltrans personnel; consequently, no devices were deemed infeasible based on this criterion. All of the devices met the drainage design criteria (see section 1.10) as well, except the StreamGuard™, which repeatedly caused localized flooding problems at the sites where it was installed. Siting of many of the BMPs was a technical challenge. The reasons for the difficulties included restrictive siting requirements related to the need for specific soil and subsurface conditions (infiltration devices), required baseflow (wet basin), or space imitations within the highway right-of-way. At many of the sites a significant portion of the cost was associated with changes to the original storm drain system to direct more runoff to the test sites. These difficulties point to the need to include BMP retrofit early in the planning stages of reconstruction projects to take advantage of possible drainage system reconstruction. This would also facilitate coordination with the right-of-way acquisition process to accommodate the land requirements of some types of BMPs.

An unexpected design element was the importance of avoiding standing water in the BMPs. Standing water presents opportunities for mosquito vectors to establish themselves. Mosquito breeding was observed at all of the sites where standing water occurred. In addition to the technologies that incorporate a permanent pool (i.e., wet basin, Storm-Filter™, MCTT, and Delaware filter), standing water also occurred in stilling basins, around riprap used for energy dissipation, in flow spreaders and in some outlet structures of other types of BMPs. In any future installations, nonessential pools should be avoided to minimize vector concerns.

16.1 Media Filters

This study confirmed the high level of pollutant removal associated with filtration systems. The Austin and Delaware sand filters and the MCTT provided substantial water quality improvement and produced a very consistent, relatively high quality effluent. Although the greatest concentration reduction occurred for constituents associated with particles, substantial reduction in dissolved metals concentrations were also observed when the influent concentrations were sufficiently high. This contradicts expectations that little removal of the dissolved phase would occur in this type of device.

Information generated in this study showed that maintenance requirements were comparable to other devices studied, with clogging of the filter (and reconditioning) only expected to occur every 3-5 years. The main question remaining concerning applicability of Austin sand filters is whether the incremental improvement in water quality over that observed in extended detention basins justifies the higher construction costs. This would be a site specific decision based on receiving water conditions and is beyond the scope of this study. It should also be noted that implementing design alternatives will result in capital cost reductions to the Austin sand filter designs implemented in this pilot program, but may increase O&M cost.

The media filters are considered technically feasible for treatment of Caltrans stormwater runoff depending on site specific conditions. The Austin and Delaware sand filters and the MCTT provided substantial water quality improvement, and are compatible with the small, highly impervious watershed characteristic of Caltrans facilities. As discussed earlier, maintenance and operation of the pumps at several of the sites was a recurring problem. Consequently, other technologies may be a better choice at sites with insufficient hydraulic head for operation of media filters by gravity flow.

The Delaware and MCTT designs both incorporate permanent pools in the sedimentation chamber, which can increase vector concerns and maintenance requirements. Alternative designs to remedy this problem would be warranted prior to deployment consideration. The Delaware filter could be applicable at certain sites where an underground vault system was desired; however, the vector issues associated with the permanent pool must be continually monitored. The MCTT was found to have a similar footprint and provide a water quality benefit comparable to the Austin sand filter; however, the permanent pool and associated vector issues of the MCTT suggest that the Austin filter would be preferred.

In general, the Storm-Filter™ did not perform on par with other media-filters tested, showing little attenuation of the peak runoff rate and producing a reduction in concentrations that was not statistically significant for most constituents. In addition, the standing water in the Storm-Filter™ has the potential to breed mosquitoes. Since Storm-Filter™ performance was less and the life-cycle cost was greater than the Austin filter; the Storm-Filter™ is not considered applicable for implementation based on the media evaluated in this study, even if the vector problems were eliminated.

Future research on construction methods and materials for sand filters is warranted to improve the cost/benefit ratio for these devices prior to consideration for deployment. In addition, evaluation of alternative media may also allow the targeting of specific constituents or improvement in the performance for constituents, such as nitrate, which are not effectively removed by a sand medium. Caltrans has initiated extensive additional research examining design alternatives to improve performance and reduce costs for sand filters.

Where media filters are to be deployed, the following guidelines are recommended:

- Avoid siting a media filter where a pump would be required due to lack of head for gravity operation.
- Develop standardized design details for the inlets, outlets and filter bed.
- Use a locally available filter sand specification that generally meets Caltrans Standard Specifications for fine aggregate in sections 90-2.02 and 90-3, which is similar to ASTM C-33 requirements.
- Include maintenance access ramps to the sedimentation chamber and sand filter chamber where the chamber side slope will exceed 1:4 (V:H).
- Do not use a level spreader to distribute flow over the sand bed. Local energy dissipation is acceptable, in lieu of the spreader.
- Slope the floor of the sedimentation chamber to the outlet riser to promote positive drainage and for ease of maintenance.
- Include provisions to allow a net to be installed over the sand bed to keep birds out of the filter.
- Continue research to reduce the device capital cost and maintenance cost, and improve filter performance.
- Follow the guidelines recommended in the final version of the MID for operation and maintenance (see Appendix D).

16.2 Extended Detention Basins

This study confirms the flexibility and performance of this conventional stormwater treatment technology. Extended detention basins have an especially extensive history of implementation in other areas and are currently considered technically feasible at suitable sites. There are few constraints for siting, although larger tributary areas can substantially reduce the cost and make clogging of the outlet orifice less likely. The relatively small head loss (as compared to sand filters) associated with this technology is particularly useful in retrofit situations where the elevations of existing stormwater infrastructure are a design constraint. The unlined installations in southern California did not experience any problems associated with establishment of wetland vegetation, erosion, or excessive maintenance (as compared to the concrete-lined basin). Except where groundwater quality may be impacted, unlined basins are preferred on a water quality basis because of the substantial infiltration and associated pollutant load reductions that were observed at these sites.

The pollutant removal observed in the extended detention basins was similar to that reported in previous studies and appeared to be independent of length/width ratio as low as 3:1, which is a commonly used design parameter. Re-suspension of previously accumulated material seemed to be more of an issue in the concrete-lined basin, which exhibited less concentration reduction than those constructed of earth.

Extended detention basins are a thoroughly studied technology; however, Caltrans is currently researching design alternatives that reduce capital cost without sacrificing performance. These studies include refinements to inlet and outlet structures and investigating reduction of the water quality capture volume.

This study found little correlation between length-to-width ratio, which is a common design specification, and pollutant removal. Consequently, further work to define this relationship may be warranted. In addition, relaxing this requirement may allow implementation at sites where a large aspect ratio may be difficult to obtain.

Where extended detention basins are to be deployed, the following guidelines are recommended:

- Site in a watershed of at least 2 ha to minimize the potential for clogging of orifice(s) in the outlet riser.
- Additional research is warranted to determine the effect of the basin length to width ratio on constituent removal performance.
- Use earth basins in favor of concrete lined basins for best constituent removal performance.
- Tolerances may be close in retrofit situations with respect to basin inlet and outlet elevations. Ensure the contractor incorporates good quality control during construction.
- Check the drain time for a full basin in the field to ensure it coincides with the calculated design value. Modify the riser outlet orifice(s) as necessary.
- Follow the guidelines recommended in the final version of the MID for operation and maintenance (see Appendix D).

16.3 Wet Basins

A wet basin was successfully sited and operated for this study and pollutant removal was found to be among the best of the piloted BMPs. As described previously, the effluent quality from a wet basin with a large permanent pool volume is largely a function of the quality of the baseflow used to maintain that pool and of the transformation of the quality of that flow during its residence time in the basin.

The largest technical challenge in siting a wet basin will be finding sites with perennial flow. The siting process found that at the sites looked at many were from small, highly impervious watersheds with no dry weather flow. Footprint size was also a factor, restricting siting opportunities and increasing construction cost. With a permanent pool volume three times the WQV, the wet basin was substantially larger than other similar technologies, such as EDBs. Larger size generally results in higher cost and land requirements above those of alternative technologies. Wet basin construction cost is among the highest of the technologies evaluated, and the annual maintenance requirements were much higher than the other devices due to vegetation management.

Two long-term operation and maintenance cost issues were not able to be determined as a part of the Pilot Study. The first issue is the possibility of harborage of endangered species in the basin. Measures were employed (such as the use of mylar in the wet basin vegetation) to preclude the harborage of endangered species during the study, but it is recognized that over a period of long-term operation, endangered species may be encountered. Further, consultation with the appropriate regulatory agency is necessary to determine the mitigation requirements for continuing maintenance at the facility if endangered species are present.

There are two additional issues related to design and operation of wet basins that warrant further research. Wetland vegetation can be sustained with interruption of baseflow for up to several months, meaning that sites receiving baseflow only during the wet season could be considered. The performance of this seasonal wet basin design alternative may differ substantially from that reported for the installation monitored in this study; consequently additional study of this design modification should be pursued. In addition, there are numerous published guidelines for sizing of the permanent pool and there could be additional work to further refine the relationship between pool size and pollutant removal for various constituents.

Where wet basins are to be deployed, the following guidelines are recommended:

- The effluent quality during storms is determined primarily by the quality of the permanent pool, which is largely a function of the baseflow.
- Additional research is needed to define the performance threshold for the minimum water quality volume to permanent pool ratio.
- Additional research is needed to determine long-term maintenance requirements and cost.
- Observe the drain time of the water quality volume to ensure that it is consistent with the design expectation. Modify the outlet riser to achieve the design drain time if needed.
- Follow the guidelines recommended in the final version of the MID for operation and maintenance (see Appendix D).

16.4 Infiltration Basins and Trenches

Infiltration basins were shown to be technically feasible at one of the piloted locations and can be an especially attractive option for BMP implementation, since they provide the highest level of surface water quality performance. In addition, they reduce the total amount of runoff, restoring some of the original hydrologic conditions of an undeveloped watershed. Maintenance requirements were especially low for infiltration trenches and construction costs are similar to those of extended detention basins; however, periodic trench rehabilitation is an expected but unknown cost. In addition, there are three main constraints to widespread implementation of infiltration devices: locating sites with appropriate soils, potential threat to groundwater quality (especially from potentially toxic spills), and the risk of site failure due to clogging.

The original siting study did not identify sufficient suitable locations for the number of infiltration device installations specified in the District 7 Stipulation within the time frame provided. This pilot study is being followed by assessments in both District 7 and District 11 to gauge the extent of infiltration opportunities, in Los Angeles with field investigations in selected highway corridors and in San Diego using existing data, but more broadly based through the District. In addition, there is concern at the state and regional levels of the impact on groundwater quality from infiltrated stormwater runoff. The portion of this study that was implemented to assess the potential impact to groundwater quality from infiltrated stormwater runoff was largely unsuccessful; however, no adverse impacts to groundwater quality were observed. Longer term more comprehensive studies than were possible under this pilot program are warranted. Despite these uncertainties, the parties in this study worked cooperatively to develop interim guidelines for siting infiltration devices in response to requests by the State and Regional Water Quality Control Boards.

In summary, although infiltration is considered to be technically feasible depending on site specific conditions it tends to be a more challenging technology in that site assessment and long-term maintenance issues are critical elements that are subject to some uncertainty. Clearly, the experience in this study is that siting these devices under marginal soil and subsurface conditions entails a substantial risk of early failure. Analysis of this experience resulted in development of a detailed set of site assessment guidelines for locating infiltration devices in the future. It is important that these guidelines be implemented to insure that infiltration is used with adequate separation from groundwater and with soil providing a favorable infiltration rate. Even at appropriate sites, degradation of soil structure, fine sediment clogging, and other changes that may occur during construction or over the life of the facility could be difficult to ameliorate.

The primary research question left unresolved is the potential impact of the infiltrated runoff on groundwater quality. Further study of these potential impacts is certainly warranted. In addition, further study of the pilot installations is recommended to better establish the expected life of these devices and the long-term cost of operation and maintenance.

Where infiltration devices are to be deployed, the following guidelines are recommended:

- Groundwater separation of at least 3 m from the device invert to the seasonal high water table is preferred.

- Conduct a minimum of three in-drill-hole permeability tests on the site to measure the in-situ hydraulic conductivity.
- Use the minimum field-measured value from the permeability tests. The minimum acceptable value is 13 mm/hr.
- Multiply the measured conductivity value by a factor of safety of 0.5.
- Basin invert area should be determined by the equation

$$A = \frac{WQV}{kt}$$

where	A	=	Basin invert area (m^2)
	WQV	=	water quality volume (m^3)
	k	=	0.5 times the lowest field-measured hydraulic conductivity (m/hr)
	t	=	drawdown time (hr)

- The use of vertical piping, either for distribution or infiltration enhancement should not be allowed to avoid device classification as a Class V injection well per 40 CFR146.5(e)(4).
- Follow the guidelines recommended in the final version of the MID for operation and maintenance (see Appendix D).

16.5 Biofiltration Swales and Strips

Vegetated swales and strips were found to be technically feasible at the piloted locations and are particularly applicable where sufficient space is available. They were among the least expensive devices evaluated in this study and were among the best performers for reducing sediment and heavy metals in runoff. It was generally not necessary to remove deposited sediment at the pilot installations during the course of this study; however, sediment removal and occasional regrading and revegetation must be considered a long-term operation and maintenance cost.

Although irrigation was used to establish the biofiltration swales and strips, natural moisture from rainfall was sufficient to maintain them once established. However, complete vegetation coverage, especially on the side slopes in swales, was difficult to maintain. Repeated hydroseeding of these areas had little effect other than to possibly increase the amount of nutrients leached from the sites. An important lesson of this study is that a mixture of drought-tolerant native grasses is preferred to the salt grass monoculture used at the pilot sites. In southern California, it is preferable to select species that grow best during the winter and spring (the wet season), and to schedule biofilter establishment accordingly. Few erosion problems were noted in the operation of the sites; however, damage by burrowing gophers was a problem at two sites.

Since the reduction of concentration and load of the constituents monitored was comparable in other respects to the results reported in other studies (Young et al., 1996), except for phosphorus, one could conclude that pollutant removal is not seriously compromised by lower vegetation density and occasional bare spots. While space limitations in highly urban areas may make siting these BMPs difficult, they are flexible relative to the alternatives in fitting into available space such as medians and shoulder areas. Consequently, these vegetated controls should certainly be considered where sufficient space and appropriate flow conditions are present. The swales are easily sited along highways and within portions of maintenance stations and do not require specialized maintenance. In addition, the test sites were similar in many regards to the vegetated shoulders and conveyance channels common along highways in many areas of the state. Consequently, one would expect these areas, which were not originally designed as treatment devices, to offer comparable water quality benefit as these engineered sites.

There are a number of research needs associated with vegetated controls. This is especially true for filter strips. There are few empirical data on the effect of slope and length on pollutant removal performance. In addition, there was no relationship between the ratio of the strip size to tributary area and pollutant removal. Consequently, additional information is needed relative to sizing of these devices. These questions are currently under study by Caltrans at eight sites throughout the state under a separate program. The pilot study implemented a monoculture of salt grass at all biofilter sites, so the effectiveness of other grass species for pollutant removal was not quantified. Finally, additional information is needed on the minimum vegetation density for effective operation and on the limitations on their deployment for other areas based on rainfall and climate considerations.

Where strips and swales are to be deployed, the following guidelines are recommended:

- A mixture of drought tolerant grasses is preferred. Species that grow best during the winter and spring (for southern California) will provide the best potential for good coverage during the storm season.
- Follow the guidelines presented in the final MID (see Appendix D) for operation and maintenance.
- Additional study is warranted to determine potential impacts to groundwater resources.
- Additional study is needed to determine the minimum dimensions and maximum slope (for both swales and strips) to maintain acceptable performance.
- Do not use concrete level spreaders to attempt to obtain a sheet flow condition for strips.

16.6 Continuous Deflective Separators

Two CDS® units were successfully sited, constructed and monitored during the study. The devices were developed in Australia with the primary objective of gross pollutant (trash and litter) removal from stormwater runoff. The devices were found to be technically feasible at the piloted locations and highly successful for removing gross pollutants, capturing an average of 88 percent, with bypass of this material occurring mainly when the flow capacity of the units was exceeded. Even though these two units were sited on elevated sections of freeways, 94 percent of the captured material by weight was vegetation. Consequently, the maintenance requirements may be excessive if these units are located in an area with a significant number of trees or other sources of vegetative material.

A secondary objective of the CDS® units is the capture of sediment and associated pollutants, particularly the larger size fractions. The average sediment concentration in the influent to the two systems was relatively low and no significant reduction was observed. Reductions in the concentrations of other constituents were also not significant.

These devices maintain a permanent pool in their sumps and mosquito breeding was observed repeatedly at the two sites. The frequency of breeding was reduced by sealing the lids of the units and installing mosquito netting over the outlet. Other non-proprietary devices developed by Caltrans for litter control, which do not maintain a permanent pool may be preferred to this technology to minimize vector concerns.

16.7 Drain Inlet Inserts

Two proprietary drain inlet inserts were evaluated. The data collected during this study indicate that the tested inserts were maintenance intensive and provided minimal pollutant removal. The absolute number of maintenance hours was not large, but timing is critical, immediately before and during storm events. Because of safety considerations, installation at maintenance stations might be considered more appropriate; however, timely maintenance is infeasible due to other demands on maintenance personnel during storm events. These devices did not operate passively and unattended.

In addition, the inserts tested were only marginally effective, with constituent removal generally less than 10 percent. These particular inserts would not be considered technically feasible at the piloted locations based on the observed performance and the fact that proper functioning required maintenance during storm events (i.e., they did not operate passively and unattended). There are many other types of proprietary drain inlet inserts on the market that were not evaluated and some new designs have become available since the study began. In addition, improvements are continually being made to the tested devices; consequently, the monitoring results may not reflect the performance of currently available models. Further, one of the inserts tested is no longer available from the manufacturer. It should be noted trash removal was not monitored as part of this study and certain types of drain inlet inserts may be effective for this purpose.

Where drain inlet inserts are to be deployed, the following guidelines are recommended:

- Considering the performance and maintenance requirements found in this study, DIIs may be more appropriate for temporary conditions (e.g., a construction project or a special operation), than for installation as a primary treatment BMP.
- Avoid installation of DIIs in areas with overhanging vegetation and other sources of material that could clog the filter.
- Avoid the use of perimeter type filter inserts where flow enters the inlet in concentrated stream.
- Be aware of poor quality control for apparent opening size in drain inlet insert fabrics.
- Follow the guidelines presented in the final MID (see Appendix D) for operation and maintenance.

16.8 Oil-Water Separator

An oil-water separator was successfully sited, constructed and monitored; however, this technology should not be considered the first choice for a stormwater BMP based on the water quality performance observed. Concentrations of free oil in stormwater runoff from the monitored site were too low for effective operation of this technology (minimum of about 50 mg/l). At these low levels, other conventional stormwater controls can provide better treatment of hydrocarbons in runoff. However, there may be appropriate in certain non-stormwater situations (e.g., where source controls cannot ensure low oil and grease concentrations).

REFERENCES

Barrett, Michael E., Walsh, Patrick M., Malina, Joseph F., Jr., Charbeneau, Randall J., 1998. "Performance of Vegetative Controls for Treating Highway Runoff," *ASCE Journal of Environmental Engineering*, Vol. 124, No. 11, pp 1121-1128.

Brown and Caldwell, and Law Crandall, 1999. *Operation Maintenance and Monitoring Plan District 7: Volumes I & II – BMP Stormwater Monitoring Field Guidance Notebooks*, prepared for the California Department of Transportation, Report No. CTSW-RT-99-052.

California Department of Transportation (Caltrans), 1996. *Caltrans Storm Water Quality Handbook, Planning and Design Staff Guide*.

California Department of Transportation (Caltrans), 2001. *Gross Solids Removal Device (GSRD) Pilot Study 2000-2001 Interim Report*. August 2001.

California Department of Transportation (Caltrans), *Highway Design Manual*. February 1995.

City of Austin, 1988. *Environmental Criteria Manual*, Drainage Utility Department, Austin, TX.

Colwell, Shanti R., Horner, Richard R., and Booth, Derek B., 2000. *Characterization of Performance Predictors and Evaluation of Mowing Practices in Biofiltration Swales*. Report to King County Land and Water Resources Division et al., by Center for Urban Water Resources Management, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA.

Corsi, S.R., Greb, S.R., Bannerman, R.T., and Pitt, R.E., 1999. *Evaluation of the Multi-Chambered Treatment Train, a Retrofit Water Quality Management Practice*. U.S. Geological Survey. Open-File Report 99-270. Middleton, WI. 24 pgs.

Gilbert, R.O., 1987. *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, NY.

Glick, Roger, Chang, George C., and Barrett, Michael E., 1998. "Monitoring and Evaluation of Stormwater Quality Control Basins," in *Watershed Management: Moving from Theory to Implementation.* Denver, CO, May 3-6, 1998, pp 369 - 376.

Kinnetic Laboratories Inc., 1999. *Operation Maintenance and Monitoring Plan District 11: Volumes I & II – BMP Storm Water Monitoring Field Guidance Notebooks*, prepared for the California Department of Transportation, CTSW-RT-99-053.

Los Angeles County Department of Public Works, 1989. *Hydrology Manual*, prepared by the Hydraulic Division, Alhambra CA.

Minton, Gary R., 2002. *Stormwater Treatment, Biological, Chemical, and Engineering Principles.* Resource Planning Associates, Seattle, WA.

Pitt, R.E., Robertson, B., Barron, P., Ayyoubi, A., and Clark, S., 1999. *Storm Water Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT)*. U.S. Environmental Protection Agency, Wet Weather Flow Management Program, National Risk Management Research Laboratory. EPA/600/R-99/017. Cincinnati, OH. 505 pgs.

RBF Consulting, 1998a. BMP Retrofit Pilot Program *Scoping Study, District 11*, prepared for the California Department of Transportation, CTSW-RT-98-026.

RBF Consulting, 1998b. BMP Retrofit Pilot *Program Scoping Study, District 7*, prepared for the California Department of Transportation, Report CTSW-RT-98-027.

RBF Consulting, 1999a. *Operation Maintenance and Monitoring Plan District 7: Volume I – Guidance for Preparing Site-specific Plans*, prepared for the California Department of Transportation, CTSW-RT-99-002.

RBF Consulting, 1999b. *Operation Maintenance and Monitoring Plan District 11: Volume I – Guidance for Preparing Site-specific Plans*, prepared for the California Department of Transportation, CTSW-RT-99-003.

RBF Consulting, 1999c. *Basis of Design Report – Drainage Design, District 11 Procurement.* Prepared for the California Department of Transportation, CTSW-RT-98-52-A1.

RBF Consulting, 1999d. *Basis of Design Report – Drainage Design, District 11 PS&E, Interstate 5/La Costa Avenue Constructed Wetland.* Prepared for the California Department of Transportation, CTSW-RT-98-52-A2.

RBF Consulting, 1999e. *Basis of Design Report – Drainage Design, District 11 PS&E.* Prepared for the California Department of Transportation, CTSW-RT-98-52.

San Diego, County of, 1993, "Hydrology Manual", prepared by the Department of Public Works, Flood Control Division, San Diego, CA.

Schueler, T.R., 1987, *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs,* Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, DC.

U.S. EPA, 1983. *Results of the Nationwide Urban Runoff Program, Volume 1 – Final Report*, Water Planning Division WH-554, Washington DC.

U.S. EPA, 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, 840-B-92-002, Office of Water, Washington, DC.

URS Greiner Woodward Clyde, 1999a. "Geotechnical Engineering Peer Review I-5/La Costa Avenue Infiltration Basin Caltrans BMP Retrofit Program Carlsbad, CA. Prepared for the California Department of Transportation.

URS Greiner Woodward Clyde, 1999b. *BMP Retrofit Pilot Program Biofilter Sod Peer Review*. Prepared for the California Department of Transportation, CTSW-RT-99-081.

Water Environment Federation and ASCE, 1998. "Urban Runoff Quality Management," *WEF Manual of Practice,* No. 23, *ASCE Manual and Report on Engineering Practice* No. 87.

Winer, R., 2000a. National Pollutant Removal Performance Database for Storm water Treatment Practices: 2nd ed., Report to the USEPA by the Center for Watershed Protection.

Winer, R., 2000b, National Pollutant Removal Performance Database for Storm water Treatment Practices 2nd ed., Prepared by the Center for Watershed Protection for the USEPA Office of Science and Technology.

Wonnacott, T.H., and Wonnacott, R.J., 1990. *Introductory Statistics* 5th ed., John Wiley and Sons, NY.

Young, G.K., et al., 1996. *Evaluation and Management of Highway Runoff Water Quality,* Publication No. FHWA-PD-96-032, U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning.

APPENDICES

The appendices to this final report can be found on the CDs attached to the inside back cover of this document. The CD-ROMs contain the following appendices:

CD-ROM NO. 1:

APPENDIX A: SITING AND SCOPING

APPENDIX B: DESIGN

APPENDIX C: CONSTRUCTION COST

APPENDIX D: OPERATION AND MAINTENANCE

APPENDIX E: VECTOR MONITORING AND ABATEMENT

APPENDIX F: MONITORING SUMMARY

CD-ROM NO. 2

APPENDIX G: AS-BUILT PLANS OF BMP PILOT SITES

APPENDIX H: QUARTERLY AND BIWEEKLY REPORTS

The following pages list the appendices and the documents contained on the CD-ROMs. Included in the CD-ROM directory is a FinRptReadme.doc, which duplicates these pages and provides links to the individual documents.

Resolution of the California Ocean Protection Council
Regarding Low Impact Development

May 15, 2008, as amended

WHEREAS, ocean water quality is critical to the health of marine and coastal ecosystems; and

WHEREAS, ongoing, traditional development of California's watersheds continues to replace natural landscapes with impervious surfaces; roads and parking lots make up about half of all impervious surfaces; and

WHEREAS, runoff from urbanized areas contains and transports pollutants – including trash, heavy metals, oil and grease, fertilizers, and pathogens – to the ocean; and

WHEREAS, these pollutants contribute to beach closures, harmful algal blooms and reduced fish populations; and

WHEREAS, increased runoff from urbanized landscapes also erodes stream banks and damages habitat for fish and a wide variety of plants and animals; and

WHEREAS, polluted runoff impacts California's $46 billion, tourist-oriented, ocean-dependent economy; and

WHEREAS, rainwater is a valuable resource which should be conserved; and

WHEREAS, the Clean Water Act and Porter-Cologne Water Quality Control Act require that California reduce stormwater pollutant discharges from municipal storm drains, new developments and redevelopments, construction sites, Caltrans facilities, and industrial facilities; the Porter-Cologne Act also requires a California Ocean Plan for water quality regulation of ocean water, and prohibits waste discharges to Areas of Special Biological Significance (ASBS) which comprise one-third of the State's coastline; and

WHEREAS, the California Coastal Act requires that development in the coastal zone maintain and, where feasible, restore the biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes; and

WHEREAS, Low Impact Development (LID) is a stormwater management strategy aimed at maintaining or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives and fulfill environmental regulatory requirements; LID employs a variety of natural and built features that reduce the rate of runoff, filter pollutants out of runoff, and facilitate the infiltration of water into the ground; and

WHEREAS, by reducing water pollution and increasing groundwater recharge, LID helps to improve the quality of receiving surface waters and stabilize the flow rates of nearby streams; and

WHEREAS, LID design detains, treats and infiltrates runoff by minimizing impervious area, using pervious pavements and green roofs, dispersing runoff to landscaped areas, and routing runoff to rain gardens, cisterns, swales, and other small-scale facilities distributed throughout a site; and

WHEREAS, LID designs can alternatively, or in conjunction with the techniques set forth above, capture, retain, and treat stormwater for onsite reuse, such as for irrigating landscaping; and

WHEREAS, a recent U.S. Environmental Protection Agency report concluded that LID drainage designs can cost 15% to 80% *less* than more conventional drainage designs; other studies have shown LID facilities are less expensive to maintain than conventional stormwater treatment facilities; and

WHEREAS, LID has also been shown to help reduce the frequency of combined sewer overflows, which plague at least one major California coastal community; and

WHEREAS, other states and federal government departments, including the Department of Defense, have been leaders in advancing LID implementation faster than California; and

WHEREAS, Caltrans should continue its efforts to lead in innovative stormwater design approaches; and

WHEREAS, some local governments are concerned that they lack sufficient funds to maintain and improve existing drainage infrastructure and fully implement stormwater pollution prevention programs; and

WHEREAS, in 2005, the Local Government Commission adopted the Ahwahnee Water Principles for Resource-Efficient Land Use, which state in relevant part that "community design should be compact, mixed use, walkable, and transit-oriented so that automobile-generated urban runoff pollutants are minimized and the open lands that absorb water are preserved to the maximum extent possible" and that "impervious surfaces such as driveways, streets and parking lots should be minimized so that land is available to absorb stormwater, reduce polluted urban runoff, recharge groundwater, and reduce flooding"; and

WHEREAS, the California Ocean Protection Act mandates that the Ocean Protection Council (OPC) – made up of the Secretaries for the Resources Agency and Cal/EPA, the chair of the State Lands Commission, one designee each from the California Senate and Assembly, and two public members appointed by the Governor – coordinate and improve the protection of California's ocean and coastal resources; and the Governor's Ocean Action Plan calls for the OPC to play a leadership role in managing and protecting California's oceans, bays, estuaries, and coastal wetlands, including integration of coastal water quality programs to increase their effectiveness.

NOW, THEREFORE, the California Ocean Protection Council hereby:

RESOLVES to promote the policy that new developments and redevelopments should be designed consistent with LID principles so that stormwater pollution and the peaks and durations of runoff are significantly reduced and, in the case of a new development, substantially the same as before development occurred on the site; and

RESOLVES to promote the retrofit of existing impervious areas throughout California with LID in all appropriate circumstances, and to support the Ahwahnee Water Principles for Resource-Efficient Land Use as described above; and

FINDS that LID is a practicable and superior approach that new and redevelopment projects can implement to minimize and mitigate increases in runoff and runoff pollutants and the resulting impacts on downstream uses, coastal resources and communities; and

RESOLVES to distribute this resolution widely, sending it to mayors, boards of supervisors, and appropriate agency managers of all coastal cities and counties and to appropriate federal agencies including resource protection agencies, the Army Corps of Engineers and the Department of Defense; and

FURTHER RESOLVES to advance LID implementation in California using the following approaches:

1. State Leadership

a. *State Government Leadership on LID* – For all state-funded (including bond-funded) development projects greater than one acre, LID should be considered to be the best available technology standard for reducing pollutants from stormwater discharges. All existing State facilities should consider retrofitting to meet LID objectives, whenever feasible. The California Environmental Protection Agency (Cal/EPA) and the California Resources Agency should assemble the relevant boards and departments within their agencies to develop a set of LID standards to be used in development projects built with state funds, including bond funds.

b. *Department of Transportation (Caltrans)* – Caltrans is encouraged to continue to develop details and specifications for permeable pavements and other LID features and to incorporate LID where feasible in projects Caltrans funds or oversees, including local assistance programs. Caltrans should consider allocating a percentage of project budgets to the implementation of stormwater controls, with LID features as the highest priority. Caltrans should evaluate and revise as necessary any design standards which unnecessarily inhibit implementation of LID, such as street widths, required pavement and other materials, curb designs, and minimum parking requirements.

c. *Office of Planning and Research* – The Office of Planning and Research (OPR) is encouraged to provide technical guidance to public agencies to promote the use of LID consistent with stormwater National Pollution Discharge Elimination System (NPDES) standards and criteria. The guidance should be provided through an OPR technical advisory and revisions to the OPR guidance for preparation of local general plans, as appropriate. OPR is also encouraged to work with the Resources Agency to develop proposals for future CEQA Guideline amendments that encourage consideration of LID in the CEQA review process.

d. *Building Standards Commission* – The Building Standards Commission is encouraged to incorporate LID objectives and methods, and to incorporate or reference applicable NPDES permit criteria for stormwater treatment, flow control and use of LID in ongoing development of its Green Building Standards.

e. *Department of Water Resources* – The Department of Water Resources (DWR) is encouraged to provide incentives for LID implementation and habitat protection goals in its integrated regional water management (IRWM) and stormwater flood management funding programs to encourage watershed resource protection. The OPC encourages DWR to adopt language to include the fostering of LID as a Program Priority in their draft IRWM guidelines.

2. State Regulatory Actions

a. *State Water Board LID Policy* – The State Water Board is encouraged to adopt a statewide policy for addressing all elements associated with changes in runoff due to hydromodification impacts, including those specifically related to urbanization. This policy would include direction on when and how to use LID to avoid, minimize and mitigate runoff so that downstream water bodies are protected.

b. *NPDES Permit Requirements* – When crafting stormwater NPDES permit requirements, the State Water Board and Regional Water Boards should ensure that LID designs are utilized as the primary approach to satisfying post-construction runoff control requirements and that LID designs can be utilized to control pollutants and the rate and volume of runoff.

c. *LID Performance Evaluation and Monitoring* – Together with the Coastal Commission, the State Water Board is encouraged to conduct ongoing evaluation of the effectiveness of their regulatory programs that promote LID (and other, similar approaches) implementation in regulated new development and redevelopment projects.

3. Incentives, Technical Support, and Research

The OPC will consider the following approaches, proposed by stakeholders and participants in public workshops sponsored by the OPC, to promote LID and to leverage funding with other agencies.

a. *Local Streets and Drainage Retrofits* – Encourage local governments to retrofit existing streets, highways, municipal parking lots, public buildings, and drainage systems with LID where feasible. Promote and consider funding research and technology transfer related to the retrofit of local facilities, including demonstration projects with interpretive displays and technical documentation of results.

b. *Technical Assistance to Local Government* – Promote and consider funding technical assistance for local agency public works, planning and engineering management and staff in the use of LID.

c. *Research and Development of LID* – Promote and consider funding technical research for development of a LID design manual, including example designs and specifications for LID features, and post-construction evaluations of the effectiveness of constructed LID features in removing pollutants and controlling runoff flows.

d. *Updating Local Development Policies* –Assist and consider funding for local governments to update standard details and specifications and other development policies to promote LID and remove barriers to LID.

e. *Local Incentives* – Promote local programs that provide incentives, including reduction of stormwater utility fees, to encourage the use of cisterns, rain gardens, and other LID strategies to retain runoff and, where feasible, reuse runoff for irrigation.

f. *Incentives for Stormwater Recharge* – Encourage water agencies to offer economic incentives for new regional and sub-regional stormwater recharge projects similar to incentives currently provided for water conservation and water reuse.

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL COAST REGION

Recommendations for Water Code Waiver for Agricultural Discharges

Staff Report

Report Proposing a Draft Agricultural Order For Public Review and Comment

November 2010

CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

Arnold Schwarzenegger, Governor
State of California

Linda S. Adams, Secretary
California Environmental Protection Agency

State Water Resources Control Board
http://www.waterboards.ca.gov/

Charles R. Hoppin, Chair
Frances Spivey-Weber, Vice Chair
Tam Doduc, Board Member
Arthur G. Baggett, Jr., Board Member

Tom Howard, Executive Director

California Regional Water Quality Control Board
Central Coast Region
http://www.waterboards.ca.gov/centralcoast

Jeffrey S. Young, Chair
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Monica S. Hunter, Board Member
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David T. Hodgin, Board Member
John H. Hayashi, Board Member

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LIST OF ACRONYMS/ABBREVIATIONS

ACL	Administrative Civil Liability
BAT	best available technology economically achievable
BCT	best practicable control technology currently achievable
BMP	best management practice
BPTC	best practicable treatment or control
CAC	County Agricultural Commissioner
CCR	California Code of Regulations
CDFA	California Department of Food and Agriculture
Central Coast Water Board	Central Coast Regional Water Quality Control Board
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
DPR	California Department of Pesticide Regulation
ECR	Existing Conditions Report
EIR	Environmental Impact Report
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FWQMP	farm water quality management plan
GQMP	groundwater quality management plan
GWMP	(local existing) groundwater management plan
GWPA	groundwater protection areas (DPR)
GWPL	groundwater protection list (DPR)
MAA	Management Agency Agreement
MCL	maximum contaminant level
MDL	method detection limit
MEP	maximum extent practicable
MP	management practice
MRP	monitoring and reporting program
NMP	nutrient management plan
NPDES	National Pollutant Discharge Elimination System
NPS Policy	State Water Board Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program
NPS	nonpoint source
PCPA	Pesticide Contamination Prevention Act
PEIR	Program Environmental Impact Report
PREC	Pesticide Regulation & Evaluation Committee (DPR)
PY	Personnel-year
RL	reporting limit
ROWD	report of waste discharge
State Water Board	State Water Resources Control Board
SVOC	semi-volatile organic compounds
SWAMP	Surface Water Ambient Monitoring Program
TMDL	Water Board Total Maximum Daily Load Program
TSS	total suspended solids
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
Waiver	conditional waiver of waste discharge requirements
Water Code	California Water Code
WDRs	waste discharge requirements
WIDB	DPR's well inventory database

µg/l	micrograms per liter

EXECUTIVE SUMMARY

Discharges of waste associated with agricultural discharges (e.g., pesticides, sediment, nutrients) are a major cause of water pollution in the Central Coast region. The water quality impairments are well documented, severe, and widespread. Nearly all beneficial uses of water are impacted, and agricultural discharges continue to contribute to already significantly impaired water quality and impose certain risks and significant costs to public health, drinking water supplies, aquatic life, and valued water resources.

The primary water quality issues associated with irrigated agriculture on the Central Coast Region are:

- Impacts to thousands of people who are drinking water contaminated with unsafe levels of nitrate or are drinking treated or replacement water to avoid drinking contaminated water. The cost to municipalities, communities, families, and individuals for treating drinking water polluted by nitrate is estimated to be in the hundreds of millions of dollars and the health impacts are serious- cancer, Parkinson's disease, Blue Baby Syndrome.

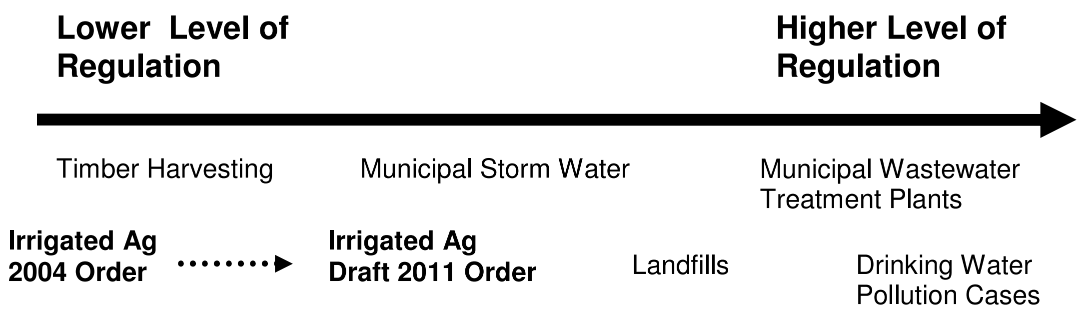
- Impacts to large stretches of rivers, creeks, and streams in the Central Coast Region's major watersheds that have been severely polluted by toxicity from pesticides, nutrients, and sediment. Agricultural discharges have caused some creeks to be found toxic (lethal to aquatic life) every time the site is sampled. As a result, these areas are often completely devoid of the aquatic life essential for a healthy functioning ecosystem. The pollution in some of these areas also creates conditions that are unsafe for recreation and fishing.

If the Central Coast Water Board and the regulated community do not adequately address the protection of water quality and beneficial uses, the environmental and health impacts are likely to become more severe and widespread. Similarly the costs are likely to increase significantly. The environmental, health and cost impacts threaten to significantly impact the future uses of the Central Coast's water resources.

The Central Coast Water Board adopted a Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands in 2004 (2004 Conditional Waiver or 2004 Order), that has been renewed twice. The 2004 Order expires in March 2011. To address the water quality pollution, and to prevent further water quality impairment and impacts to beneficial uses caused by toxicity, nitrates, pesticides and sediment in agricultural runoff and leaching to groundwater associated with irrigated agriculture, the Central Coast Water Board will consider renewing the 2004 with revisions .

Water Board staff has prepared a Draft Conditional Waiver of Waste Discharge Requirements for Irrigated Agricultural Discharges (2011 Draft Order, to control these discharges. This proposed 2011 Draft Order will adjust the level or degree of regulation for agriculture to better match the degree of regulation compared to other Water Board programs based on the relative impacts to water quality. The diagram below, titled "Relative Degree of Water Board Regulation for Various Programs" illustrates that the Water Board's current regulation of irrigated agriculture (via the 2004 Order) is very low relative to other programs. This is the case even though the level of pollution discharged from irrigated agriculture and the resulting impacts to beneficial uses are far greater than any other regulated activity. The draft 2011 Order increases the Water Board's degree of regulation modestly compared to other programs.

Relative Degree of Water Board Regulation for Various Programs



The conditions proposed in the 2011 Draft Order were developed to address or be consistent with Water Board direction and public input.

The Water Board established the following water quality goals for the 2011 Draft Order:

- eliminate toxic discharges of agricultural pesticides to surface waters and groundwater;
- reduce nutrient discharges to surface waters to meet nutrient standards
- reduce nutrient discharges to groundwater to meet groundwater standards
- minimize sediment discharges from agricultural lands
- protect aquatic habitat

The Water Board also directed staff to make the 2011 Draft Order consistent with the following criteria:

- resolve water quality impairments associated with irrigated agriculture;
- comply with minimum statutory requirements; and
- include milestones, targets, and schedules for achieving water quality standards and protecting beneficial uses.

Staff also identified the following key concepts as important to stakeholders and Water Board members from review of stakeholder and Board member input:

- Prioritize based on water quality impacts and make protection of human health and drinking water the highest priority.
- "One size does not fit all." Require more of those discharging the most, creating the greatest impacts, or most threatening water quality.
- Provide reasonable timeframes to control discharges and meet water quality goals.
- Require reasonable amount of implementation, monitoring and reporting requirements.

- Allow dischargers flexibility to comply with requirements based on uniqueness of individual operations.

Staff's recommendations address these issues as thoroughly as possible while meeting all regulatory and legal obligations for issuing an Order to control waste discharges from irrigated agricultural operations.

The 2011 Draft Order groups farm operations, or dischargers, into three tiers, each tier distinguished by four criteria that indicate threat to water quality: size of farm operation, proximity to an impaired watercourse, use of chemicals of concern, and type of crops grown. Dischargers with the highest threat have the greatest amount of discharge control conditions, individual monitoring, and reporting. Conversely, dischargers with the lowest threat have the least amount of discharger control conditions, individual monitoring, and reporting.

For example, the 2011 Draft Order proposes the following implementation and reporting requirements:

- Implement pesticide management practices to reduce toxicity in discharges so receiving waterbodies meet water quality standards;
- Implement nutrient management practices to eliminate or minimize nutrient and salt in discharges to surface water so receiving waterbodies meet water quality standards;
- Implement nutrient management practices to minimize fertilizer and nitrate loading to groundwater to meet nitrate loading targets ;
- Install and properly maintain back flow prevention devices for wells or pumps that apply fertilizers, pesticides, fumigants or other chemicals through an irrigation system;
- Implement erosion control and sediment management practices to reduce sediment in discharges so receiving water bodies meet water quality standards;
- Protect and manage existing aquatic habitat to prevent discharge of waste to waters of the State and protect the beneficial uses of these waters;
- Implement stormwater runoff and quality management practices.
- Develop, implement, and annually-update Farm Water Quality Management Plans.
- Submit an Annual Compliance Document (for higher threat dischargers) that includes individual discharge monitoring results, nitrate loading risk evaluation and, if nitrate loading risk is high, irrigation and nutrient management plan, verification of irrigation and nutrient management plan effectiveness.
- Submit a water quality buffer plan (for higher threat dischargers), if operations contain or are adjacent to a waterbody identified on the Clean Water Act section 303(d) List of Impaired Waterbodies as impaired for temperature or turbidity.

The Draft Monitoring and Reporting Program (Draft MRP) includes receiving water monitoring, individual surface water discharge monitoring, individual groundwater monitoring, and individual riparian and wetland photo-monitoring. The Draft MRP recommends that all dischargers in Tier 1, the lowest Tier, conduct the following monitoring:

- Receiving water monitoring- monthly and in cooperation with other dischargers, unless a discharger elects to do this individually (similar to the existing MRP)
- Groundwater monitoring- two times in one year during the five years of the Draft Order.

The Draft MRP recommends that all dischargers in Tier 2, conduct the following monitoring:

- Receiving water monitoring- same as above for Tier 1
- Groundwater monitoring- same as above for Tier 1

- Individual riparian and wetland photo-monitoring- once every three years and only for operations that contain or are adjacent to a waterbody impaired for temperature, turbidity, or sediment

The Draft MRP recommends that all dischargers in Tier 3, conduct the following monitoring

- Receiving water monitoring- same as above for Tiers 1 and 2
- Groundwater monitoring- quarterly for one year
- Individual riparian and wetland photo-monitoring- same as above for Tier 2
- Individual surface water discharge monitoring- four times each year for operations greater than 5000 acres and two times each year for operations between 1000 and 5000 acres for these parameters.
    - Flow measured or calculated in gallons per day
    - Nitrate concentration measured mg/L
    - Clarity measure turbidity NTUs

In developing this recommendation, staff considered and compared several options or alternatives to this Draft Order. These included the existing Order, the Preliminary Draft Order distributed February 1, 2010, three alternatives submitted April 1, 2010- one from the California Farm Bureau Federation and other agricultural groups, one from OSR Enterprises, Inc. and one from the Monterey Coastkeeper and other environmental groups. Staff also considered several different options for implementation, monitoring and reporting requirements within the 2011 Draft Order.

Water Board staff recommends the Central Coast Water Board adopt this Draft Order (after allowing public comment and responding) to require owners and operators of irrigated agricultural lands to achieve compliance with water quality standards and objectives in a timely manner with compliance verification monitoring. To achieve compliance with water quality standards and objectives, property owners and growers may have to implement effective management practices, treatment and control practices, and may have to change farming practices. This draft Order establishes accountability and transparency on behalf of the public and public resources.

I. INTRODUCTION

The Central Coast Water Board currently regulates discharges from irrigated lands with a Conditional Waiver of Waste Discharge Requirements (Order No. R3-2010-0040, hereafter referred to as the 2004 Order) that expires in March 2011. The Central Coast Water Board began a process in December 2008, to consider renewing the 2004 Order, including revising and adding conditions to more effectively reduce or eliminate discharges of waste associated with irrigated agriculture in the Central Coast Region (toxicity, pesticides, nutrients, sediment, impacts to drinking water, degradation of aquatic habitat).

There are numerous and varying irrigated agricultural operations within the Central Coast Region that have varying degrees of impact on water quality. . As indicated in a December 2008 letter to stakeholders, to directly address and resolve the major water quality issues associated with irrigated agriculture in the Central Coast region, staff is recommending a revised Order that includes the following:

- Clear articulation of water quality standards to ensure consistency with applicable Water Board plans and policies;
- Specific conditions to address water quality impairments;
- Milestones to measure progress;
- Time schedules to achieve compliance;
- Monitoring and reporting to verify compliance;

This report (1) summarizes the information Central Coast Water Board staff (staff) have considered in the development of a renewed Order, (2) describes the range of regulatory options considered, and (3) provides staff's recommendations for a revised Draft Order.

What is the Central Coast Water Board's regulatory role?

The Central Coast Water Board has the statutory responsibility to protect water quality and beneficial uses such as drinking water and aquatic life habitat. Any Order adopted by the Central Coast Water Board must be consistent with the California Water Code (Water Code) and Water Board plans and policies, including the Water Quality Control Plan for the Central Coast Region (Basin Plan). (Cal. Wat. Code § 13269) The Central Coast Water Board regulates discharges of waste to the region's surface water and groundwater to protect the beneficial uses of the water. In some cases, such as the discharge of nitrate to groundwater, the Water Board is the principle state agency with regulatory responsibility for coordination and control of water quality.. (Cal. Wat. Code §13001.)

Pursuant to the Porter-Cologne Water Quality Control Act (Wat. Code Div. 7), the Central Coast Water Board is required to regulate discharges of waste that could impact the quality of waters of the state. It can impose in orders, prohibitions on types of waste or location of discharges, requirements for discharging waste, and conditions on discharges of waste. The Water Board enforces violations of the prohibitions and requirements in these Orders. The Central Coast Water Board also develops water quality standards and implements plans and programs. These activities are conducted to best protect the State's waters, recognizing the local differences in climate, topography, geology and hydrology.

The 2004 Order expires in March 2011. The Water Board will consider renewing the 2004 Order to revisions, including revised and new conditions to assure protection of waters of the state within the Region.

Among the highest priorities is to ensure that agricultural discharges do not continue to impair Central Coast communities' and residents' access to safe and reliable drinking water. This proposed Draft Order prioritizes those agricultural operations and areas of the Central Coast Region already known to have, or be at great risk for, severe water quality pollution. The proposed Draft Order would establish a known and reasonable time schedule, with clear and direct methods of verifying compliance and monitoring progress over time. The proposed Draft Order must enable the regulated community and stakeholders to understand when Dischargers are in compliance with requirements and successfully reducing their contribution to the water quality problems and maintaining adequate levels of water quality protection.

What is the issue?

Agricultural discharges are a major cause of water pollution in the Central Coast region. The water quality impairments are well documented, severe, and widespread. Nearly all beneficial uses of water are impacted, and agricultural discharges continue to contribute to already significantly impaired water quality and impose certain risk and significant costs to public health, drinking water supplies, aquatic life, and valued water resources.

The primary water quality issues associated with irrigated agriculture on the Central Coast are:

- Impacts to thousands of people who are drinking water contaminated with unsafe levels of nitrate or are drinking treated or replacement water to avoid drinking contaminated water. The cost to municipalities, communities, families, and individuals for treating drinking water polluted by nitrate is estimated to be in the hundreds of millions of dollars;

- Impacts to large stretches of rivers, creeks, and streams in the Central Coast region's major watersheds that have been severely polluted by toxicity from pesticides, nutrients, and sediment. Agricultural discharges have caused some creeks to be found toxic (lethal to aquatic life) every time the site is sampled (e.g., 2 times each year sampled for five years). As a result, these areas are often completely devoid of the aquatic life essential for a healthy functioning ecosystem. The pollution in these areas also creates conditions that are unsafe for recreation and fishing.

The Central Coast Water Board has the authority and responsibility to protect water quality and beneficial uses. The regulated community has the responsibility to comply with the Water Code. Failure to do so could result in costs and other impacts that are likely to increase significantly and severely limit the future of the Central Coast's water resources.

Why is the issue important?

Millions of Central Coast residents depend on groundwater for nearly all their drinking water from both deep municipal supply wells and shallow domestic wells. In addition, the Central

Coast Region's coastal and inland water resources are unique, special, and in some areas still of relatively high quality. The Region supports some of the most significant biodiversity of any temperate region in the world and is home to many sensitive natural habitats and species of special concern. Agricultural discharges continue to severely impact and threaten these resources and beneficial uses.

At the same time, the agricultural industry in the Central Coast Region is also one of the most productive and profitable agricultural regions in the nation, reflecting a gross production value of more than six billion dollars in 2008, contributing 14 percent of California's agricultural economy. For example, agriculture in Monterey County supplies 80 percent of the nation's lettuces and nearly the same percentage of artichokes and sustains an economy of 3.4 billion dollars.[1]

Resolving agricultural water quality issues will greatly benefit public health, present and future drinking water supplies, aquatic life, recreational, aesthetic and other beneficial uses. Resolving agricultural water quality issues will also require changes in farming practices, will impose increasing costs to individual farmers and the agricultural industry at a time of competing demands on farm income, regulatory compliance efforts, and food safety challenges, and may impact the local economy. No industry or individual has a legal right to pollute and degrade water quality, while everyone has a legal right to clean water. Similar to all other Dischargers, the agricultural community is responsible for identifying, preventing and resolving pollution caused by irrigated agriculture and complying with water quality requirements.

Healthy watersheds and a sustainable agricultural economy can coexist. Protecting water quality and the environment while protecting agricultural benefits and interests will require change, and may shift who bears the costs and benefits of water quality protection. Continuing to operate in a mode that causes constant or increasingly severe receiving water problems is not a sustainable model.

2. STAFF RECOMMENDATION

The proposed Draft Order regulates discharges of waste from irrigated lands to ensure that such dischargers are not causing or contributing to exceedances of any Regional, State, or Federal numeric or narrative water quality standard, such that all beneficial uses are protected. The proposed Draft Order directly addresses agricultural discharges – especially contaminated irrigation runoff and percolation to groundwater causing toxicity, unsafe levels of nitrate, unsafe levels of pesticides, and excessive sediment in surface waters and/or groundwater. The proposed Draft Order also focuses on those areas of the Central Coast Region already known to have, or at great risk for, severe water quality impairment. In addition, the proposed Draft Order requires all dischargers to effectively implement management practices (related to irrigation, nutrient, pesticide and sediment management) that will most likely yield the greatest amount of water quality protection. The proposed Draft Order includes more stringent conditions to eliminate or minimize the most severe or impactful agricultural discharges and includes clear and direct methods and indicators for verifying compliance and monitoring progress over time. The proposed Draft Order also includes reasonable time schedules to eliminate or minimize degradation from all agricultural discharges.

Staff recognizes that the pollution caused by irrigated agriculture is significant and will not be resolved in a short time frame. Staff's priority in the short term is to take deliberate steps towards water quality improvement and eliminate or reduce agricultural discharges that load additional

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[1] Salinas Valley Chamber of Commerce http://atlantabrains.com/ag_industry.asp

pollutants to water bodies and groundwater basins that are already polluted or at high risk of pollution.

Given the scale and severity of pollution in agricultural areas and the impacts to beneficial uses, including drinking water sources, staff recommends greater public transparency and Discharger accountability regarding on-farm discharges and individual compliance with requirements. Additionally, greater public transparency and discharger accountability will insure consistency with the State Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program (NPS Policy).

Staff recommends that the Central Coast Water Board adopt this Draft Order to control discharges from irrigated lands. The rationale for this recommendation is summarized below and futher explained in Sections 4 and 5 and the Appendices of this report.

The Draft Order is consistent with legal requirements and goals and criteria established by the Water Board for developing a revised or new Order (see Appendix I.). The Draft Order also incorporates input from members of the public representing the dischargers, environmental groups, environmental justice groups and many others (see Section 3.B).

In developing this recommendation, staff considered and compared several options or alternatives to this Draft Order (see Section 3.B). These included the existing 2004 Order, the Preliminary Draft Order distributed February 1, 2010, three alternatives submitted April 1, 2010- one from the California Farm Bureau Federation and other agricultural groups, one from OSR Enterprises, Inc. and one from the Monterey Coastkeeper and other environmental groups. Staff also considered several different options for implementation, monitoring and reporting requirements within the Draft Agricultural Order (see Section 2.D. and Appendix D).

Finally, staff developed this proposed Draft Order to address the documented severe and widespread water quality problems in the Central Coast Region, predominately unsafe levels of nitrate in ground water used for drinking water and toxicity decimating or impairing communities of aquatic organisms (see Section 3.E. and Appendix G).

Staff recommends that the Central Coast Water Board adopt proposed Order R3- 2011-0006.

3. PROPOSED DRAFT ORDER

A. SUMMARY OF PROPOSED DRAFT CONDITIONS, MONITORING AND REPORTING REQUIREMENTS

Water Board staff developed the recommendations for the Draft Order to be responsive to the issues raised by members of the public and Water Board members, and determined to be important through Water Board staff's evaluation of water quality conditions and options to control polluted discharges. Water Board staff attempted to address these issues as thoroughly as possible while meeting all regulatory and legal obligations for issuing an Order to control waste discharges from irrigated agricultural operations. The following discussion summarizes many, but not all, conditions of the Draft Order.

The Draft Order establishes three tiers of conditions based on threat to water quality. The Draft Order requires Dischargers to comply with conditions for the "tier" that applies to their operation. The tiers are based on four criteria that indicate threat to water quality: size of farm operation, proximity to an impaired watercourse, use of chemicals of concern, and type of crops grown. Dischargers with the highest threat have the greatest amount of discharge control requirements, monitoring and reporting. Conversely, dischargers with the lowest threat have the least amount of discharger control requirements, individual monitoring and reporting.

Dischargers fall into the Tiers as listed below if they meet the sets of criteria for that Tier as shown in the table below.

TIER 1	**TIER 2**	**TIER 3**
does not use chlorpyrifos or diazinon AND	located within 1000 feet of impaired waterbody AND total irrigated acreage is less than 1000 acres AND does not use chlorpyrifos or diazinon; OR	total irrigated acreage greater than or equal to 1000 acres AND grows crops with high nitrate loading potential[2] OR
not located within 1000 feet of impaired waterbody[1] AND	not located within 1000 feet of impaired waterbody AND total irrigated acreage is less than 1000 acres AND uses chlorpyrifos or diazinon; OR	total irrigated acreage greater than or equal to 1000 acres AND applies chlorpyrifos or diazinon OR
total irrigated acreage is not greater than 1000 acres, AND does not grow crops with high nitrate loading potential[2]	not located within 1000 feet of impaired waterbody AND total irrigated acreage is greater than or equal to 1000 acres AND does not grow crop with high nitrate loading potential[2] does not use chlorpyrifos or diazinon.	adjacent to a impaired waterbody[1] AND applies chlorpyrifos or diazinon

1- listed for toxicity, pesticides, nutrients, or sediment on the Clean Water Act Section 303(d) List of Impaired Waterbodies
2- crop types with high potential to discharge nitrogen to groundwater, including: beet, broccoli, cabbage, cauliflower, celery, Chinese cabbage (Nappa), collard, endive, kale, leaks, lettuce (leaf and head), mustard, onion (dry and green), parsley, pepper (fruiting), spinach, and strawberry.

The conditions, monitoring and reporting requirements in the Draft Order are summarized in Table 2 below.

Table 1. Summary of Required Conditions, Monitoring and Reporting in the Draft Agricultural Order

CONDITIONS	**Due in:**[2]
Pesticide Runoff/Toxicity Elimination	
All dischargers must implement management practices to eliminate or minimize toxicity and pesticide discharges so receiving water bodies meet water quality standards	immediately
Nutrient and Salt Management	
All dischargers must implement nutrient management practices to minimize nutrient and salt discharges so receiving water bodies meet water quality standards	immediately
All dischargers must minimize nutrient discharges from fertilizer and nitrate loading to groundwater so receiving water bodies meet water quality standards and safe drinking water is protected	immediately
Tier 3 dischargers must evaluate the nitrate loading risk factor (as high, medium or low) of their operations, annually	1 Yr
Tier 3 dischargers *with a high nitrate loading risk* must develop and initiate implementation of a certified Irrigation and Nutrient Management Plan (INMP) to meet specified nitrogen balance ratio targets	2 Yrs
Sediment Management / Erosion Control / Stormwater Management	
All dischargers must implement erosion control and sediment management practices to eliminate or minimize the discharge of sediments and turbidity so receiving water bodies meet water quality standards	3 Yrs
All dischargers must protect existing aquatic habitat (including perennial, intermittent, or ephemeral streams, lakes, and riparian and wetland area habitat or other waterbodies) to prevent discharges of waste so receiving water bodies meet water quality standards.	immediately
All dischargers must implement stormwater management practices to minimize stormwater runoff	immediately
Tier 2 and Tier 3 Dischargers must evaluate conditions of riparian and wetland habitat areas *if their operations contain or are adjacent to a waterbody identified on the Clean Water Act Section 303(Dd) List of Impaired Waterbodies as impaired for temperature or turbidity.*	1 Yr
Tier 3 dischargers must develop and initiate implementation of a Water Quality Buffer Plan to prevent waste discharge or water quality degradation, *if their operations contain or are adjacent to a waterbody identified on the Clean Water Act Section 303(d) List of Impaired Waterbodies as impaired for sediment, temperature or turbidity and the discharger's runoff drains to that waterbody.* The plan must include the following or the functional equivalent: minimum of 30 foot buffer; wider buffer if necessary to prevent discharge of waste; three zones with distinct types of vegetation (moving from area closest to waterbody to areas away from waterbody) to jointly provide shade, pollutant treatment through infiltration and reduced velocity of flow to promote sediment deposition; schedule for implementation; and maintenance provisions.	4 Yrs
General Groundwater Protection Requirements	
All dischargers that apply fertilizers, pesticides, fumigants or other chemicals through an irrigation system must have functional and properly maintained back flow prevention devices installed at the well or pump to prevent contamination of groundwater or surface water.	3 Yrs
All dischargers must properly destroy all abandoned groundwater wells, exploration holes or test holes, in such a manner that they will not produce water or act as a conduit for mixing or otherwise transfer groundwater or waste constituents between permeable zones or aquifers.	NA
All dischargers who choose to utilize containment structures (such as retention ponds or reservoirs) to achieve treatment or control of the discharge of wastes, must construct and maintain such containment structures to avoid percolation of waste to groundwater that causes or contributes to exceedancess of water quality standards and to avoid surface water overflows that have the potential to impair water quality	NA
MONITORING	
All dischargers must sample private domestic and agricultural supply groundwater wells located at their operation, twice in one year	2Yrs
All dischargers must conduct watershed-scale (receiving water) monitoring as part of cooperative group or individually, monthly for five years	6 Months
Tier 2 and Tier 3 dischargers must photo-document existing conditions of riparian and wetland habitat areas, one time in five years, *if their operation(s) contain or are adjacent to a waterbody identified on the Clean Water Act Section 303(d) List of Impaired Waterbodies as impaired for sediment, temperature or turbidity.*	1 Yr

[2] Where specified time periods/deadlines are included in the proposed Order. NA = no time period specified in order.

Tier 3 dischargers must conduct individual discharge monitoring, two to four times per year for five years	6 months
REPORTING	
All dischargers must submit Notice of Intent to Enroll	60 days
All dischargers must submit results of groundwater sampling and related well information	6 Months
Tier 2 and 3 dischargers must submit an Annual Compliance Document that includes status information on implementation of required conditions (e.g. implementation of management practices) and results of any required sampling or monitoring, appropriate for the tier applicable to the discharger's operation.	2 Yrs
Tier 2 and Tier 3 dischargers must submit photo-documentation of conditions of riparian and wetland habitat areas with the Annual Compliance Document, *if their operation(s) contain or are adjacent to a waterbody identified on the Clean Water Act Section 303(d) List of Impaired Waterbodies as impaired for sediment, temperature or turbidity.*	1 yr
Tier 3 dischargers must submit results of individual discharge monitoring	2 Yrs
Tier 3 dischargers must submit results of evaluating nitrate loading risk factor (high, medium, or low)	1 Yr
Tier 3 dischargers *with a high nitrate loading risk* must submit verification of Irrigation and Nutrient Management Plan (INMP) and other related nitrate loading and balance information	2 Yrs
Tier 3 dischargers must submit Water Quality Buffer Plan to prevent waste discharge or water quality degradation, *if their operations contain or are adjacent to a waterbody identified on the Clean Water Act Section 303(d) List of Impaired Waterbodies as impaired for sediment, temperature or turbidity.*	4 Yrs

The Draft Order includes a requirement for Tier 2 and 3 Dischargers to submit an Annual Compliance Document. Some of the information required to be in this report includes the following:

For Tier 2 AND 3 Dischargers:

- Information describing individual operations (e.g., crop type, acreage, irrigation type, containment structures);
- Proof of proper backflow prevention devices;
- Proof of California Department of Fish and Game Streambed Alteration Agreements if required for work proposed in riparian areas; and
- Results of photo monitoring of existing riparian or wetland area habitat if operations contain or are adjacent to a waterbody identified on the Clean Water Act Section 303(d) List of Impaired Waterbodies as impaired for temperature or turbidity.

For Tier 3 Dischargers only:

- Evaluate Nitrate Loading Risk annually (see description below); and
- If Nitrate Loading Risk Factor is high,
    - Evaluate Nitrogen Budget parameters;
    - Develop and implement a certified irrigation and nutrient management plan (INMP);
    - Meet Nitrogen Balance ratio targets; and
    - Verify the overall effectiveness of the INMP in protecting groundwater quality and achieving water quality standards for nitrate.
- If operations contain or are adjacent to a waterbody identified on the Clean Water Act Section 303(d) List of Impaired Waterbodies as impaired for sediment, temperature or turbidity,
    - develop a water quality buffer plan (see description below) to prevent or reduce discharges of waste or submit evidence that discharge is controlled to prevent or reduce impacts associated with temperature or turbidity sufficient to attain water quality standards.
- Attain pesticide water quality standards in receiving waters associated with non-stormwater discharges within two years;

- Attain sediment and turbidity water quality standards in receiving waters associated with non-stormwater discharges within three years;
- Attain nutrients and salts water quality standards in receiving waters associated with non-stormwater discharges (not including subsurface drainage to tile drains) within four years.

Nitrate Loading Risk is a measure of the relative risk of loading nitrate to groundwater. The Nitrate Loading Risk Factor considers the Nitrate Hazard Index Rating (Delgado, et al. 2008) by crop type irrigation system type and irrigation water nitrate concentration for each ranch/farm. Dischargers with a high Nitrate Hazard Index Rating must evaluate Nitrogen budget parameters including: crop nitrogen uptake values, total nitrogen applied, nitrogen balance ration, estimate of nitrate loading to groundwater and estimate of reduction in nitrate loading to groundwater.

Water Quality Buffer Plans must include the following or the functional equivalent:
minimum of 30 foot buffer; wider buffer if necessary to prevent discharge of waste; appropriate mix of vegetation to jointly provide shade, pollutant treatment through infiltration and reduced velocity of flow to promote sediment deposition; schedule for implementation; and maintenance provisions.

The Draft Order includes the following types of monitoring.

Receiving water monitoring, such as that currently done by the Cooperative Monitoring Program for Agriculture under the existing Order, is conducted in receiving waterbodies (e.g. streams, drains, estuaries), rather than directly in discharges. There are different types of receiving water monitoring, including long-term trend monitoring at fixed sites, follow-up monitoring for problem solving, and stormwater monitoring._Trend monitoring sites are typically monitored frequently enough (e.g. monthly) to show seasonal variability and to provide enough data to be able to show long-term trends over time (e.g. multiple years). They answer the question, “Is the water quality in this creek getting better?” Sites location is chosen to best represent water quality from areas of interest (e.g. a reach of stream draining an agricultural area), to integrate conditions over a broad length of a stream (e.g. at the bottom of a watershed), or to inform changes from an individual operation’s or small area’s discharge of pollutants into the receiving water body. Follow-up monitoring sites are sampled for a short “study” period, and allow additional questions to be answered about the trend data, such as better geographic isolation of problem areas, sources of problems, chemical cause of toxicity, etc. Stormwater monitoring is conducted during active storm events with the intent of capturing condition of water quality during runoff events, since some pollutants, like sediment and attached chemicals, move primarily during these events.

Overall, receiving water monitoring provides for long-term trend detection, status of water body conditions, spatial locations of water quality problems, and whether beneficial uses are being protected. This data can then inform staff decisions related to follow-up activities, 303(d) Listing, Total Maximum Daily Load development and compliance monitoring.

Individual discharge monitoring assesses the quality of discharges leaving individual farm operations and entering surface or ground waters. Individual discharge monitoring includes an initial characterization of surface and/or groundwater discharges. For continuous discharge there is ongoing monitoring to establish compliance and assess loading to receiving waters. This type of monitoring is generally intended to answer the question, “What is the quality of water and load of contaminants leaving this farm?” Individual discharge monitoring may include discharge characterization, surface discharge monitoring and groundwater monitoring. Individual surface discharge monitoring and Individual groundwater discharge monitoring are ongoing monitoring of farm discharges to assess compliance with the Order that are required if the IDC shows that these discharges are present.

Individual Discharge Monitoring is proposed for some Dischargers to document compliance with conditions of the Order. Dischargers will sample to document pollutant source, load reductions, and achievement with water quality objectives. Individual Discharge Monitoring will also provide feedback to the dischargers to address pollutants found in the individual discharge. Individual discharge monitoring information may also be used to direct additional implementation, monitoring, and reporting as necessary to address problems. Individual discharge monitoring data may be used to inform inspection and enforcement activities. This type of monitoring would be used to verify the adequacy and effectiveness of the Order's implementation at the individual farm operation.

Groundwater monitoring will help characterize the groundwater conditions and allow prioritization of on-farm activities or regional areas based on groundwater conditions. Groundwater monitoring is proposed to assess groundwater conditions around farm operations, as this data is not currently collected. The frequency of sampling needed for groundwater, particularly for assessment purposes (as compared to tracking groundwater remediation progress) is less frequent than for surface water sampling. Groundwater well sampling is, typically quarterly for on-going groundwater quality characterization and to track changes and less frequently, such as annually, for simpler, broader characterization or indications of groundwater quality conditions.

Individual riparian and wetland habitat monitoring is a photographic assessment of habitat quality and extent on agricultural land, done on each farm adjacent to waterways. This type of monitoring is generally intended to answer the question, "What is the extent and quality of riparian and wetland habitat on this farm?" Each farm operation with a watercourse, wetland or waterbody would have to photo-document the physical conditions of existing water areas and associated riparian and wetland habitat. This information would help Water Board staff evaluate riparian and wetland habitat quality and ability to buffer or remove pollutants from entering a water course or remove them running into the water course. This type of monitoring provides a survey of physical conditions that do not usually change frequently so is only needed every few years.

The Draft Order proposes the following types of monitoring for Dischargers in each Tier as follows.

Tier 1: Receiving water monitoring and Groundwater monitoring

Tier 2: Receiving water monitoring, Individual groundwater monitoring, and Individual riparian and wetland photo-monitoring

Tier 3: Receiving water monitoring, Individual groundwater monitoring,
Individual riparian and weland photo-monitoring, andIndividual surface water discharge monitoring

B. Summary of Draft Milestones and Time Schedule for Compliance

Table 3 describes the general time schedules for key compliance dates and milestones related to Order Conditions for all dischargers and Table 4 describes the same for Tier 2 and Tier 3 Dischargers. Dischargers must achieve compliance with requirements by dates specified. Milestones indicate progress towards compliance.

Table 2. Time Schedule for Key Compliance Dates All Dischargers (Tier 1, Tier 2, and Tier 3)

REQUIREMENT	COMPLIANCE DATE[1]
Submit Notice of Intent (NOI)	Within 30 days of adoption of Order or Within 30 days acquiring ownership/ control, and prior to any discharge or commencement of activities that may cause discharge.
Submit Updated NOI	Within 30 days, upon change
Submit Notice of Termination	Immediately, when applicable
Implement best management practices, treatment or control measures, or change farming practices to achieve compliance with this Order.	Immediately
Protect existing aquatic habitat to prevent discharge of waste	Immediately
Submit Quality Assurance Project Plan and, Sampling And Analysis Plan, for receiving water quality monitoring	Within three months
Initiate receiving water quality monitoring	Within six months
Submit receiving water quality monitoring annual report	Within one year, and annually thereafter
Initiate sampling of groundwater wells	Within 12 months
Develop and Implement Farm Plan	Within 18 months
Complete 15 Hours Of Farm Water Quality Education	Within 18 months
Submit Groundwater Report	Within two years
Install and Maintain adequate backflow prevention devices.	Within three years

1 General time schedules for key compliance dates and milestones related to Order Conditions. Dates are relative to adoption of this Order or enrollment date for Dischargers enrolled after the adoption of this Order, unless otherwise specified. Dischargers must achieve compliance for requirements by dates specified. Milestones indicate progress towards compliance.

Table 3. Additional Time Schedule for Key Compliance Dates for Tier 2 and Tier 3 Dischargers

REQUIREMENT	COMPLIANCE DATE[1]
Tier 2 and Tier 3:	
Submit Annual Compliance Document with all required reporting information as listed in MRP No. R3-2011-00XX)	October 1, 2012, and annually thereafter.
Conduct photo monitoring of riparian or wetland are habitat (if operation contains or is adjacent to a waterbody impaired for temperature, turbidity, or sediment)	October 1, 2012, and every 3 years thereafter
Report Nitrate Loading Risk level in Annual Compliance Document	October 1, 2012, and annually thereafter.
Report total nitrogen applied per acre, per crop in Annual Compliance Document (if discharge has High Nitrate Loading Risk)	October 1, 2014, and annually thereafter.
Only Tier 3:	
Submit Quality Assurance Project Plan and, Sampling And Analysis Plan, for Individual Discharge Monitoring	Within four months
Initiate individual discharge monitoring	Within six months
Determine Crop Nitrogen Uptake (if discharge has High Nitrate Loading Risk)	Within one year
Submit individual discharge monitoring annual report	Within two years, and annually thereafter
Develop Irrigation and Nutrient Management Plan (INMP) (if discharge has High Nitrate Loading Risk)	Within two years
Report INMP elements in Annual Compliance Document	October 1, 2014, and annually thereafter
Demonstrate that discharge is not causing or contributing to exceedances of pesticide or toxicity water quality standards in waters of the State or United States[2].	Within 2 years Milestones: Individual Discharge Monitoring indicates – 12 Months - one of two samples is not toxic. 24 Months - two of two samples is not toxic.
Achieve Nitrogen Balance Ratio target equal to one (1) for crops in annual rotation (e.g. cool season vegetables)	Within 3 years
Achieve Nitrogen Balance Ratio target equal to 1.2 for annual crops occupying the ground for the entire year (strawberries or raspberries)	
Demonstrate that discharge is not causing or contributing to exceedances of sediment and turbidity water quality standards in waters of the State or United States[2].	Within 3 years Milestones: Individual Discharge Monitoring indicates – 12 Months – Four samples collected. 24 Months – 75% reduction in turbidity / sediment load
Demonstrate that discharge (not including	Within 4 years

subsurface drainage to tiledrains) is not causing or contributing to exceedances of nutrient water quality standards in waters of the State or United States[2].	Milestones: Individual Discharge Monitoring indicates – 12 Months – Four samples collected 24 Months – 50% load reduction of measured nutrients in irrigation runoff 36 Months – 75% load reduction of measured nutrients in irrigation runoff
Submit Water Quality Buffer Plan	Within 4 years
Submit INMP Effectiveness Report (if discharge has High Nitrate Loading Risk)	Within 5 years
Demonstrate that discharge is not causing or contributing to exceedances of nitrate drinking water quality standards in groundwater[2].	Within 10 years Milestones: Years 3 – 5, Annual reduction in nitrogen loading to groundwater

1- General time schedules for key compliance dates and milestones related to Order Conditions. Dates are relative to adoption of this Order or enrollment date for Dischargers enrolled after the adoption of this Order, unless otherwise specified. Dischargers must achieve compliance for requirements by dates specified. Milestones indicate progress towards compliance.

2- Documentation may include data and information related to groundwater sampling, individual discharge monitoring, implementation of best management practices, treatment or control measures, or changes in farming practices to achieve compliance with this Order.

C. Summary of Options Considered

The options considered are discussed in Appendix D.

4. DEVELOPMENT OF THE DRAFT ORDER

A. February 2010 Preliminary Draft Order

Staff developed the preliminary recommendations for an Agricultural Order by building upon the 2004 Order to advance efforts to improve agricultural water quality and gain compliance with applicable water quality standards. Thus, staff recommended the same regulatory tool, a Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands, to regulate agricultural discharges. To ensure understanding of applicable water quality standards, staff included explicit clarification of water quality discharge and compliance requirements. In addition, to improve implementation actions directly addressing the specific priority water quality issues, the Preliminary Draft Agricultural Order built upon the development and implementation of Farm Plans, including effective implementation of management practices (related to irrigation, nutrient, pesticide and sediment management) that will most likely yield the greatest amount of water quality protection. The Preliminary Draft Agricultural Order also built upon the existing Cooperative Monitoring Program by retaining watershed-scale, receiving water monitoring, but added individual monitoring and reporting to improve Water Board staff's ability to identify specific discharges loading pollutants or contributing to impacts, verify compliance with the requirements by dischargers and measure progress over time at the farm and watershed scales. The Preliminary Draft Agricultural Order focused on reducing or eliminating agricultural discharges – especially contaminated irrigation runoff and percolation to groundwater in the most severely impaired areas. Due to the unique conditions related to irrigated lands and individual farming operations, the Preliminary Draft Agricultural Order included multiple options for compliance to maximize Dischargers' flexibility in achieving desired water quality improvement according to a specific time schedule and specific milestones. Similar to the 2004 Conditional Waiver, the Preliminary Draft Agricultural Order also included significantly reduced monitoring and reporting requirements for those agricultural discharges identified as having relatively low-risk for water quality impairment. The conditions for compliance, the monitoring and reporting requirements and the time schedule for compliance are summarized in the following paragraphs.

<u>Compliance Requirements</u>

The Preliminary Draft Agricultural Order included the following requirements for dischargers to demonstrate compliance:

- Enroll to be covered by the Order
- Develop and implement a farm plan that includes management practices with certain conditions and specifications
- Eliminate non-storm water discharges, or use source control or treatment such that non-storm water discharges meet water quality standards
- Demonstrate through water quality monitoring that individual discharges meet certain basic water quality targets (that are or indicate water quality standards that protect beneficial uses). For example, non-storm water discharge monitoring should find:
    - No toxicity

- Nitrate ≤ 10 mg/L NO3 (N)
- Turbidity ≤ 25 NTUs
- Un-ionized Ammonia < 0.025 mg/L (N)
- Temperature ≤ 68°F

- Demonstrate through water quality monitoring that receiving water is trending toward water quality standards that protect beneficial uses or is being maintained at existing levels for high quality water
- Farm operation must support a functional riparian system and associated beneficial uses (e.g., recreational uses like swimming, wading, or kayaking, fishing, wildlife habitat, etc.)

Monitoring and Reporting
Monitoring requirements were designed to support the implementation of the Preliminary Draft Agricultural Order (specifically as a Conditional Waiver of Waste Discharges). Monitoring must verify the adequacy and effectiveness of the Order's conditions. Monitoring information and data must be reported to the Water Board. The reporting requirements that staff recommended with the Preliminary Draft Agricultural Order included all farm operations to report on management practice implementation at the time of enrollment, to report on management practices at least once during the period of the Order, to update their farm plans annually with monitoring and site evaluation results, and to update their plans annually with specific adjustments in response to any results that indicate unacceptable progress (e.g., do not meet interim milestones set forth in the Order).

The current monitoring program for the 2004 Conditional Waiver uses a third party for meeting all monitoring and reporting requirements (Preservation, Inc., the nonprofit organization that implements the Cooperative Monitoring Program). Under the current monitoring and reporting program, Dischargers are responsible for monitoring and reporting either individually or collectively, and they must comply with the requirements of the Board-approved Monitoring and Reporting Program. The preliminary draft monitoring and reporting requirements provided for Dischargers to continue to use a third party as long as the third party is approved by the Executive Officer.

The existing monitoring program does not collect sufficient information regarding:
- Groundwater quality
- Pollution source identification
- Individual compliance
- Terrestrial riparian conditions

In the Preliminary Draft Agricultural Order, Water Board staff recommended a monitoring program that required four categories of monitoring: Individual Discharge Characterization Monitoring, Individual Discharge Monitoring, Watershed (receiving water) Monitoring, and Additional Monitoring if required by the Executive Officer (receiving water and/or discharge).

Staff recommended this monitoring program because it:
- Addresses all surface water (tailwater, tile drain water, stormwater, etc) and groundwater
- Provides complete identification of individual operations responsible for discharge
- Allows for immediate management of known discharges with the potential to impact water quality
- Limits costs for farms that are in compliance
- Prioritizes further regulatory action on farms that are not progressing toward compliance

- Uniformly distributes costs for trend and stormwater monitoring across all growers resulting in similar costs for all growers based on acreage farmed
- Provides data for surface and groundwater trends, individual compliance, management practice implementation, riparian protection, and stormwater
- Allows data collection, analysis, and reporting to be performed by a non-regulatory single third party
- Provides follow up monitoring to identify and mitigate known discharges with the potential to impact water quality

Proposed Time Schedule for Compliance
Water Board Staff considered a time schedule that would support timely and effective implementation. Under this Preliminary Draft Agricultural Order, either irrigation runoff would need to be eliminated within two years of adoption of the Order or the following pollutants in irrigation runoff would need to be eliminated and/or treated or controlled to meet applicable water quality standards by the dates specified:

- Toxicity – within two years of adoption of the Order
- Turbidity – within three years of adoption of the Order
- Nutrients – within four years of adoption of the Order
- Salts – within four years of adoption of the Order

Additionally, dischargers must implement management practices to reduce pollutant loading to groundwater.

Staff recommended the time-schedule in this Preliminary Draft Agricultural Order as a reasonable starting point to improve water quality. This schedule acknowledges that to fully control all discharges and achieve compliance will take longer than the five years of this Preliminary Draft Agricultural Order. In a separate, but related effort regarding regulation of agricultural discharges, staff is evaluating and developing a time schedule for actions and to meet interim milestones that extends out to 2025.

B. Results of Public Outreach

Workshop Outcomes
At the Workshop on May 12, 2010, staff presented a summary of water quality conditions, preliminary draft staff recommendations, and an evaluation of the alternatives submitted that concluded the agricultural alternatives did not meet the criteria set forth by the Board nor the water quality goals and requirements that staff established as necessary for a revised order when development of the 2011 Draft Order began prior to December 2008. See Table 5.

Table 4A. Evaluation of Alternatives based on Agricultural Order Requirements

Authority	Legal Requirement	Confirmation of Compliance	Point of Compliance	Milestone(s) to Measure Progress	Time to Compliance

Porter-Cologne, Basin Plan	Eliminate toxic discharges of agricultural pesticides to surface waters and groundwater	AG: SMART sampling/ farm plan compliance document OSR: practice checklist ENV: On- farm and watershed scale monitoring and farm plan compliance document	None None Edge of farm; in stream	General Management Practice implementation General management practice implementation Specific requirements	None 5 years for education; 2 years for farm plan and checklist Timeframes found in preliminary draft order or shorter
Porter-Cologne, Basin Plan	Reduce nutrient discharges to surface waters to meet nutrient standards	AG: SMART sampling/ farm plan OSR: Compliance document/ practice checklist ENV: On- farm and watershed scale monitoring and farm plan compliance document	None None Edge of farm; in stream	General Management Practice implementation General management practice implementation Specific requirements	None 5 years for education; 2 years for farm plan and checklist Timeframes found in preliminary draft order or shorter
Porter-Cologne, Basin Plan	Reduce nutrient discharges to groundwater to meet groundwater standards	AG: none OSR: none ENV: On- farm and watershed scale monitoring and farm plan compliance document	None None Edge of farm: in stream	None None Specific requirements	None None Timeframes found in preliminary draft order, or shorter
Porter-Cologne, Basin Plan	Minimize sediment discharges from agricultural lands	AG: SMART sampling/ farm plan OSR: Compliance document/ practice checklist ENV: On- farm and watershed scale monitoring and farm plan compliance document	None None Edge of farm; in stream	General Management Practice implementation General management practice implementation Specific requirements	None 5 years for education; 2 years for farm plan and checklist Timeframes found in preliminary draft order or shorter

Authority	Legal Requirement	Confirmation of Compliance	Point of Compliance	Milestone(s) to Measure Progress	Time to Compliance

Porter-Cologne, Basin Plan	Eliminate toxic discharges of agricultural pesticides to surface waters and groundwater	AG OSR ENV DRAFT CW	ENV DRAFT CW	AG OSR ENV DRAFT	OSR ENV DRAFT
Porter-Cologne, Basin Plan	Reduce nutrient discharges to surface waters to meet nutrient standards	AG OSR ENV DRAFT CW	ENV DRAFT CW	AG OSR ENV DRAFT	OSR ENV DRAFT
Porter-Cologne, Basin Plan	Reduce nutrient discharges to groundwater to meet groundwater standards	ENV DRAFT CW	ENV DRAFT	ENV DRAFT	ENV DRAFT
Porter-Cologne, Basin Plan	Minimize sediment discharges from agricultural lands	AG OSR ENV DRAFT CW	ENV DRAFT CW	AG OSR ENV DRAFT	OSR ENV DRAFT
Porter-Cologne, Basin Plan	Protect aquatic habitat	AG OSR ENV DRAFT CW	ENV DRAFT	ENV DRAFT	ENV DRAFT

Table 5 Continued: Evaluation of Alternatives based on Agricultural Requirements

[1]Alternatives:
AG= CA Farm Bureau Federation and other Ag Organizations
OSR = OSR Enterprises, Inc.
ENV=Monterey Coast keeper and other Environmental Organizations
DRAFT= Draft Order released November 2010
CW= Existing 2004 Conditional Waiver for Irrigated Agriculture
[2]Requirements established as framework for development of Draft Ag Order in December 2008

The Board listened to public comments on the recommendations, and public presentations on proposed alternatives for regulating agricultural discharges. More than 375 members of the public attended the meeting and more than 80 individuals addressed the Water Board.

Proponents of alternatives to the Preliminary Draft Agricultural Order, California Farm Bureau Federation and local Farm Bureaus, Monterey Coastkeeper and partner environmental organizations, and OSR Enterprises, Inc, described their alternatives to the Board. Members of the public showed both support and opposition for the Order and commented on the following issues.

- Water quality conditions from agricultural discharges are severe, particularly nitrate contamination of drinking water;
- Costs to clean up the nitrate has been conveyed to communities that have been impacted by water pollution, in the form of increased health care costs, bottled water costs, and missing work;
- Implementation of the Order will be complex ,costly and infeasible;
- The Order timeline is aggressive;
- We have lost the collaborative process to develop the order;
- The Order needs strong numeric requirements, streamside buffers and riparian protections, and individual farm monitoring.
- The agricultural alternatives do not meet the criteria set forth by the Board.

Board members offered their own comments on what they heard at the Workshop and read in the staff reports and preliminary draft order. Some of the comments that Board members made, include:

- Tiered approach and phasing are essential; we need to focus on short term actions that address drinking water concerns. The worst areas should be addressed first.
- How do we coordinate with the food safety issues?
- Will there be enough staff to analyze all the information being requested from the Ag community?
- Will we be able to protect proprietary information requested in the farm plans?
- A required education element should be considered (15 hours in five years?).
- Need reasonable timelines.
- Individual Waste Discharge Requirements might have a role.
- There should be enforcement on the remaining growers that are not enrolled.
- Water quality issues identified are real and need to be addressed; consider prioritization of the issues.
- Perhaps the next waiver should look like a ten year plan and consider other components, and lay the framework at how we are going to get at all these issues.

Board members concluded that staff should move forward with next steps considering stakeholder and Board member input from the Workshop, meeting with stakeholders further and preparing a revised draft order. They also agreed to continue the Workshop at the July Board meeting in Watsonville.

On Thursday, July 8, 2010 the Water Board held a public workshop continuing the May 12 public workshop. Staff received 16 additional comment letters. These comments generally covered issues similar to the comments submitted prior to the May 12 Board Workshop and included:

General Support for Preliminary Draft Agricultural Order (over 880 letters including multiple copies of some form letters):

- Support for the process, the Agricultural Regulatory Program and preliminary draft recommendations for an updated Agricultural Order.
- Support for the prioritization of agricultural water quality and urges Central Coast Water Board to take timely actions to prevent further degradation.
- Support for the regulation of agricultural discharges to groundwater and the protection of drinking water sources.

- Support for requirements for individual groundwater monitoring, including private domestic wells and submittal of data and technical reports.

General Concern about Preliminary Draft Agricultural Order (over 200 letters):

- Requirements will result in economic hardship.
- Requirements will result in crop yield reductions and farmers will go out of business.
- The current process is inadequate, including California Environmental Quality Act (CEQA) requirements and specifically requirements to consider the social, environmental and economic impacts, and evaluate alternatives.
- Lack of cooperation with the growers and farm organizations to develop requirements.
- Objections to proposed aquatic habitat requirements.
- Objections to individual monitoring and reporting.

At the workshop, commenters presented the following issues and made the following comments:

- Advocacy for "SMART" sampling which is similar to the current confidential on-farm monitoring that the Cooperative Monitoring Program (CMP) conducts;
- Examples of ranchers who have adapted their practices and operations in response to SMART sampling to improve water quality;
- Expert presentations on technical hurdles of reducing nitrate loading to levels protective of water quality;
- Advocacy for individual discharger monitoring and riparian protection;
- Consideration of individual commodities (like strawberries);
- Need for flexibility;
- Need to evaluate technical feasibility of water quality improvements;
- Need for long timeframes;
- Include education requirements;
- Set reasonable and scientifically determined targets;
- Recognize benefits and challenges (costs and effectiveness) of riparian and vegetative buffers.
- agricultural alternatives do not meet the criteria set forth by the Board.

Board members made the following observations:

- Impacts to human health are the highest priority and need a short-term response;
- Build on original draft, and use good ideas heard at workshop;
- Support tiered approach and prioritizing where main problems are and based on commodities that are biggest risks;
- Consider recommendation to allow two years of private monitoring, and then require submittal of data and make it public;
- Focus on what staff can do in the next five years given reduced resources;
- Refine tiers beyond just impaired and unimpaired areas; also consider threats to water quality; find ways to tier requirements for groundwater impacts;
- Measure trends and hope to show improvements and meeting goals;
- No need for another workshop but anyone who wants to offer information to the Board should submit it or contact staff.

<u>Public Outreach Meetings</u>

Following the release of the draft report and supporting documents and continuing through September 2010, Water Board staff participated in several outreach meetings and events. To ensure a diverse representation of stakeholders, staff initially made a deliberate effort to engage stakeholders who were not represented on the Ag Panel and who were not already actively participating in the process to renew the Agricultural Order, including technical assistance providers, municipalities, environmental justice organizations, and agricultural industry groups not yet involved. In addition to discussing potential conditions and alternatives, staff met with stakeholders to discuss water quality conditions and priorities, methods to outreach to underrepresented groups, technical considerations associated with achieving water quality standards, potential costs of compliance to agriculture and potential costs to communities impacted by agriculture. Staff also met specifically with representatives from agriculture and specific commodity groups.

Specific outreach meetings and events included the following (in Table 6):

Table 5. Agricultural Order Renewal Outreach Meetings and Event

Date	**Meeting / Event**
November 17, 2009	2009 Sustainable Ag Expo, sponsored by the Central Coast Vineyard Team
January 12, 2010	American Society of Agronomy, California Certified Crop Advisers
February 17, 2010	Monterey Coastkeeper
February 22, 2010	Santa Cruz County, Resource Conservation District of Santa Cruz County, and Big Sur Land Trust
March 3, 2010	San Luis Obispo County Water Resources Advisory Committee
March 8, 2010	Technical Assistance Providers (University of California Cooperative Extension, Cal Poly Irrigation Training Research Center, Monterey Bay National Marine Sanctuary, Natural Resources Conservation Service, Resource Conservation District of Monterey County)
March 9, 2010	Annual Monterey County Ag Expo – Presentation to Spanish speaking growers and irrigators
March 17, 2010	California Strawberry Commission
March 22, 2010	San Luis Obispo County Farm Bureau – North Coast Farm Center
March 23, 2010	The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Antinetti Consulting, Inc.
March 30, 2010	Central Coast Vineyard Team, Department of Pesticide Regulation, State Water Resources Control Board, Central Valley Regional Water Quality Control Board
April 11, 2010	Presentation to Association of California Water Agencies on Water Quality and Water Supply
April 14, 2010	Agricultural Water Quality Alliance (Monterey Bay National Marine Sanctuary, Resource Conservation District of Monterey County, Natural Resources Conservation Service, Central Coast Agricultural Water Quality Coalition, Central Coast Water Quality Preservation, Inc., Resource Conservation District of Monterey County, University of California Cooperative Extension, AWQA RCDs)
April 28, 2010	Interagency Meeting (U.S. Environmental Protection Agency, U.S. Fish and Wildlife, California Department of Public Health, California Department of Water Resources, California Department of Food and Agriculture, California Department of Fish and Game, California State Parks, County public health agencies, County Agriculture Commissioners)
April 29, 2010 *(Pending)*	Farm, ***Food Safety***, Conservation Network
April 30, 2010	California Association of Nurseries and Garden Centers, University of

	California Cooperative Extension
May 24, 2010 (Pending)	Agriculture & Land-Based Training Association – Presentation to Spanish speaking growers "Programa Educativo Para Agricultores"
August 16, 2010	Multiple Agricultural Stakeholders: CA Farm Bureau Federation, County Farm Bureaus, Coalition, Grower-Shipper Association, Strawberry Commission, Central Coast Vineyard Team,and Other Agricultural Industry Representatives
August 16, 2010	Public Meeting: Scoping for California Environmental Quality Act
August 17, 2010	Environmental Defense Center, Monterey Coastkeeper, Surfrider, Santa Barbara Channelkeeper, Environmental Justice Coalition for Water
August 18, 2010	CA Association of Nurseries and Garden Centers, Nursery/Greenhouse Representatives
August 19, 2010	San Luis Obispo County Farm Bureau, Local Agricultural Representatives
September 8, 2010	Strawberry Commission
November 10, 2010	Board Member field trip to runoff treatment sites in Monterey County
November 15, 2010	Staff Presentation at Sustainable Ag Expo in Seaside, Monterey County

Changes in Response to Public Input

Staff changed the preliminary draft Agricultural Order based on feedback received from stakeholders and included the following changes in the 2011 Draft Order.

- removed conditions related to rainwater and containerized plants;
- clarified the intent to address irrigation runoff in the short term with immediate conditions vs. tiledrains in the long term;
- removed "tributaries" as a consideration for prioritizing farming operations in close proximity to impaired waterbodies for more stringent or immediate conditions;
- revised the table of high risk pesticides;
- revised aquatic habitat conditions;
- revised the level of prescription in conditions ;
- developed a compliance document for reporting instead of using the Farm Plan;
- included evaluations or milestones for pollutant loading in exchange, or in addition to, pollutant concentrations;
- evaluated and developed additional ways to define tiers of dischargers and associated conditions based on relative threat to water quality and apply the most stringent compliance requirements to highest threat tier;
- increased and staggered timeframes for compliance with various requirements;
- evaluated and developed additional options for monitoring and reporting that scale monitoring requirements so highest threat dischargers have more monitoring requirements than lower threat dischargers.

C. Summary of Public Comments on Draft Order

[NOTE TO READER: THIS IS PLACEHOLDER FOR A SUMMARY OF COMMENTS RECEIVED ON DRAFT ORDER AFTER NOVEMBER 19, 2010 WHEN THIS DRAFT STAFF REPORT PUBLISHED]

D. Summary of Environmental Setting and Water Quality Conditions

1. Water Resources on the Central Coast

The Central Coast Region's coastal and inland water resources are unique, special, and in some areas still of relatively high quality. Many Central Coast residents depend heavily on groundwater for drinking water from both deep municipal supply wells and shallow domestic wells. In addition, the region supports some of the most significant biodiversity of any temperate region in the world and is home to many sensitive natural habitats and species of special concern. These resources and the beneficial uses of the Central Coast water resources are severely impacted or threatened by agricultural discharges.

Thousands of people rely on public supply wells with unsafe levels of nitrate and other pollutants. Excessive nitrate concentration in drinking water is a significant public health issue resulting in risk to infants for methemoglobinemia or "blue baby syndrome", and adverse health effects (i.e., increased risk of non-Hodgkin's, diabetes, Parkinson's disease, Alzheimers, endrocrine disruption, cancer of the organs) among adults as a result of long-term consumption exposure. Water Board staff estimate several additional thousands of people are drinking from shallow private domestic wells. Shallow groundwater is generally more directly susceptible to pollution from overlying land use. Groundwater quality data collection from shallow wells (especially agricultural or domestic drinking water wells) is not required and data is only broadly available, thus limiting evaluations related to potential public health risks and shorter term indications of water quality changes. For these wells, water quality is not regulated, not treated, or treated at significant cost to the well owner.

Agricultural discharges of fertilizer are the main source of nitrate contamination to groundwater based on local nitrate loading studies. In some cases, up to 30 percent of applied nitrogen may have leached to groundwater in the form of nitrate. Due to elevated concentrations of nitrate in groundwater, many public water supply systems have abandoned wells and established new wells or sources of drinking water, or are required to remove nitrate before delivery to the drinking water consumer, often, at significant cost.

Agricultural discharges have impaired surface water quality in the Central Coast Region, such that some creeks are found toxic (lethal to aquatic life) every time the site is sampled and as a result many areas are devoid of aquatic organisms essential to ecological systems. Vertebrates, including fish, rely on invertebrates as a food source. Consequently, invertebrates are key indicators of stream health, and are commonly used for toxicity analyses and assessments of overall habitat condition. The majority of creeks, rivers and estuaries in the Central Coast Region are not meeting water quality standards. Most of these waterbodies are impacted by agriculture. These conditions were determined and documented on the Central Coast Water Board's 2008 Clean Water Act Section 303(d) List of Impaired Waterbodies. The three main forms of pollution from agriculture are excessive runoff of pesticides and toxicity, nutrients, and sediments. In a statewide study, the Central Coast Region had the highest percentage of sites with pyrethroid pesticides detected and the highest percentage of sites exceeding toxicity limits. In addition, there are more than 46 waterbodies that exceed the nitrate water quality standard and several waterbodies routinely exceed the nitrate water quality standard by five-fold or more. In addition to causing the human health impacts discussed previously, these high levels of nitrate are impacting sensitive fish species such as the threatened Steelhead, endangered Coho Salmon, by causing algae blooms that remove oxygen from water, creating conditions unsuitable for aquatic life.

The water quality conditions throughout the region are also impacting several other threatened and endangered species, including the marsh sandwort (arenaria paludicola), Gambel's watercress (nasturtium rorippa gambelii), California least tern (sterna antillarum browni), and red-legged frog (Rana aurora). The last remaining known populations of the two endangered plants, marsh sandwort and Gambel's watercress, occur in Oso Flaco Lake, are critically imperiled and depend upon the health of the Oso Flaco watershed to survive.

a. Summary of Groundwater Quality Conditions

To develop a comprehensive assessment of groundwater quality in agricultural areas throughout the Region, staff evaluated available groundwater data collected by the California Department of Water Resources, California Department of Public Health (CDPH), U.S. Geological Survey (USGS), State Water Resources Control Board (SWRCB) Groundwater Ambient Monitoring and Assessment (GAMA) Program, Lawrence Livermore National Laboratory (LLNL), local and county water resources agencies, and researchers. Although available groundwater quality data generally represent conditions at the groundwater basin and sub-basin scale, these data indicate widespread and severe nitrate impacts due to agricultural land uses over a broad scale given major portions of entire groundwater basins or aquifers are severely impacted with nitrate in areas subject to intensive irrigated agricultural activity. Groundwater quality data for the purposes of characterizing specific individual agricultural discharges are generally not available. However, a growing number of studies are available showing a direct link between irrigated agricultural practices and ongoing and significant nitrate loading to groundwater. In addition, numerous studies indicate nitrate in groundwater is the most significant water quality problem nationally, statewide and within the Region and that commercial fertilizer is the primary source of loading, particularly in areas of intensive agriculture.

The report contained within Appendix G focuses primarily on nitrogen/nitrate pollution. The report also refers to a more limited body of data that indicates irrigated agriculture is likely responsible for widespread leaching of salts and discharges of other chemicals such as pesticides with the potential to impact drinking water beneficial uses.

,
An evaluation of the sources of nitrogen, nitrogen loading to groundwater from irrigated agriculture and groundwater quality conditions is detailed in Appendix G to this staff report (with references cited) and summarized below.

Sources of Nitrogen Input and Loading Analyses -

- Fertilizer accounts for approximately 69 percent of the estimated available nitrogen input regionally of the three largest sources of nitrogen within the Region related to human activities (fertilizer, human waste and livestock waste).
- Approximately 83.6 percent of the estimated nitrogen loading to groundwater in the Salinas Valley is attributable to the commercial application of agricultural fertilizers.
- Approximately 45,404 tons of nitrogen were applied on average every year for agricultural purposes within the Region between 1998 and 2008.
- Over 17,000 tons of nitrogen (75,225 tons of nitrate) has been estimated to discharge/leach to groundwater on average every year for the last ten years from irrigated agriculture in the Region. This equates to an average groundwater loading of approximately 74 pounds of nitrogen (327.5 pounds of nitrate) per cropping acre of irrigated agriculture per year.

- For lettuce, nitrogen leachate concentrations of 104.9 to 178 mg/L nitrate-N were documented in a 2009 study in the Salinas Valley. These leachate concentrations are approximately 10 to 18 times the drinking water standard (using the federal standard convention of 10 mg/L nitrate-N for comparison) and would consequently require up to 18 times as much clean groundwater flowing under the site as the water percolating down from irrigation (volume of leachate) to dilute the water to the standard. And of course up gradient water is typically not "clean," but also carries some nitrogen load. Based on 2008 and 2009 county Ag Commissioner cropping acre data, lettuce accounts for approximately 45 percent of the cropping acres in Monterey County and 38 percent in the Region. Lettuce typically requires less fertilizer-nitrogen application than the four other primary crops grown in the Region, strawberries, broccoli, cauliflower and celery.
- A 2005 report by LLNL indicates that nitrate impacts within the shallow aquifer of the Llagas subbasin are due to more recent fertilizer-nitrogen loading and not that of legacy farming practices or other sources. Groundwater ages in shallow aquifer wells east of Gilroy containing nitrate concentrations, exceeding twice the drinking water standard, were determined to be less than seven years old and in some locations less than two years old. Similarly, preliminary data from a 2010 LLNL special study indicated that shallow wells sampled in the Arroyo Seco area also had relatively "young" groundwater- about five years old.
- The potentially significant loading of salts to groundwater from irrigated agriculture warrants the collection and analysis of groundwater quality data for salt constituents and metrics of salinity within and around agricultural areas.

Nitrate Impacts to Groundwater Beneficial Uses -

- 55 percent of the drinking water standard violations in public supply wells (for water systems with fifteen or more service connections) in the Central Coast Region were attributable to nitrate (data from Department of Water Resources).
- Approximately 9.4 percent of all public water supply wells in the Region had concentrations of nitrate in excess of the drinking water standard between 1994 and 2000.
- 18 percent of public supply wells within the Salinas Valley groundwater basin (excluding the Paso Robles subbasin), contained nitrate in excess of the drinking water standard during the period between 1979 and 2009. Excluding the Seaside, Langley and Corral de Tierra subbasins of the Salinas Valley groundwater basin that are not as intensively farmed but are subject to greater potential nitrogen loading from septic systems, the number of wells containing nitrate in excess of the drinking water standard increased to 23 percent. Approximately 37 percent of the public supply wells in the Salinas Valley contained nitrate concentrations between background levels and the drinking water standard.
- 27 percent of public supply wells in the Santa Maria groundwater basin contained nitrate in excess of the drinking water standard. 40 percent of the wells contained nitrate concentrations between background levels and the drinking water standard.
- 19 percent of the small water supply system (with two to 14 service connections) wells sampled in Monterey County exceeded the nitrate drinking water standard and 44 percent contained nitrate concentrations between background levels and the drinking water standard during the 2008-2009 fiscal year.
- 55.3 percent of the 508 domestic wells sampled in the Llagas subbasin had concentrations of nitrate in excess of the drinking water standard at levels and up to 4.5 times the drinking water standard, as well as average and median nitrate concentrations just above the drinking water standard during a voluntary nitrate sampling program conducted in 1998. Comparison of the 1998 domestic well data with three previous domestic well studies indicated that average nitrate concentrations within domestic wells in the Llagas subbasin increased steadily from 19.5 mg/L nitrate-NO_3 in 1963 to 47.7 mg/L nitrate-NO_3 in 1998. The relative

percentage of wells with nitrate in excess of the drinking water standard increased from 11.3 to 55.3 percent in the Llagas subbasin during this time period.

Pesticide in Groundwater-

- 6.9 percent of wells sampled in the Region contained pesticides, although numerous well sampling data collected by DPR between 1984 and 2009 indicated pesticides are infrequently detected above preliminary health goals or drinking water standards.

b. Summary of Surface Water Quality Conditions

Surface water bodies throughout the region are degraded as evidenced by high levels of nitrates and consistent toxicity measurements. The highest nitrate concentrations and most severe toxicity occur in agricultural watersheds.

To determine surface water conditions, staff reviewed data collected by CMP and CCAMP, and conducted a review of other water quality available water quality information, for marine areas for example, in the Central Coast Region.

Surface water conditions are detailed in Attachment 1 to this staff report and summarized below.

Indicators of Surface Water Quality Impairment-

- Most of the same areas that showed serious contamination from agricultural pollutants five years ago are still seriously contaminated.
- The proposed 2010 Clean Water Act Section 303(d) List of Impaired Waters for the Central Coast Region (Impaired Waters List) identifies surface water impairments for approximately 167 water quality limited segments related to a variety of pollutants (e.g., salts, nutrients, pesticides/toxicity, and sediment/turbidity). Sixty percent of the surface water listings identified agriculture as one of the potential sources of water quality impairment.
- Agricultural discharges most severely affect surface waterbodies in the lower Salinas and Santa Maria watersheds, both areas of intensive agricultural activity. Evaluated through a multi-metric index of water quality, 82 percent of the most degraded sites in the Central Coast Region are in these agricultural areas.
- Nitrate concentrations in areas that are most heavily impacted are not improving significantly or in any widespread manner and in a number of sites in the lower Salinas/Tembladero and Santa Maria watershed areas appear to be getting worse in the last few years (from CCAMP and CMP data) .
- Thirty percent of all sites from CCAMP and CMP have average nitrate concentrations that exceed the drinking water standard, and approximately 60 percent exceed the level identified to protect aquatic life. Several of these water bodies have average nitrate concentrations that exceed the drinking water standard by five-fold or more. Some of the most seriously polluted waterbodies include the Tembladero Slough system (including Old Salinas River, Alisal Creek, Alisal Slough, Espinosa Slough, Gabilan Creek and Natividad Creek), the Pajaro River (including Llagas Creek, San Juan Creek, and Furlong Creek), the lower Salinas River (including Quail Creek, Chualar Creek and Blanco Drain), the lower Santa Maria River (including Orcutt-Soloman Creek, Green Valley Creek, and Bradley Channel), and the Oso Flaco watershed (including Oso Flaco Lake, Oso Flaco Creek, and Little Oso Flaco Creek).

- Toxicity is widespread in Central Coast waters, with 65 percent of all waterbodies monitored for toxicity showing some measure of lethal effect. Twenty-nine waterbodies are on the proposed 2010 Clean Water Act, Section 303(d) List of Impaired Waters because of sediment and/or water toxicity.
- Ninety percent of severely toxic sites are in agricultural areas of the lower Santa Maria and Salinas/Tembladero watershed areas.
- Discharges from a number of agricultural drains have shown toxicity nearly every time the drains are sampled. Researchers collaborating with CCAMP have shown that these toxic discharges can cause toxic effects in river systems that damage benthic invertebrate communities.
- Water column invertebrate toxicity is primarily associated with high concentrations of diazinon and chlorpyrifos pesticides; sediment toxicity is likely caused by chlorpyrifos and pyrethroid pesticide mixtures.
- Agricultural use of pyrethroid pesticides in the Central Coast Region and associated toxicity are among the highest in the state. In a statewide study of four agricultural areas conducted by the Department of Pesticide Regulation (DPR), the Salinas study area had the highest percent of surface water sites with pyrethroid pesticides detected (85 percent), the highest percent of sites that exceeded levels expected to be toxic (42 percent), and the highest rate (by three-fold) of active ingredients applied (113 lbs/acre).
- Agricultural discharges contribute to sustained turbidity with many sites heavily influenced by agricultural discharges exceeding 100 NTUs as a median value. For comparison, most CCAMP sites have a median turbidity level of under 5 NTUs. Resulting turbidity greatly exceeds levels that impact the ability of salmonids to feed. Many of these more turbid sites are located in the lower Santa Maria and Salinas-Tembladero watersheds.
- Lack of shading in creek channels modified for agricultural purposes can cause water temperatures to exceed levels that are healthy for salmonids. Several high temperature areas are in major river corridors that provide rearing and/or migration habitat for salmonids. These include the Salinas, Santa Maria, and Santa Ynez rivers.
- Bioassessment data shows that creeks in areas of intensive agricultural activity have impaired benthic communities. Aquatic habitat is often poorly shaded, high in temperature, and has in-stream substrate heavily covered with sediment.
- Several Marine Protected Areas (MPAs) along the Central Coast are at risk of pollution impacts from sediment and water discharges leaving river mouths. Three of the MPAs, Elkhorn Slough, Moro Cojo Slough and Morro Bay, are estuaries that receive runoff into relatively enclosed systems. In two of these MPAs (Moro Cojo Slough and Elkhorn Slough), nitrates, pesticides and toxicity are documented problems.
- Research in the Monterey Bay area has shown that discharge of nitrate from the Salinas and Pajaro river systems can increase the initiation and development of phytoplankton blooms, and some of these blooms have resulted in the deaths of hundreds of sea birds.

Indicators of Surface Water Quality Trends -

- Some drainages in the Santa Barbara area are improving in nitrate concentrations (such as Bell Creek, which supports agricultural activities) and on Pacheco Creek in the Pajaro watershed. A number of locations in the lower Salinas and Santa Maria areas show increasing nitrate concentrations over the past five years of the CMP. However, flow volumes have declined at some of these sites, so at these locations nitrate loads may not necessarily be getting worse in spite of upward trends in concentrations;

- Dry season flow volume is declining in some areas of intensive agriculture, implying reductions in tailwater volume;
- Detailed flow analysis by the CMP showed that 18 of 27 sites in the lower Salinas and Santa Maria watersheds had statistically significant decreases in dry season flow over the first five years of the program;
- CCAMP monitoring has detected declining flows at other sites elsewhere in the Region, likely because of drought;
- Several sites along the main stem of the Salinas River showed significant increases in turbidity during the dry season; significant decreases in turbidity were seen at two locations in the Santa Maria watershed.
- One CCAMP monitoring site on the Salinas Reclamation Canal (309JON) shows statistically significant improvement in survival of invertebrate test organisms in water.

Surface Water Quality Data and Information Gaps -

- The timeframe and frequency of data collection, especially for toxicity, limit the evaluation of statistical trends for some water quality parameters in surface waterbodies;
- In-stream water quality is an effective long-term measure of water quality improvement (especially for nutrients), and more time may be necessary in some locations to identify significant change.
- In-stream water quality monitoring data is necessary to show compliance with Total Maximum Daily Loads and to list or delist waterbodies from the Clean Water Act, Section 303(d) List of Impaired Waters. These are both key Water Board management tools.
- Flow information and water quality data are not reported for agricultural discharges from individual farms, so correlations cannot be made between reductions in irrigation runoff or improvements in agricultural discharge quality and in-stream changes.
- Because there is no individual on-farm monitoring or reporting, it is unknown how individual farms contribute to surface water quality improvement or impairment. In addition, it is unknown if individual Dischargers are in compliance with water quality standards (given the magnitude and scale of documented impacts, it is highly likely that most discharges are not in compliance).
- In Marine Protected Areas, there is no monitoring of sediments that carry pesticides in attached forms. Without this information it is difficult to determine if these pesticides, carried downstream attached to sediments and discharged to the ocean, harm marine life.
- Additional research could increase understanding of the impacts of nutrient discharges from rivers to nearshore ocean waters.

c. Summary of Aquatic Habitat Conditions

Aquatic habitat is degraded in many areas of the region as evidenced by poor biological and physical conditions. Most surface waterbodies in agricultural watersheds are not suitable for safe recreational fishing or to support aquatic life.

To determine aquatic habitat conditions, staff reviewed data collected by CMP and CCAMP, and conducted a review of available riparian and wetland information for the Central Coast Region. While the 2004 Conditional Waiver did not specifically require aquatic habitat monitoring, it stated that cooperative monitoring of in-stream effects would enable the Central Coast Water Board to assess the overall impact of agricultural discharges to beneficial uses, such as aquatic life and habitat. The 2004 Conditional Waiver also requires protection of beneficial uses including aquatic and wildlife habitat. The proposed 2010 order continues that requirement.

Aquatic habitat conditions are detailed in Attachment 1 to this staff report and summarized below.

Indicators of Aquatic Habitat Degradation -

- Agricultural activities result in the alteration of riparian and wetland areas, and continue to degrade the waters of the State and associated beneficial uses. Owners and operators of agricultural operations historically removed riparian and wetland areas to plant cultivated crops and in many areas continue to do so.
- As a result of riparian and wetland habitat degradation, watershed functions that serve to maintain high water quality, aquatic habitat and wildlife - by filtering pollutants, providing shade and protection from predators, recharging aquifers, providing flood storage capacity, have been disrupted.
- Data collected from CCAMP and CMP indicate that population characteristics of aquatic insects (benthic macroinvertebrates) important to ecological systems reflect poor water quality, degradation or lack of aquatic habitat, and poor overall watershed health at sites in areas with heavy agricultural land use. Aquatic habitat is often poorly shaded, high in temperature, and stream bottoms are heavily covered with sediment.
- The lower Salinas watershed and lower Santa Maria watersheds score low for common measures of benthic macroinvertebrate community health and aquatic habitat health.
- Unstable, bare dirt and tilled soils, highly vulnerable to erosion and stormwater runoff, are common directly adjacent to surface waterbodies in agricultural areas. Erosion and stormwater runoff from agricultural lands contribute sediment and sustained turbidity at levels that impact the ability of salmonids to feed. Many of these sites are located in the lower Santa Maria and Salinas-Tembladero watersheds.
- Degradation of aquatic habitat also results in water temperatures that exceed levels that are desirable for salmonids at some sites in areas dominated by agricultural activity. Several of these sites are in major river corridors that provide rearing and/or migration habitat for salmonids. These include the Salinas, Santa Maria, and Santa Ynez rivers.
- Real and/or perceived incompatible demands between food safety and environmental protection and subsequent actions taken by Dischargers to address food safety concerns associated with environmental features have resulted in the removal of aquatic habitat and related management practices.
- According to a Spring 2007 survey by the Resource Conservation District of Monterey County (RCDMC), 19 percent of 181 respondents said that their buyers or auditors had suggested they remove non-crop vegetation from their ranches. In response to pressures by auditors and/or buyers, approximately 15 percent of all growers surveyed indicated that they had removed or discontinued use of previously adopted management practices used for water quality protection. Grassed waterways, filter or buffer strips, and trees or shrubs were among the management practices removed (some were grant funded –*right?*).

Indicators of Aquatic Habitat Improvements -

- Riparian areas can improve water quality by trapping sediment and other pollutants contained in terrestrial runoff (NRC 2002; Flosi and others 1998; Pierce's Disease/Riparian Habitat Workgroup PDRHW 2000; Palone and Todd 1998). intact riparian area helps decrease rate of water flow, stores floodwaters, and dissipates stream energy, increasing infiltration (Palone and Todd 1998).
- The Watershed Institute Division of Science & Environmental Policy at California State University Monterey Bay implemented wetland restoration projects in the Gabilan

Watershed and surrounding Southern Monterey Bay Watersheds. These projects increased plant and bird populations and improved water quality (removed sediment, nitrate and pesticides loading to waterbodies).

- Coastal Conservation and Research and Moss Landing Marine Laboratories implemented restoration projects in the Moro Cojo Slough. These projects reduced nitrate levels in runoff, increased plants and vertebrates populations, and supported endangered species.
- The Watershed Institute at California State University Monterey Bay and Moss Landing Marine Laboratories studied changes in stream turbidity in restoration sites in the Hansen Slough area near Watsonville. The study concluded that stream turbidity decreased by more than 50-fold and nitrate concentrations in water flowing through decreased from levels at and above 140 mg/L to levels between 5 mg/L and 40 mg/L.

d. Waste Discharges from Irrigated Agricultural Lands

Water quality of agricultural discharges is often poor, carrying nitrates at concentrations above safe drinking water levels and pesticides at concentrations above toxic levels to waterbodies in the region. Agricultural discharges contribute significantly to water quality conditions. In some cases, agricultural discharges are the sole or primary source of pollution in impaired waterbodies. Even in areas where agricultural is not the only source of pollution, it is a primary contributor.

Numerous studies document the impact of agricultural discharges on water quality and specific pollutants contained in irrigation runoff. Research conducted by the Food and Agriculture Organization of the United Nations found that irrigation return flow resulted in a significant increase in nitrogen, phosphorous, pesticide residues, and sediments.
Agricultural research conducted by University of California Cooperative Extension (UCCE) found nitrate values in agricultural tailwater at 26, 53, and 75 mg/L NO3-N (up to 7.5 times the drinking water standard). UCCE researchers indicated that the high levels of nitrate at the site were likely caused by the grower injecting nitrogen fertilizer into the irrigation water during the 2nd and 3rd irrigation events. A UC Davis study of Salinas Valley farms found that by the second and third crop cycles, farm soils had begun to accumulate nitrogen, but that growers continued with the same fertilization schedule. In addition, soils are high enough in phosphorus that in some areas no added phosphorus is necessary; however, growers continue to add this chemical to their fields. These practices lead to excess fertilizer leaving the farm, which ultimately cause significant water quality impairment. Similar to tailwater, tile drain water with elevated nitrate levels has been found draining into surface water bodies. Nitrate concentrations in selected waterbodies in the Pajaro Valley Watershed have been found to range from 19 to 89.5 mg/l NO3 as N (compared to the drinking water standard, 10 mg/l).

Pesticides have been detected in agricultural tailwater and routinely exceed the toxicity water quality standard (lethal to aquatic life). Regionwide, CCAMP and the Cooperative Monitoring Program have conducted toxicity monitoring in 80 streams and rivers. Some measure of lethal effect (as opposed to growth or reproduction effect) has been observed at 65 percent of the water bodies monitored.

E. Summary of Draft Environmental Analysis Pursuant to CEQA

The Draft Environmental Analysis is discussed in Appendix H.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

April 3, 2009

MRP Tentative Order Comments
Attn: Dale Bowyer
San Francisco Bay Regional Water Quality Control Board
1515 Clay Street, Suite 1400
Oakland, CA 94612

Re: Draft MS4 Permit for San Francisco Bay Municipal Regional Stormwater NPDES Permit (Permit No. CAS612008)

Dear Mr. Bowyer:

The following are EPA Region 9's comments on the revised draft of the San Francisco Bay Municipal Regional Stormwater NPDES Permit (Permit No. CAS612008) dated February 11, 2009. In February 2008, we provided comments on the previous draft permit which was distributed for comment by the Board in December 2007. Consistent with our previous comments and discussions on reissuance of this permit, the revised draft permit needs additional, prescriptive requirements related to low impact development, trash control, and incorporation of TMDLs. EPA may consider objecting to the permit, if these issues cannot be addressed satisfactorily.

Our comments are informed by our review of other MS4 permits throughout our Region, and our review of the implementation of these permits via audits of nearly 50 MS4 programs. The audit reports repeatedly show the need for prescriptive requirements to clarify the permits and to ensure measurable, enforceable requirements.

1. Implementation of Low Impact Development (LID) Requirements

EPA is encouraged that the tentative order includes specific provisions to promote the implementation of LID, including site design, minimizing impervious surfaces, landscape-based treatment, and use of natural feature systems. However, while the permit encourages LID to the extent "practicable", the permit does not establish a clear, measurable performance standard to require landscape-based treatment, on-site retention, and/or storage for re-use.

As you are aware, EPA commented in February 2008 on the December 2007 draft permit that "to ensure adequate enforceability and clarity of the permit, we believe the permit needs to include a numeric value for quantity of runoff which would be directed to pervious areas." EPA's primary objective for incorporating LID into renewed MS4 permits, especially for those that represent the third or fourth generation of permits regulating these discharges, is that the permit must include clear, measurable, enforceable provisions for implementation of LID. In our review of MS4 programs across our Region, we have found that it is common for permits to rely on the development of plans to achieve certain permit objectives, rather than including prescriptive requirements in the permits. While the permittees often make significant and sincere efforts in their development of these plans, the plans often result in a reliance on qualitative provisions rather than specific measurable criteria. As a result, we have found that there often is uncertainty among both the MS4 permittees and the permitting agencies as to specific permit expectations. The incorporation of LID techniques into MS4 permits provides an opportunity to establish clear, measurable performance standards for the implementation of LID.

In order to incorporate clear, enforceable LID requirements into the Bay Area permit, sections C.3.c.i.2.(a) through (f) should be revised to clarify that regulated projects must utilize LID design elements to ensure onsite management of stormwater. Provisions describing these design elements should be revised to remove qualifiers such as "to the extent feasible" and "as practicable."[1] The permit should stipulate that use of these design elements must result in the onsite management of the total section C.3.d specified runoff. Any runoff that is not managed via these LID design elements must be addressed via the means described in section C.3.c.i.2(g) and (h). However, the permit should be clear that the use of the conventional means in C.3.c.i.2(g) and (h) would not be counted in determining whether projects meet the permit's LID requirements. Sections C.3.c.(4) through (6), which allow regulated projects to avoid use of LID design elements in favor of vault-based treatment systems, should be deleted.

EPA agrees that it may be beneficial to apply less stringent LID requirements to specific types of preferred development (as the draft permit provides in section C.3.e.). We also recognize that there may be situations where achievement of specified volumetric criteria for management of stormwater via LID design elements may be infeasible due to physical site constraints. The permit should include a clearly defined, enforceable process for requiring off-site mitigation for projects where use of LID design elements is infeasible. We'd suggest consideration of the Alternatives and In-Lieu Programs approach in the MS4 permit for Orange County proposed by the Santa Ana Regional Board (NPDES permit No. CAS618030), or another means whereby the Executive Officer may ensure that projects that cannot practically meet the LID performance requirements provide appropriate mitigation in the project vicinity.

[1]In addition, these qualifiers appear to allow self-regulation by the permittees rather than require oversight by the Regional Board on the issues of feasibility and practicability. See Environmental Defense Center, Inc. v. EPA, 344 F.3d 832 (9th Cir. 2003), and Waterkeeper Alliance, Inc. v. EPA, 399 F.3d 486 (2nd Cir. 2005)

EPA is today emphasizing LID (also called "green infrastructure") as a preferable approach to treating and reducing stormwater flow to MS4s[2] and its inclusion in provisions of MS4 permits. EPA believes that LID is an approach to storm water management that is cost-effective, sustainable, and environmentally-sound. The effectiveness of landscape-based treatment for stormwater is generally superior to the "conventional" treatment addressed in section C.3.d of the proposed permit because landscape-based treatment can remove a broader range of pollutants in a more robust and redundant fashion, and can achieve multiple environmental and economic benefits in addition to reducing downstream water quality impacts, such as enhanced water supplies, cleaner air, reduced urban temperatures, increased energy efficiency and other community benefits such as aesthetics, recreation, and wildlife areas.[3] The benefits of LID include:

- ***Stormwater Pollutant Reductions*** - Green Infrastructure techniques infiltrate runoff close to its source and help prevent pollutants from being transported to nearby surface waters. Once runoff is infiltrated into soils, plants and microbes naturally filter and break down many common pollutants found in stormwater.

- ***Maintenance requirements*** – Many conventional stormwater treatment systems are functional only so long as they are being properly maintained. For systems such as vaults that are underground and not readily accessible, maintenance requires specialized equipment and personnel and, without frequent maintenance, may re-suspend and re-release trapped pollutants. A benefit to landscape-based techniques is that maintenance requirements do not generally require specialized equipment or personnel, and maintenance is often consistent with the requirements of other landscaping (e.g., mowing, mulching, trash clearing, etc.).

- ***Reduced and Delayed Stormwater Runoff Volumes*** - Green infrastructure reduces stormwater runoff volumes and reduces peak flows by utilizing the natural retention and absorption capabilities of vegetation and soils. By increasing the amount of pervious ground cover, green infrastructure techniques increase stormwater infiltration rates, thereby reducing the volume of runoff entering our combined or separate sewer systems, and ultimately our lakes, rivers, and streams.

- ***Enhanced Groundwater Recharge*** - The natural infiltration capabilities of green infrastructure technologies can improve the rate at which groundwater aquifers are 'recharged' or replenished. This is significant because groundwater provides

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[2]EPA et al., Green Infrastructure Statement of Intent, April 19, 2007, available at http://www.msdgc.org/downloads/wetweather/greenreport/Files/Green_Report_Exhibit_A.pdf

[3]Managing Wet Weather with Green Infrastructure, Action Strategy, EPA, January 2008, available at http://cfpub.epa.gov/npdes/greeninfrastructure/information.cfm#greenpolicy

about 40% of the water needed to maintain normal base flow rates in our rivers and streams. Enhanced groundwater recharge can also boost the supply of drinking water for private and public uses.

- ***Reduced Sewer Overflow Events*** - Utilizing the natural retention and infiltration capabilities of plants and soils, green infrastructure limits the frequency of sewer overflow events by reducing runoff volumes and by delaying stormwater discharges.

- ***Increased Carbon Sequestration*** - The plants and soils that are part of the green infrastructure approach serve as sources of carbon sequestration, where carbon dioxide is captured and removed from the atmosphere via photosynthesis and other natural processes.

- ***Urban Heat Island Mitigation and Reduced Energy Demands*** - Urban heat islands form as cities replace natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat. The displacement of trees and vegetation minimizes their natural cooling effects. Additionally, tall buildings and narrow streets trap and concentrate waste heat from vehicles, factories, and air conditioners. By providing increased amounts of urban green space and vegetation, green infrastructure can help mitigate the effects of urban heat islands and reduce energy demands. Trees, green roofs and other green infrastructure can also lower the demand for air conditioning energy, thereby decreasing emissions from power plants.

- ***Improved Air Quality*** - Green infrastructure facilitates the incorporation of trees and vegetation in urban landscapes, which can contribute to improved air quality. Trees and vegetation absorb certain pollutants from the air through leaf uptake and contact removal. If widely planted throughout a community, trees and plants can even cool the air and slow the temperature-dependent reaction that forms ground-level ozone pollution (smog).

- ***Additional Wildlife Habitat and Recreational Space*** - Greenways, parks, urban forests, wetlands, and vegetated swales are all forms of green infrastructure that provide increased access to recreational space and wildlife habitat.

- ***Improved Human Health*** - An increasing number of studies suggest that vegetation and green space - two key components of green infrastructure - can have a positive impact on human health. Recent research has linked the presence of trees, plants, and green space to reduced levels of inner-city crime and violence, a stronger sense of community, improved academic performance, and even reductions in the symptoms associated with attention deficit and hyperactivity disorders. Additional information is available: http://www.lhhl.uiuc.edu/all.scientific.articles.htm

- ***Increased Land Values*** - A number of case studies suggest that green infrastructure can increase surrounding property values. In Philadelphia, a green retrofit program that converted unsightly abandoned lots into "clean & green" landscapes resulted in economic impacts that exceeded expectations. Vacant land improvements led to an increase in surrounding housing values by as much as 30%. This translated to a $4 million gain in property values through tree plantings and a $12 million gain through lot improvements.

2. Trash Control

EPA is encouraged that the tentative order includes requirements to address trash impairments in San Francisco Bay and its watersheds. However, EPA believes that the permit should include measurable and enforceable goals for trash reduction. For additional Federal regulatory support for the fact sheet, we suggest you also cite 40 CFR 122.26(d)(2)(iv)(A)(*1*) which requires the following for a stormwater management program:

> A description of maintenance activities and a maintenance schedule for structural controls to reduce pollutants (*including floatables*) in discharges from municipal separate storm sewers (emphasis added)

Commenters on the December 2007 version of the draft permit frequently expressed concern about the costs of the trash control program. For example, BASMAA in its comments to the Board estimated costs of $8.6 to $265 million (average of $128 million) for member agencies to implement "full capture devices" for just the 5% of the Bay Area urbanized areas for which such devices would have been required by the previous draft permit. However, these cost estimates are not supported by the experiences of the City of Los Angeles, which as noted in the fact sheet, intends to install such devices in the entire City of Los Angeles (with an area roughly comparable to the area to be covered by the Bay Area permit) for $72 million.

We recognize that in Los Angeles the requirements are being driven by TMDL requirements and similar requirements have yet to be developed for the Bay Area. However, the fact sheet for the Bay Area permit provides good support for the need for additional controls to reduce trash in Bay Area waterways, and the regulatory basis for the additional controls. Further, the San Francisco Bay Regional Board's draft 303(d) list includes a long list of waters (the Bay shoreline and 24 tributaries) impaired for trash, which may well lead to TMDLs for trash in the near future. Given the accomplishments thus far in the Los Angeles area, and the data provided to the Regional Board that justified the draft 303(d) listings, we believe that setting a percent load reduction over each year of the permit life for all proposed listed waterbodies, at a minimum, would be necessary for compliance with the requirements for trash control to the maximum extent practicable (MEP) of section 402(p)(3)(B) of the Clean Water Act. We believe that the proposed "hot spot" identification and methodology in the draft permit language is unnecessary and not based on already identified impairment. We encourage trash control efforts in commercial and industrial areas in addition to the waterbodies identified on the draft 303(d) list as impaired for trash.

Moreover, trash-control requirements in the previous MS4 permit were not completed, and thus it may be yet more compelling for the permittees to take more direct implementation actions to achieve reductions in loadings. This could be an optimal time to put in place already-tested methods from others and have a successful approach in place well before future trash TMDL adoption.

3. Total Maximum Daily Loads (TMDLs)

Pursuant to 40 CFR 122.44(d)(1)(vii)(B), Water Quality-Based Effluent Limits (WQBELs) in NPDES permits must be consistent with the assumptions and requirements of all applicable TMDL Waste Load Allocations (WLAs) approved by EPA. The fact sheet for the permit notes the EPA policy memo of November 22, 2002 which recommends BMPs as the effluent limits for most municipal stormwater permits when complying with TMDLs and the WLAs assigned to MS4 permittees. The policy memo stated that when using BMPs as the effluent limits, the fact sheet needs to demonstrate that the BMPs are expected to be sufficient to comply with the WLAs. However, given the uncertainties in the performance of many of the BMPs commonly used for stormwater pollution control, it is often difficult to make such a demonstration. As such, for WLAs such as those applicable to the Bay Area MS4s, Region 9 encourages the use of numeric limits because these will provide greater assurance of consistency with the WLAs and will enhance the enforceability of the permit with regards to the WLAs.

a. Mercury TMDL

It is our position that the permit should include the numeric 10-year and 20-year WLAs for mercury for the MS4s even though the compliance deadlines for these WLAs extend beyond the anticipated term of the permit. In a letter from Region 9 to the State Board and the Regional Board dated October 31, 2007, Region 9 included a guidance memo from EPA Headquarters dated May 10, 2007 which stated that to ensure enforceability of a compliance schedule, a permit must include the full schedule, even if it extends beyond the term of the permit. This will ensure the requirements of the schedule can be enforced even in the event the permit is not reissued in a timely manner.

We note the mercury TMDL was adopted by the Regional Board on August 9, 2006; as such, the permit should include a requirement to meet the 10-year and 20-year WLAs 10 and 20 years, respectively, following the adoption date.

The inclusion of the numeric WLAs would also provide greater assurance of consistency with the WLAs for urban runoff, and enhance the enforceability of the requirements, as noted in our general comments above.

b. Pesticides Toxicity Control

The basin plan amendment adopted by the Regional Board in 2005 includes numeric WLAs for the permittees for diazinon and toxicity. The basin plan amendment indicates the BMPs included in the permit will initially be considered sufficient to comply with the WLAs. However, the amendment also indicates that if the BMPs prove to be insufficient, the Board may require additional control measures. To cover this possibility, we recommend the permit include a reopener clause which would provide that if the initial BMPs prove insufficient to comply with the numeric WLAs, the permit may be reopened to include additional controls as necessary to ensure consistency with the WLAs. It is our position that the permit should include the numeric WLAs themselves, as this would provide greater assurance of consistency with the TMDL and would enhance the enforceability of the permit with regards to the WLAs.

We appreciate the opportunity to provide our views on the new draft permit. If you would like to discuss these comments, please contact John Tinger of the NDPES Permits Office at (415) 972-3518, or Eugene Bromley of the NPDES Permits Office at (415) 972-3510.

Sincerely,

Douglas E. Eberhardt
Chief, NPDES Permits Office

State of West Virginia
Department of Environmental Protection
Division of Water and Waste Management
601 57th Street, SE
Charleston, WV 25304-2345

General
National Pollution Discharge Elimination System
Water Pollution Control Permit

Permit No.: WV0116025

Issue Date: June 22, 2009

Subject: Stormwater Discharges From small Municipal Separate Storm Sewer Systems

Effective Date: July 22, 2009

Expiration Date: July 22, 2014

Supersedes: WV/NPDES General Water Pollution Control Permit No. WV0116025, issued March 7, 2003

To Whom It May Concern:

This is to certify that operators of small municipal separate storm sewer systems (MS4s) located in the State of West Virginia who have satisfied the registration requirements and agreeing to be regulated under the terms and conditions of this general permit are hereby granted coverage under the General WV/NPDES Water Pollution Control Permit to discharge stormwater into waters of the State.

All operators of regulated small municipal separate storm sewer systems are required to apply for and obtain coverage in accordance with this permit, unless waived in accordance with CFR § 122.32(a).

This permit is subject to the following terms and conditions:

The information submitted on and with the site registration application form, once approved, will hereby be known as the stormwater management program (SWMP). The information submitted on and with the site registration application, also known as the SWMP, once approved, will hereby be made terms and conditions of the permit with like effect as if all such information were set forth herein, and other conditions set forth in Parts I, II, III, IV, Appendices A through D and the SWMP approval letter.

The validity of this permit is contingent upon the payment of the applicable annual permit fee, as required by Chapter 22, Article 11, Section 10 of the Code of West Virginia.

Part I

Coverage under this General Permit

A. Permit Area

1. This permit covers all areas of the State of West Virginia.

B. Eligibility

1. Jurisdictions including, but not limited to; municipalities, counties, transportation facilities, Federal and State owned prison systems, and universities that are located within the boundaries of a Bureau of the Census defined "Urbanized Area" (UA) based on the latest decennial census.

2. Municipalities that are designated by the Division of Water and Waste Management (DWWM) under 40 CFR 122.32(a)(2). Designation criteria are included in Appendix D of this general permit.

C. This permit authorizes the following non-stormwater discharges provided they have been determined not to be substantial contributors of pollutants to a particular small MS4 applying for coverage under this permit. However, the DWWM recommends that your stormwater management program include public education and outreach activities directed at reducing these discharges even if they are not substantial contributors of pollutants to your system.

1. Uncontaminated water line flushing
2. Landscape irrigation,
3. Diverted stream flows,
4. Uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20)),
5. Uncontaminated pumped groundwater,
6. Discharges from potable water sources,
7. Foundation drains,
8. Air conditioning condensate,
9. Irrigation water,
10. Springs,
11. Water from crawl space pumps,
12. Footing drains,
13. Lawn watering runoff,
14. Water from individual residential car washing,
15. Flows from riparian habitats and wetlands,
16. Residual street wash water,
17. Discharges or flows from fire fighting activities, and
18. A discharge authorized by a separate National Pollutant Discharge Elimination System (NPDES) permit.

D. This permit does not relieve entities that cause illicit discharges, including spills, of oil or hazardous substances, from responsibilities and liabilities under State and Federal law and regulations pertaining to those discharges.

E. This permit does not authorize a violation of West Virginia State Water Quality Standards (Title 47 CSR Series 2) and West Virginia Ground Water Quality Standards (Title 47 CSR Series 58).

F. Continuation of this general permit

If this general permit is not reissued or replaced prior to the expiration date, it will be administratively continued in accordance with 47 CSR 10 and remain in force and effect. If you were authorized to discharge under this general permit prior to the expiration date, any discharges authorized under this permit will automatically remain covered by this general permit until the earliest of:

- Your authorization for coverage under a reissued general permit or a replacement of this general permit following your timely and appropriate submittal of a complete application requesting authorization to discharge under the new general permit and compliance with the requirements of the new permit; or

- Your submittal of notification that the facility has ceased operations; or issuance or denial of an individual permit for the facility's discharge; or

- A formal permit decision by DWWM not to reissue this general permit, at which time DWWM will identify a reasonable time period of covered dischargers to seek coverage under an alternative general permit or individual permit. Coverage under this permit will cease at the end of this time period.

Part II

Notice of Intent (NOI) and Stormwater Management Program (SWMP) Applications

A. Applications

Within thirty (30) days of the effective date of this permit, all operators of small MS4s shall submit a Notice of Intent (NOI) on the form provided in Appendix A of this permit.

Within six months of the effective date of this permit, all operators of regulated small MS4s shall submit on a site registration application their stormwater management program (SWMP) to the DWWM. A SWMP can be submitted on the site registration application form provided by DWWM, or in a prescribed manner acceptable to the DWWM that contains all necessary components.

NOIs and SWMPs shall be submitted to:

WVDEP - Division of Water and Waste Management
MS4 / NPDES Stormwater Permitting
601 57th Street, SE
Charleston, WV 25304

B. Requirements of SWMP

1. The permittee must develop a stormwater management program designed to reduce the discharge of pollutants from its small municipal separate storm sewer system to the maximum extent practicable (MEP), to protect water quality, and satisfy the appropriate requirements of the Clean Water Act.

2. The permittee shall, to the maximum extent practicable, use known, available, and

reasonable methods of prevention, control and treatment to prevent and control stormwater pollution from entering waters of the State.

3. In order to meet public notice requirements of NPDES permits, the permittee shall make available to the public, in accordance with Code of State Regulations; Title 47, Series 10, Section 12, the opportunity to comment on MS4 stormwater management programs.

4. The SWMP must include the minimum control measures described in Section C of this part along with measurable goals and milestones appropriate for each measure and justifications for each milestone. Information about developing measureable goals can be found on the USEPAs website: http://cfpub.epa.gov/npdes/stormwater/measurablegoals/part3.cfm

5. Subject to the five-year limitation noted below in this paragraph, extension of milestones will be granted for good cause shown. Failure to implement effective best management practices (BMPs) is not good cause to extend milestones.

6. The SWMP must also provide details on how the permittee will implement and enforce the program. The terms and conditions of this permit and the permittees approved SWMP must be fully implemented, except where noted, within five years of the effective date of this permit.

7. The SWMP shall include an ongoing program for gathering, tracking, maintaining, and using information to evaluate the stormwater management program development, implementation and permit compliance.

8. If the permittees small MS4 discharges into waters listed on the Clean Water Act Section 303(d) list of impaired waters or waters with an approved Total Maximum Daily Load (TMDL), the SWMP must document how the proposed BMP's will control the discharge of the pollutants of concern, as described in Part III.D. Permittees discharging to waters with an approved TMDL shall meet the applicable wasteload allocations of that TMDL.

9. An annual report prescribed in Part IV.D of this permit shall be submitted to DWWM each year on the anniversary of the SWMP approval.

10. In instances where this permit specifies that the MS4 regulate public projects and facilities, the MS4 is expected to only regulate those entities where they have jurisdiction and/or authority. It is understood that there are some public entities that are not subject to the authority of the MS4.

C. Stormwater Management Program for small MS4s

a. Requirements

1. Permittees implementing BMPs specific to their current SWMP shall continue to do so until such time as their SWMP with new and updated BMPs is approved. However, permittees should begin implementation of the terms and conditions of this permit as soon as this permit becomes effective, as full implementation is required within five years.

2. a. Coordination among entities covered under the small MS4 general permit may be necessary to comply with certain conditions of the SWMP. The SWMP shall

include, when applicable, coordination mechanisms among entities covered under the small MS4 general permit to encourage coordinated stormwater related policies, programs and projects within adjoining or shared areas. Entities covered under the small MS4 permit include, but are not limited to, municipalities, transportation agencies, universities, colleges, hospitals, prisons, and military bases.

b. Coordination mechanisms shall specify roles and responsibilities for the control of stormwater and its associated pollutants between physically interconnected MS4s covered by the small MS4 general permit.

c. Coordination mechanisms shall coordinate stormwater management activities for shared water bodies among permittees with the goal of avoiding conflicting plans, policies and regulations.

b. Minimum Control Measures

The SWMP shall include all components described in Part II, Sections B and C. In accordance with 40 CFR 122.35(a), a small MS4 may rely on another entity to implement one or more of the components in this section. If the permittee is relying on another entity to implement any component of the SWMP, that entity must be fully disclosed in the SWMP.

1. **Public Education and Outreach**

The SWMP shall include an education program aimed at residents, businesses, industries, elected officials, policy makers, planning staff and other employees of the permittee. The goal of the education program is to reduce or eliminate behaviors and practices that cause or contribute to adverse stormwater impacts. An education program may be developed locally or regionally.

The minimum performance measures are:

a. The permittee shall continue to implement their education and outreach program for the area served by the MS4 that was established during the previous permit cycle. The outreach program shall be designed to achieve measurable improvements in the target audience's understanding of stormwater pollution and steps they can take to reduce their impacts. Newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.1. within six months of the approval of their SWMP.

Education and outreach efforts shall target the following audiences and subject areas:

i. General public

- General impacts of stormwater flows into surface waters.
- Impacts from impervious surfaces.
- Source control BMPs and environmental stewardship actions and opportunities in the areas of pet waste, vehicle maintenance, landscaping, and rain water reuse.

ii. General public, businesses, including home-based and mobile businesses

- BMPs for use and storage of automotive chemicals, hazardous cleaning supplies, carwash soaps and other hazardous materials.
- Impacts of illicit discharges and how to report them.

iii. Homeowners, landscapers and property managers

- Yard care techniques that protect water quality.
- BMPs for use and storage of pesticides and fertilizers.
- BMPs for carpet cleaning and auto repair and maintenance.
- Runoff reduction techniques, including site design, pervious paving, retention of forests and mature trees.
- Stormwater pond maintenance.

iv. Engineers, contractors, developers, review staff and land use planners

- Technical standards for construction site sediment and erosion control.
- Runoff reduction techniques, including site design, pervious pavement, alternative parking lot design, retention of forests and mature trees.
- Stormwater treatment and flow control BMPs.
- Impacts of increased stormwater flows into receiving water bodies.

b. Each permittee shall measure the understanding and adoption of the targeted behaviors among the targeted audiences. The resulting measurements shall be used to direct education and outreach resources most effectively, as well as to evaluate changes in adoption of the targeted behaviors.

c. Each permittee shall track and maintain records of public education and outreach activities.

2. **<u>Public Involvement and Participation</u>**

The SWMP shall include ongoing opportunities for public involvement through advisory councils, watershed associations and/or committees, participation in developing rate structures, stewardship programs, environmental activities or other similar activities. The permittee shall facilitate opportunities for direct action, educational, and volunteer programs such as riparian planting, volunteer monitoring programs, storm drain marking or stream cleanup programs. Each permittee shall comply with any applicable State and local public notice requirements when developing their SWMP.

The minimum performance measures are:

a. No later than six months from the effective date of this permit, all permittees shall create opportunities for the public to participate in the decision making processes involving the development, implementation and update of the permittees SWMP. Each permittee shall develop and implement a process for consideration of public comments on their SWMP.

b. No later than six months from the effective date of this permit, all permittees shall establish a method of routine communication to groups such as watershed associations and environmental organizations that are located in the same watershed/s as the permittee, or organizations that conduct environmental stewardship projects located in the same watershed/s or in close proximity to the permittee. This is to make these groups aware of opportunities for their direct involvement and assistance in stormwater activities that are in their watershed.

c. Each permittee shall make their SWMP and their annual report required under this permit available to the public when requested. The current SWMP and the latest annual report shall be posted on the permittees website. To comply with the posting requirement, a permittee that does not maintain a website may submit the updated SWMP and annual report in electronic format to the DWWM for electronic distribution when it is requested.

3. **Illicit Discharge Detection and Elimination**

The SWMP shall include an ongoing program to detect and remove illicit connections, discharges as defined in 40 CFR 122.26(b)(2), and improper disposal, including any spills not under the purview of another responding authority, into the municipal separate storm sewers owned or operated by the permittee. Newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.3 of this permit within one year of the approval of their SWMP.

The minimum performance measures are:

a. The Permittees existing municipal storm sewer system map/s that were created during the first permit cycle shall be updated on an annual basis and shall include the following information:

i. The location of all known storm sewer outfalls, receiving waters and structural stormwater BMPs owned, operated or maintained by the permittee. The location and type of all other stormwater conveyances located within the boundaries of the permittees MS4 watershed. The permittee may opt to include land use on the map also. In the process of updating the map, when stormwater outfalls become known, they are to be added to the permittees map.

ii. An update of known connections to the municipal separate storm sewer authorized or allowed by the permittee after the effective date of this permit.

iii. Geographic areas that discharge stormwater into the permittees MS4, which may not be located within the municipal boundary.

iv. Each permittee shall maintain their storm sewer system map at their local office, and make it available upon request. Any paper maps submitted to DWWM shall be a scale of 1” = 500 ft. and on pages sized 24”x36” or 22”x36” and folded to 8 x 11 inches.

b. Each permittee shall implement a program or system to review and update their Illicit Discharge Detection and Elimination (IDDE) Ordinance or other regulatory mechanism to effectively prohibit and eliminate non-stormwater, illegal discharges, and/or dumping into the permittees municipal separate storm sewer system to the regulatory extent allowable under State and Local law. The ordinance or other regulatory mechanism shall be reviewed on an annual basis and updated when necessary. The IDDE program shall be adequately funded to fulfill the general permit requirements.

i. The regulatory mechanism does not need to prohibit the following categories of non-stormwater discharges, *unless* they are identified to be significant sources of pollutants to waters of the State:

- Diverted stream flows,
- Rising ground waters,
- Uncontaminated ground water infiltration (as defined at 40 CFR 35.2005(20)),
- Uncontaminated pumped groundwater,

- Foundation drains,
- Air conditioning condensation,
- Irrigation water from agricultural sources
- Springs,
- Water from crawl space sump pumps,
- Footing drains,
- Flows from riparian habitats and wetlands,
- Non-stormwater discharges covered by another NPDES permit,
- Discharges or flows from fire fighting activities

ii. The regulatory mechanism shall prohibit the following categories of non-stormwater discharges *unless* the stated conditions are met:

- Discharges from potable or non-potable water sources, including but not limited to; hyperchlorinated water line flushing, pipeline hydrostatic test water and other water discharges with a potential to violate water quality standards. For planned discharges to the MS4, the discharge shall be dechlorinated to a concentration of 0.1ppm or less, pH adjusted, if necessary, and volumetrically and velocity controlled to prevent resuspension of sediments in the MS4.

- Discharges from lawn watering and other irrigation runoff. These shall be minimized through; at a minimum, public education activities described in Part II, Section C.1. of this permit.

- Street, parking lot and sidewalk wash water, water used to control dust, and routine external building wash down, that does not use detergents. The permittee shall reduce these discharges through; at a minimum, public education activities described in Part II, Section C.1. of this permit. To avoid washing pollutants into the MS4, permittees must minimize the amount of street wash and dust control water used. At active construction sites, street sweeping must be performed prior to washing the street.

iii. The permittees SWMP shall, at a minimum, address each category in ii above in accordance with the conditions stated therein.

iv. The SWMP shall further address any category of discharges in i or ii above if the discharges are identified as significant sources of pollutants to waters of the State.

v. The ordinance or other regulatory mechanism shall include escalating enforcement procedures and actions.

vi. The permittee shall develop an enforcement strategy and implement the enforcement provisions of the ordinance or other regulatory mechanism.

c. Each permittee shall continue to assess, update and implement their ongoing program to detect and address non-stormwater discharges, spills, illicit connections and illegal dumping into the permittees MS4. New permittees shall develop the aforementioned program. This program shall include:

i. Procedures for locating priority areas likely to have illicit discharges, including at a minimum, evaluating land uses associated with business/industrial activities present; areas where complaints have been registered in the past; and areas with storage of large quantities of materials that could result in spills.

ii. Field assessment activities, including visual inspection of priority outfalls identified in i, above, during dry weather and for the purposes of verifying outfall locations, identifying previously unknown outfalls, and detecting illicit discharges.

- Receiving waters shall be prioritized for visual inspection no later than three years from the effective date of this permit, including a field assessment of at least two water bodies. At a minimum, one field assessment shall be made each year thereafter.

- Screening for illicit connections shall be conducted consistent with: Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments, Center for Watershed Protection, October 2004, or another methodology of comparable effectiveness.

iii. Procedures for characterizing the nature of, and potential public or environmental threat posed by, any illicit discharges found by or reported to the Permittee. Procedures shall include detailed instructions for evaluating whether the discharge must be immediately contained and steps to contain the discharge.

Compliance with this provision shall be achieved by investigating within fifteen (15) days, any complaints, reports or monitoring information that indicates a potential illicit discharge, spill, or illegal dumping, and immediately investigating problems and violations determined to be emergencies or otherwise judged to be urgent or severe. In some instances, when imminent water quality impairments are deemed severe or urgent, the incident should be referred to WVDEP.

iv. Procedures for tracing the source of an illicit discharge; including visual inspections, and when necessary, opening manholes, using mobile cameras, collecting and analyzing water samples, and/or other detailed inspection procedures.

v. Procedures for removing the source of the discharge; including notification of appropriate authorities; notification of the property owner; follow up inspections, and if necessary; escalating enforcement and legal actions if the discharge is not eliminated.

Compliance with this provision shall be achieved by initiating an investigation within fifteen (15) days of a report or discovery of a suspected illicit connection to determine the source of the connection, the nature and volume of discharge through the connection, and the party responsible for the connection. The permittee shall establish a system to prioritize responding to and verifying elimination of illicit connections. The permittee shall assign a higher priority on illicit connections that pose an imminent threat to water quality.

d. Permittees shall inform public employees, businesses, and the general public of hazards associated with illegal discharges and improper disposal of waste.

i. Distribute appropriate information to target audiences pursuant to Part II, Section C.1. of this permit.

ii. Publicly list and publicize a hotline or other local telephone number for public reporting of spills and other illicit discharges. Keep a record of calls received and follow-up actions taken in accordance with Part II, Section C.3. of this permit; include a summary in the annual report.

e. Permittees shall adopt and implement procedures for program evaluation and assessment, including tracking the number and type of spills or illicit discharges identified, inspections made; and any feedback received from public education efforts. A summary of this information shall be included in the Permittees annual report.

f. Each permittee shall provide appropriate training for municipal staff on the identification and reporting of illicit discharges into MS4s.

i. Permittees shall ensure that all municipal field staff who are responsible for identification, investigation, termination, cleanup, and reporting illicit discharges, including spills, improper disposal and illicit connections are trained to conduct these activities. Follow up training shall be provided on an annual basis to address changes in procedures, techniques or requirements. Permittees shall document and maintain records of the training provided and the staff trained.

ii. Permittees shall develop and implement an ongoing training program for all municipal staff, which, as part of their normal job responsibilities, might come into contact with or otherwise observe an illicit discharge or illicit connection to the storm sewer system. Employees shall be trained on the identification of an illicit discharge/connection, and on the proper procedures for reporting and responding to the illicit discharge/connection. Follow up training shall be provided on an annual basis to strengthen knowledge of illicit discharges/connections and to address changes in procedures, techniques or requirements. Permittees shall document and maintain records of the training provided and the staff trained.

4. Controlling Runoff from Construction Sites

The SWMP shall include an ongoing program to assess, implement, and enforce the existing program to reduce pollutants in stormwater runoff to your small MS4 from construction site activities that result in a land disturbance of one acre or greater. Reduction of stormwater discharges from construction activity disturbing less than one acre must be included in your program if that construction activity is part of a larger common plan of development or sale that will disturb one acre or more. Permittee may opt to include in this program construction sites that are less than one acre. Newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.4 of this permit within one year of the approval of their SWMP.

The minimum performance measures are:

a. Permittees shall implement a program or system to review and update their ordinance or other regulatory mechanism that addresses stormwater runoff from construction sites one acre or greater. Newly permitted MS4s that do not yet have an ordinance in place shall begin development an ordinance or other regulatory mechanism within twelve months of the effective date of this permit. The ordinance or other enforceable mechanism shall include, at a minimum:

i. Implementation of erosion and sediment control BMPs at regulated construction sites. Sediment and erosion control BMPs shall be consistent with the BMPs contained in West Virginia's Erosion and Sediment Control Best Management Practices Manual and/or other State manuals, as appropriate, listed in Appendix E.

ii. Requirements for construction site operators to implement appropriate erosion and sediment control BMPs. More stringent requirements may be used, and certain requirements may be tailored to local circumstances through the use of basin or watershed plans or other similar water quality and quantity planning efforts. Such local requirements shall provide equal protection of receiving waters and equal levels of pollutant control to those provided by DWWM WV/NPDES stormwater permits.

iii. Requirements for construction site operators to control waste such as discarded building materials, concrete truck washout, chemicals, litter, and sanitary waste at the construction site that may cause adverse impacts to water quality.

iv. Requirements for demonstration that registration under the WV/NPDES construction stormwater general permit has been obtained for those sites one acre and greater. Provided that the DWWM has not approved the permittee as a 'Qualifying Local Program' in which coverage under WV/NPDES construction stormwater permit will be issued by the permittee and not by the DWWM.

v. Establishment of authority for site plan review, which incorporate consideration of potential water quality impacts and review of individual pre-construction site plans to ensure consistency with local and State sediment and erosion control requirements.

vi. Establishment of authority for receipt and consideration of comments and information submitted by the public.

vii. Establishment of authority for site inspections and enforcement of control measures including steps to identify priority sites for inspection and enforcement based on the nature of the construction activity, topography, and the characteristics of soils and receiving water quality.

viii. Adequate funding for site inspections and enforcement of control measures.

ix. Measures to provide educational and training measures for construction site operators, including requiring a stormwater pollution prevention plan for construction sites within your jurisdiction.

b. The program shall include a permitting and/or approval process with plan review, inspection and enforcement capability, for both private sector and public sector construction sites. At a minimum, the construction site runoff program shall be applied to all sites that disturb a land area of one acre or greater, including projects less than one acre that are part of a larger common plan of development. For newly permitted MS4s the permitting and/or approval process shall be in place no later than two years from the approval date of their SWMP. In addition to an Ordinance described in Part II, Section C.4.a, the following elements shall be incorporated into this program:

i. Procedures to incorporate plan review of new and redevelopment projects with the planning and approval process of these same projects with other municipal departments within the permittees MS4.

ii. Procedures for routine inspections of permitted construction sites during construction to verify proper installation and maintenance of required erosion and sediment controls. Enforcement shall be conducted as necessary based on the inspection.

iii. Development of an enforcement strategy to respond to issues of non-compliance.

iv. Procedures for providing educational and training measures for construction site operators and the permittees inspectors.

v. Development of an application process whereby the construction site operator will describe the sediment and erosion control measures to be taken on the site. This application process can include submittal of the stormwater pollution prevention plan that was used to obtain registration under DWWM WV/NPDES construction stormwater permit. The application shall include a listing of all water bodies into which the construction site will discharge and whether or not they are on the 303(d) list for impaired waters.

vi. Development of procedures for keeping records of all regulated construction activities within your MS4, inspection reports, warning letters, and any other enforcement documentation. A summary of inspection and enforcement activities that are conducted shall be included in the annual report.

5. **Controlling Runoff from New Development and Redevelopment**

The SWMP shall include an ongoing program to develop, assess, implement, and enforce their program to reduce pollutants in stormwater runoff to your small MS4 from new development and redevelopment activities. This program shall be applied to all sites that disturb a land area one acre or greater, including projects less than one acre that are part of a larger common plan of development or sale. The program shall apply to private sector and public sector development, including roads. The program must ensure that controls are in place that will increase groundwater recharge of stormwater runoff where and when possible, and would protect water quality and reduce the discharge of pollutants. Except where otherwise stated, newly permitted MS4s shall *begin* implementation of the requirements contained in Part II.C.5 of this permit within two years after the approval date of their SWMP.

The program shall include the following measures:

a. Long-term Stormwater Controls

The permittee shall protect the physical, chemical and biological integrity of receiving waters, and their designated uses, from the impacts of stormwater discharges through the implementation of watershed protection elements and site and neighborhood design elements. The purpose of *watershed protection* elements is to manage the impacts of stormwater on receiving waters that occur because of regional or watershed-scale management decisions. The primary purpose of *site and neighborhood design* elements is to manage the impacts of stormwater on receiving waters that occur because of site and neighborhood design management decisions. The technical principles of these management practices have many complementary similarities, and must be implemented in tandem.

All elements and standards are required, and must be described in the stormwater management program plan.

i. Watershed Protection

The permittee shall incorporate watershed protection elements into the subdivision ordinance or equivalent document. In addition, the permittee shall incorporate watershed protection elements into all relevant policy and/or planning documents as they come up for regular review. If a relevant planning document is not scheduled for review during the term of this permit, the permittee must identify the elements that cannot be implemented until that document is revised, and provide the DWWM a schedule for incorporation and implementation that cannot exceed seven years from the effective date of this permit. Planning documents include, but are not limited to; comprehensive or master plans, subdivision ordinances, general land use plan, zoning code, transportation master plan, specific area plans, such as sector plan, site area plans, corridor plans, or unified development ordinances.

A. *Watershed protection elements.* As relevant, policy and/or planning documents must include the following, except where noted:

(1) Minimize the amount of impervious surfaces (roads, parking lots, roofs, etc.) within each watershed, by minimizing the creation, extension and widening of parking lots, roads and associated development.

(2) Preserve, protect, create and restore ecologically sensitive areas that provide water quality benefits and serve critical watershed functions. These areas may include, but are not limited to; riparian corridors, headwaters, floodplains and wetlands.

(3) Implement stormwater management practices that prevent or reduce thermal impacts to streams, including requiring vegetated buffers along waterways, and disconnecting discharges to surface waters from impervious surfaces such as parking lots.

(4) Seek to avoid or prevent hydromodification of streams and other water bodies caused by development, including roads, highways, and bridges.

(5) Implement standards to protect trees, and other vegetation with important evapotranspirative qualities.

(6) Implement policies to protect native soils, prevent topsoil stripping, and prevent compaction of soils.

B. *Measurable Goals.* For each of the six watershed elements in i.A, the permittee shall develop quantifiable objectives that include a time frame for achieving them. Short-term objectives (less than five years) and long-term objectives (greater than five years) are appropriate for many of these elements.

C. *Reporting.* Annual reports must include status of implementation of these elements with respect to incorporation into relevant documents and implementation via relevant policies. Reports should include proposed time frames, changes and measurable goals.

ii. Site and Neighborhood Design

The permittee shall develop a program to protect water resources by requiring all new and redevelopment projects to control stormwater discharge rates, volumes, velocities, durations and temperatures. These standards shall apply at a minimum to all new development and redevelopment disturbing one acre or greater, including projects less than one acre that are part of a larger common plan of development or sale. The permittee shall *begin* implementation of the requirements contained in Part II.C.5.a.ii [other than Part II.C.5.a.ii.A(3) and Part II.C.5.a.ii.A.(4)] within four years after the approval of the SWMP.

A. *Performance Standards.* The permittee must implement and enforce via ordinance and/or other enforceable mechanism(s) the following requirements for new and redevelopment:

1. Site design standards for all new and redevelopment that require, in combination or alone, management measures that keep and manage on site the first one inch of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation. Runoff volume reduction can be achieved by canopy interception, soil amendments, evaporation, rainfall harvesting, engineered infiltration, extended filtration and/or evapotranspiration and any combination of the aforementioned practices. This first one inch of rainfall must be 100% managed with no discharge to surface waters, except when the permittee chooses to implement the conditions in paragraph 4 below. This can be achieved through on site utilization of practices to include dry swales, bioretention, rain tanks and cisterns, soil amendments, roof top disconnections, permeable pavement, porous concrete, permeable pavers, reforestation, grass channels, green roofs and other practices that alone or combined will capture the first one inch of rainfall runoff volume. Extended filtration practices that are designed to capture and retain up to one inch of rainfall may discharge volume in excess of the first inch through an under drain system. An Underground Injection Control permit may be required when certain conditions are met.

2. The following additional water quality requirements, as applicable:

   i. A project that is a potential hot spot with reasonable potential for pollutant loading(s) must provide water quality treatment for associated pollutants (e.g., petroleum hydrocarbons at a vehicle fueling facility) before infiltration.

   ii. A project that is a potential hot spot with reasonable potential for pollutant loading(s) that cannot implement adequate preventive or water quality treatment measures to ensure compliance with groundwater and/or surface water quality standards, must properly convey stormwater to a NPDES-permitted wastewater treatment facility or via a licensed waste hauler to a permitted treatment and disposal facility.

iii. A project that discharges or proposes to discharge to any surface water or ground water that is used as a source of drinking water must comply with all applicable requirements relating to source water protection.

3. When considered at the watershed scale, certain types of development can either reduce existing impervious surfaces, or at least create less ‘accessory’ impervious surfaces. Incentive standards may be applied to these types of projects. A reduction of 0.2 inches from the one inch runoff reduction standard may be applied to any of the following types of development. Reductions are additive up to a maximum reduction of 0.75 inches for a project that meets four or more criteria. The permittee may choose to be more restrictive and allow a reduction of less than 0.75 inches if they choose. In no case will the reduction be greater than 0.75 inches.

    a) Redevelopment
    b) Brownfield redevelopment
    c) High density (>7 units per acre)
    d) Vertical Density, (Floor to Area Ratio (FAR) of 2 or >18 units per acre)
    e) Mixed use and Transit Oriented Development (within ½ mile of transit)

4. For projects that cannot meet 100% of the runoff reduction requirement on site, two alternatives are available: off-site mitigation and payment in lieu. If these alternatives are chosen, then the permittee must develop and fairly apply criteria for determining the circumstances under which these alternatives will be available. A determination that standards cannot be met on site may not be based solely on the difficulty or cost of implementing measures, but must include multiple criteria that would rule out an adequate combination of the practices set forth in section 1, above, such as: too small a lot outside of the building footprint to create the necessary infiltrative capacity even with amended soils; soil instability as documented by a thorough geotechnical analysis; a site use that is inconsistent with capture and reuse of stormwater; too much shade or other physical conditions that preclude adequate use of plants. In instances where alternatives to complete on site management of the first inch of rainfall are chosen, technical justification as to the infeasibility of on site management is required to be documented.

   These alternatives are available, in combination or alone, for up to 0.6 inches of the original obligation at a 1:1.5 ratio, i.e., mitigation or payment in lieu must be for 1.5 times the amount of stormwater not managed on site. If, as demonstrated to the permittee, it is technically infeasible to manage on site a portion of all of the remaining 0.4 inches, off site mitigation or payment in lieu will be applied at a 1:2 ratio for that portion. For any of these options to be available, the permittee must create an inventory of appropriate mitigation projects, and develop appropriate institutional standards and management systems to value, evaluate and track transactions.

i. *Off-site mitigation.* Runoff reduction practices may be implemented at another location in the same sewershed/watershed as the original project, approved by the permittee. The permittee shall identify priority areas within the sewershed/watershed in which mitigation projects can be completed. Mitigation must be for retrofit or redevelopment projects, and cannot be applied to new development. The permittee shall determine who will be responsible for long term maintenance on mitigation projects.

ii. *Payment in lieu.* Payment in lieu may be made to the permittee, who will apply the funds to a public stormwater project. MS4s shall maintain a publicly accessible database of approved in lieu projects.

5. When public (local or otherwise) streets or parking lots, that are greater than 5000 square feet but less than one acre, are modified or reconstructed runoff reduction practices shall be included in the design work. These requirements apply only to projects begun after the effective date of this permit.

B. *Plan Review, Approval and Enforcement*. To ensure that all new development and redevelopment projects conform to the standards stipulated in Part II, Section C.5.ii, the permittee shall develop project review, approval and enforcement procedures. The review, approval and enforcement procedures shall apply at a minimum to all new development and redevelopment disturbing greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, and shall include:

(1) Requirements to submit for review and approval a pre-application concept plan that describes how the performance standards will be met. A pre-application meeting attended by a project land owner or developer, the project design engineer, and municipal planning staff to discuss conceptual designs may also meet this requirement.

(2) Development of procedures for the site plan review and approval process(es) that include inter-departmental consultations, as needed, and a required re-approval process when changes to an approved plan are desired.

(3) A requirement for submittal of 'as-built' certifications within 90 days of completion of a project.

(4) A post-construction verification process to ensure that stormwater standards are being met, that includes enforceable procedures for bringing noncompliant projects into compliance.

(5) A description of a program to educate both internal staff and external project proponents of the requirements of Part II, Section C.5 of this permit.

C. *Maintenance Agreements*. The permittee shall require that all development subject to the requirements of Part II, Section C.5.ii. of this permit develop a maintenance agreement and maintenance plan for approved stormwater management practices. The permittee shall require that property owners or operators provide verification of maintenance for the approved stormwater management practices. These agreements shall allow the permittee, or its designee, to conduct inspections of the stormwater management practices and also account for transfer of responsibility in leases and/or deed transfers. The agreement shall also allow the permittee, or its designee, to perform necessary maintenance or corrective actions neglected by the property owner/operator, and bill or recoup costs from the property owner/operator when the owner/operator has not performed the necessary maintenance within thirty (30) days of notification by the permittee or its designee. Verification shall include one or more of the following as applicable:

(1) The owner/developer's signed statement accepting responsibility for maintenance until the maintenance responsibility is legally transferred to another party; and/or

(2) Written conditions in the sales or lease agreement that require the recipient to assume responsibility for maintenance; and/or

(3) Written conditions in project conditions, covenants and restrictions for residential properties assigning maintenance responsibilities to a home owner's association, or other appropriate group, for maintenance of structural and treatment control stormwater management practices; and/or

(4) Any other legally enforceable agreement that assigns permanent responsibility for maintenance of structural or treatment control stormwater management practices.

D. *Inventory and Tracking of Management Practices*. The permittee shall develop a system designed to track stormwater management practices deployed at new development and redevelopment projects. Tracking of stormwater management practices shall begin during the plan review and approval process with a database or geographic information system (GIS). The database or tracking system shall include information on both public and private sector projects that are within the jurisdiction of the permittee. In addition to the standard information collected for all projects (such as project name, owner, location, start/end date, etc.), the tracking system shall also include:

1. Source control stormwater management practices (type, number, design or performance specifications)

2. Treatment control stormwater management practices (type, number, design or performance specifications)

3. Latitude and longitude coordinates of stormwater BMP controls using a global positioning system

4. Digital photographs of stormwater management practice controls

5. Maintenance requirements of stormwater management practices (frequency of required maintenance and inspections)

6. Inspection information (date, findings, follow up activities, compliance status)

E. *Stormwater BMP Inspections*. In order to ensure that all stormwater BMPs are operating correctly and are properly maintained, the permittee shall, at a minimum:

1. Develop an inspection calendar for stormwater BMPs. Inspections should be performed so that all stormwater BMP's are inspected at least once during the permit cycle.

2. Complete inspection reports shall include:

i. Facility type,
ii. Inspection date,
iii. Name and signature of inspector,

iv. GIS location and nearest street address,
v. Management practice ownership information (name, address, phone number, fax, and email),
vi. A description of the stormwater BMP condition including the quality of: vegetation and soils; inlet and outlet channels and structures; embankments, slopes, and safety benches; spillways, weirs, and other control structures; and sediment and debris accumulation in storage and forebay areas as well as in and around inlet and outlet structures,
vii. Photographic documentation of all critical stormwater BMP components, and
viii. Specific maintenance items or violations that need to be corrected by the stormwater BMP owner along with deadlines and reinspection dates.

3. Develop an enforcement and response plan to ensure that stormwater BMPs are properly maintained. This plan shall include procedures to enforce correction orders and include a contingency plan if correction orders are not followed through by the responsible party. The permittee shall promptly notify the stormwater BMP owner or operator of any deficiencies discovered during a maintenance inspection. The permittee shall follow its enforcement response plan to ensure that management practices are maintained. The permittee must conduct a subsequent inspection to ensure completion of all required repairs.

F. *Reporting*. The permittee shall demonstrate compliance with the requirements for post-construction controls by summarizing the following in the Annual Report:

(1) A description of how the permittees legal authority addresses the watershed protection elements in Part II, Section C.5.

(2) A summary of the number and types of projects that the permittee reviewed for new and development considerations.

(3) A summary of the number and types of stormwater BMPs approved in new and redevelopment projects, including the number of approved projects that qualified for each of the incentives described in Part II, Section C.5.a.ii.A.3, and that qualified for each of the alternatives described in Part II, Section C.5.a.ii.A.4.

(4) A summary of the number and types of maintenance agreements approved.

(5) A summary of stormwater BMP maintenance inspections conducted by the permittee, including a summary of the number requiring maintenance or repair, the number brought into compliance and the number of enforcement actions taken.

(6) A summary of any evaluation data collected for long-term stormwater controls, including water quality information, stormwater BMP performance, and model results.

b. Assessments

The permittee shall conduct the following assessment to provide a foundation for program improvements to be implemented during the next permit term.

1. Street/Parking Design Assessment.

Permittee shall submit to DWWM a report assessing current street design guidelines and parking requirements that affect the creation of impervious cover, with the third year annual report. The assessment shall include recommendations and proposed schedules for incorporating policies and standards into relevant documents and procedures to maximize vegetation and to minimize impervious cover attributable to parking and street designs. The local planning commission and the local transportation commission should be involved in the assessment.

6. **<u>Pollution Prevention & Good Housekeeping for Municipal Operations</u>**

Each permittee shall continue to implement their operations and maintenance (O&M) program that includes a training component and has the ultimate goal of preventing or reducing polluted runoff from municipal operations. Newly permitted MS4s shall have one year from the approval date of their SWMP to *begin* implementation of the requirements contained in Part II.C.6 of this permit.

The minimum performance measures are:

a. Develop and implement an operation and maintenance program that incorporates good housekeeping components at all municipal facilities, including but not limited to; municipal waste water treatment facility, potable drinking water facility, municipal fleet operations, maintenance garages, parks and recreation, street and infrastructure maintenance, and grounds maintenance operations.

i. Each permittee shall develop and establish maintenance standards at all municipal facilities that will help protect the physical, chemical and biological integrity of receiving waters.

ii. Each permittee shall establish an inspection schedule in which to perform inspections to determine if maintenance standards are being met. Inspections shall be performed no less than once per calendar year.

iii. Each permittee shall develop procedures for record keeping and tracking inspections and maintenance at all municipal facilities.

b. Establish and implement policies and procedures to reduce the discharge of pollutants in stormwater runoff from all lands owned or maintained by the permittee and subject to this permit, including but not limited to: parks, open space, road right-of-way, maintenance yards, water/sewer infrastructure and stormwater treatment and flow practices. These policies and procedures shall address, but are not limited to:

i. Application of fertilizer, pesticides, and herbicides including the development of nutrient management and integrated pest management plans.

ii. Sediment and erosion control.

iii. Landscape maintenance and vegetation disposal.

iv. Trash management.

v. Building exterior cleaning and maintenance.

vi. Chemical and material storage.

vii. Street sweeping and inlet/catch basin cleaning.

c. Using training materials that are available from WVDEP, USEPA or other organizations, develop and implement an on-going training program for employees of the permittee whose construction, operations or maintenance job functions may impact stormwater quality. The training program shall include, but is not limited to, employees who work in the following areas:

- Street/sewer and right-of-way construction and maintenance,
- Water and sewer departments,
- Parks and recreation department,
- Municipal water treatment and waste water treatment,
- Fleet maintenance,
- Fire departments,
- Building maintenance and janitorial,
- Garage and mechanic crew,
- Contractors and subcontractors who may be contracted to work in the above described areas,
- Personnel responsible for answering questions about the permittees stormwater program, this includes persons who may take phone calls about the program,
- Any other department of the permittee that may impact stormwater runoff

i. The training program shall address the importance of protecting water quality, the requirements of this permit, operation and maintenance standards, inspection procedures, selecting appropriate BMPs, ways to perform their job activities to prevent or minimize impacts to water quality, and procedures for reporting water quality concerns, including potential illicit discharges. Follow-up and refresher training shall be provided at a minimum of once every twelve months, and shall include any changes in procedures, techniques or requirements. Permittees shall document and maintain records of training provided.

d. **Industrial Stormwater coverage for Municipal Operations**

Each permittee that owns or operates a publicly owned treatment works, including sanitary boards, maintenance garages and/or any other industrial activity must obtain coverage for their stormwater discharges, unless coverage is already granted under DWWM WV/NPDES General Permit for Storm Water Discharges associated with Industrial activity, or an individual WV/NPDES permit.

The following monitoring requirements apply:

Pollutants of Concern	Cut-off Concentration	Measurement Frequency
BOD-5	30 mg/l	Once/Six months
COD	120 mg/l	Once/Six months
TSS	100 mg/l	Once/Six months
Ammonia Nitrogen	4 mg/l	Once/Six months
Oil & Grease	15 mg/l	Once/Six months
pH	6.0 – 9.00 s.u.	Once/Six months

Permittees that receive discharges into their small MS4 from their sewage treatment works must, in addition to the above listed monitoring requirements, also meet the following monitoring requirements for those discharges:

Pollutants of Concern	Cut-off Concentration	Measurement Frequency
Fecal Coliform, General	400 counts/100 ml	Once/Six months

Samples shall be collected once every six months, during the spring and fall seasons. Monitoring results shall be submitted to the DWWM with the annual report.

Stormwater samples shall be collected during the "first flush" of rainfall runoff, at least twenty minutes, but not more than fifty minutes after rainfall of at least 0.5 inches has begun, preceded by a period of dry weather of at least 48 hours.

Part III. Special Conditions

A. **Sharing Responsibility**

If you are relying on another MS4 regulated under the stormwater regulations to satisfy one or more of your permit obligations, you must note that fact in your stormwater management program. This other entity must, in fact, implement the control measure(s); the measure of component thereof, must be at least as stringent as the corresponding WV/NPDES permit requirement; and the other entity must agree to implement the control measure on your behalf. This agreement between the two or more parties must be documented in writing in the stormwater management plan and be retained by the permittee for the duration of this permit, including any automatic extensions of the permit term.

B. Discharge Compliance with Water Quality Standards

This general permit requires, at a minimum, that permittees develop, implement and enforce a stormwater management program designed to reduce the discharge of pollutants to the maximum extent practicable, to protect water quality, and satisfy the appropriate requirements of the Clean Water Act. If stormwater discharges have a reasonable potential to cause or contribute to violations of water quality standards in the receiving water, additional controls are required. Full implementation of selected BMPs, using known, available, and reasonable methods of prevention, control and treatment to prevent and control stormwater pollution from entering waters of the State of West Virginia is considered an acceptable effort to reduce pollutants from the municipal storm drain system to the maximum extent practicable.

C. Requiring an Individual Permit

The DWWM may require any person authorized by this permit to apply for and/or obtain an individual WV/NPDES permit. Where the DWWM requires application for an individual WV/NPDES permit, the DWWM will notify the permittee in writing that a permit application is required. This notification shall include a brief statement of the reasons for this decision, an application form and a statement setting a deadline for the permittee to file the application.

D. Discharge to Impaired Waters

1. **303(d) Listed Waters**:

This permit does not authorize new sources or new discharges of pollutants of concern to impaired waters unless consistent with an approved Total Maximum Daily Load (TMDL) and applicable state law. Impaired waters are those that do not meet applicable water quality standards. Impaired waters are identified on the West Virginia, Section 303(d) list until a TMDL is developed and approved by USEPA. Pollutants of concern are those pollutants for which the water body is listed as impaired. A list of impaired water bodies in West Virginia can be found at: http://www.wvdep.org/item.cfm?ssid=11&ss1id=720

a. MS4s that discharge into a receiving water which has been listed on the West Virginia Section 303(d) list of impaired waters, and with discharges that contain the pollutant(s) for which the water body is impaired, must document in the SWMP how the BMPs will control the discharge of the pollutant(s) of concern, and must demonstrate that there will be no increase of the pollutants of concern.

b. If a TMDL is approved during this permit cycle by USEPA for any waterbody into which an MS4 discharges, the MS4 must review the applicable TMDL to see if it includes requirements for control of stormwater discharges. Within six (6) months of the TMDL approval, the MS4 must modify its stormwater management program to include best management practices specifically targeted to achieve the wasteload allocations prescribed by the TMDL. The MS4 must include a monitoring component in the SWMP to assess the effectiveness of the BMPs in achieving the wasteload allocations. Monitoring shall be specifically for the pollutants of concern and be of sufficient frequency to determine if the stormwater BMPs are adequate to meet wasteload allocations. Monitoring can entail a number of activities including but not limited to; outfall monitoring to in-stream monitoring to modeling. For more information see the USEPA/State guidance titled: *Evaluating the effectiveness of municipal stormwater programs* and *Understanding Impaired Waters and Total Maximum Daily Load (TMDL) Requirements for Municipal Stormwater Programs.* Both of these guidance documents can be found on WVDEP's website: http://www2.wvdep.org/dwwm/stormwater/MS4_docs.htm

   After monitoring results are carefully considered, the permittee shall ascertain if the SWMP and the mix of BMPs need to be modified to comply with wasteload allocations.

2. **Discharging into Waters with Approved TMDLs**

If a MS4 discharges into a water body with an approved TMDL, and the TMDL contains requirements for control of pollutants from the MS4 stormwater discharges, then the SWMP must include BMPs specifically targeted to achieve the wasteload allocations prescribed by the TMDL. A monitoring component to assess the effectiveness of the BMPs in achieving the wasteload allocations must also be included in the SWMP. Monitoring shall be specifically for the pollutants of concern and be of sufficient frequency to determine if the stormwater BMPs are adequate to meet wasteload allocations. Monitoring can entail a number of activities including but not limited to; outfall monitoring to in-stream monitoring to modeling. For more information see the USEPA/State guidance titled: *Evaluating the effectiveness of municipal stormwater programs* and *Understanding Impaired Waters and Total Maximum Daily Load (TMDL) Requirements for Municipal Stormwater Programs.* Both of these guidance documents can be found on WVDEP's website: http://www2.wvdep.org/dwwm/stormwater/MS4_docs.htm

After monitoring results are carefully considered, the permittee shall ascertain if the SWMP and the mix of BMPs need to be modified to comply with wasteload allocations.

E. Endangered and Threatened Species

If a MS4 discharges to a stream where federally endangered or threatened species or its habitat are present, the applicant shall contact the US Fish and Wildlife Service to insure that requirements of the Federal Endangered Species Act are met.

Part IV. Monitoring, Recordkeeping, Reporting and Program Review

A. Evaluating the Stormwater Management Program

MS4s shall evaluate the effectiveness of their stormwater management programs and BMPs implemented to comply with this general permit. The permittee shall use a sufficient number of known, available, and reasonable methods necessary to evaluate the effectiveness of the SWMP. This information shall be submitted in the annual report in accordance with Part IV, Section D. For more information about evaluating your stormwater management program see the USEPA/States guidance titled: *Evaluating the effectiveness of municipal stormwater programs.* This guidance document can be found on WVDEP's website: http://www2.wvdep.org/dwwm/stormwater/MS4_docs.htm

B. Stormwater Monitoring

The permittee shall monitor stormwater from a minimum of one outfall that is representative of the stormwater discharge from the MS4. A representative outfall is one located in the most densely populated section of the MS4. The permittee shall, at a minimum, monitor one outfall for the following parameters:

Parameter	EPA Method No.	Method Detection Limit (mg/l)
Total Kjeldahl Nitrogen	351.4	0.03
Nitrate Nitrogen	300.0	0.002
Nitrite Nitrogen	300.0	0.004
Total Phosphorous	365.4	0.01

The DWWM recognizes there is not an EPA approved method to directly test for Total Nitrogen. The Total Nitrogen value to be reported on the permittees Discharge Monitoring Reports' (DMRs) shall be the sum of the following parameters; Total Kjeldahl Nitrogen, Nitrate, and Nitrite.

If all three constituents of total nitrogen are not detected at its method detection limit (MDL), the permittee shall sum the actual MDLs for each constituent and report the result as less than the calculation.

When calculating the sum of the constituents for total nitrogen, the permittee shall use actual analytical results when these results are greater than or equal to the MDL for a particular constituent and should use zero (0) for a constituent if one or two of the constituents are less than the MDL.

The methods and detection levels in the table above are recommended to be used unless the permittee desires to use an EPA approved method with a detection level equal to or lower than those specified above.

Stormwater samples shall be collected once every six months, during the spring and fall seasons.

Stormwater samples shall be collected during the "first flush" of rainfall runoff, at least twenty minutes, but not more than fifty minutes after rainfall of at least 0.5 inches has begun, preceded by a period of dry weather of at least 48 hours.

C. Recordkeeping and Public Availability of SWMP and Annual Report

The permittee shall keep records under this general permit for at least three years after termination of this general permit. Records shall be submitted to the DWWM only when permittees are specifically asked to do so.

The permittee shall make their SWMP and their annual report available to the public at reasonable times during regular business hours. In addition, the SWMP and the annual report shall be posted on the permittees website. If the permittee does not maintain or utilize a website, an electronic copy of the SWMP and annual report shall be submitted to DWWM for distribution when it is requested.

D. Reporting

Annually, the permittee shall submit a report to the DWWM. The report shall include:

1. A description of the activities undertaken and implemented for each of the minimum control measures;

2. An explanation of how the permittee measured the effectiveness of each of the activities implemented;

3. The status of compliance with each of the BMPs that were specified in the permittees stormwater management program;

4. An assessment of the progress toward achieving the identified measurable goals for each of the minimum control measures;

5. Results of information collected and analyzed, including monitoring data, during the annual reporting period;

6. A summary of the stormwater activities the permittee plans to undertake during the next annual reporting period;

7. A change in any identified measurable goals that apply to the minimum control measures;

8. A description of the status of the street and parking design assessment;

9. A description of the coordination efforts with other MS4's, County Governments, colleges, universities, correctional facilities, prisons, and any other entity regarding the implementation of the minimum control measures including the status of any memorandum of understanding (MOU) or other agreement executed between the permittee/s and any other entity;

10. A summary of construction site inspections and enforcement activities as described in Part II, Section C.4.b.vi.;

11. A summary of post construction controls as described in Part II, Section C.5.a.ii.F., and Part II, Section C.5.a.i.C.,

12. A description of specific BMPs *that were implemented* in order to reduce pollutants of concern in impaired receiving waters and waters in which a TMDL has been developed, and

13. A fiscal analysis of capital and operating expenditures to implement the minimum control measures. The fiscal analysis shall include only those expenditures by the locality seeking coverage under this general permit and not those for minimum control measures implemented by other entities.

E. Program Review

In order to assess the effectiveness of the permittees NPDES program for eliminating non-storm water discharges and reducing the discharge of pollutants to the maximum extent possible, the DWWM will review program implementation and annual reports. Additional periodic evaluations may be conducted to determine compliance with permit conditions.

The permittee must comply with all terms and conditions of this permit. Permit noncompliance constitutes a violation of the federal Clean Water Act (CWA) and State Act, Chapter 22, Article 11 & Article 12 and is grounds for enforcement action; for permit modification, suspension or revocation.

Failure to comply with the terms and conditions of this permit, with the plans and specifications submitted with the site registration application, the most currently approved SWMP, and the appropriate appendices shall constitute grounds for the revocation or suspension of this permit and for the invocation of all the enforcement procedures set forth in Chapter 22, Article 11 of the Code of West Virginia.

This permit is issued in accordance with the provisions of Chapter 22, Article 11 of the Code of West Virginia

BY: ______________________________

Scott G. Mandirola
Acting Director

Appendix A

WV/NPDES GENERAL PERMIT NUMBER WV0116025

SMALL MUNICIPAL SEPARATE STORM SEWER SYSTEMS

NOTICE OF INTENT (NOI)

1. MS4 Operator Information:

Name of city, county, or other jurisdiction that operates a Phase II MS4:

____

Contact Person: ________________________ Telephone: _________________

E-mail address of contact person: _______________________________________

Address: ____

City: ______________________________ State:________ Zip Code: __________

2. Receiving stream(s): ____

3. Fee - $17.50 per acre of area served by the MS4. Maximum fee is $1750.00

Amount enclosed: _________________________

NOTE:

The Notice of Intent provides MS4 entities initial coverage under the WV/NPDES MS4 General Permit. This permit requires the permittee to submit their Stormwater Management Program within six months of the issuance date of the General Permit.

I CERTIFY UNDER PENALTY OF LAW THAT I HAVE PERSONALLY EXAMINED AND AM FAMILIAR WITH THE INFORMATION SUBMITTED ON THIS FORM. I AM ALSO AWARE THAT THE STORMWATER MANAGEMENT PROGRAM/SITE REGISTRATION APPLICATION MUST BE SUBMITTED WITHIN SIX MONTHS OF THE ISSUANCE DATE OF THE GENERAL PERMIT NO. WV0116025.

I AM AWARE THAT THERE ARE SIGNIFICANT PENALTIES FOR SUBMITTING FALSE INFORMATION, INCLUDING THE POSSIBILITY OF FINE AND IMPRISONMENT.

OFFICIAL SIGNATURE ______________________ DATE _______________

PRINT NAME ____

Return To: WVDEP - DWWM
MS4/NPDES
601 57th Street, SE
Charleston, WV 25304

Appendix B

Definitions

Accessory Impervious Surfaces means those additional impervious surfaces that are created to service new development; including roads, shopping centers, office parks and parking lots.

Best Management Practices (BMP's) means schedules of activities, prohibitions of practices, maintenance procedures, policies, and other management practices to prevent or reduce the pollution of waters of the State of West Virginia. BMP's also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, waste disposal or drainage from material storage. BMP's can include structural as well as non-structural practices.

Bioretention is the water quality and water quantity stormwater management practice using the chemical, biological and physical properties of plants, microbes and soils for the removal of pollution from stormwater runoff.

Canopy Interception is the interception of precipitation, by leaves and branches of trees and vegetation that does not reach the soil.

Clean Water Act (CWA) means Public Law 92-500, as amended by Public Law 95-217, Public Law 97-117 and Public Law 95-576; U.S.C. 1251 et seq.

Common Plan of Development is a contiguous construction project where multiple separate and distinct construction activities may be taking place at different times on different schedules but under one plan. The "plan" is broadly defined as any announcement or piece of documentation or physical demarcation indicating construction activities may occur on a specific plot; included in this definition are most subdivisions and industrial parks.

Cut off concentration is a concentration at which stormwater could potentially impair, or contribute to impairing water quality.

Director means the Director of the Division of Water and Waste Management, West Virginia Department of Environmental Protection, or his/her designated representative.

Engineered Infiltration is an underground device or system designed to accept stormwater and slowly exfiltrates it into the underlying soil. This device or system is designed based on soil tests that define the infiltration rate.

Evaporation means rainfall that is changed or converted into a vapor.

Evapotranspiration means the sum of evaporation and transpiration of water from the earth's surface to the atmosphere. It includes evaporation of liquid or solid water plus the transpiration from plants.

Extended Filtration is a structural stormwater practice which filters stormwater runoff through vegetation and engineered soil media. A portion of the stormwater runoff drains into an underdrain system which slowly releases it after the storm is over.

Hydromodification means the alteration of the natural flow of water through a landscape, and often takes the form of channel straightening, widening, deepening, or relocating existing, natural stream channels. It can also involve excavation of borrow pits or canals, building of levees, streambank erosion, or other conditions or practices that change the depth, width or location of waterways. Hydromodification usually results in water quality and habitat impacts.

Illicit Discharge means any non-permitted discharge to a regulated small MS4 or to waters of the State of West Virginia that does not consist entirely of stormwater or authorized non-stormwater discharges covered under a NPDES permit.

Infiltration is the process by which stormwater penetrates into soil.

Land Use means the way in which land is used, especially in farming and municipal planning.

Maintenance Agreement means a formal agreement or contract between a local government and a property owner designed to guarantee that specific maintenance functions are performed.

Municipal Field Staff means employees of the municipality and its departments that spend a portion of their employment in the marketplace, outside of the company office.

Municipal Separate Storm Sewer System (MS4) means conveyances for stormwater, including, but not limited to, roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, human made channels or storm drains owned or operated by any municipality, sewer or sewage board, State agency or Federal agency or other public entity that discharges directly to surface waters of the State of West Virginia.

Municipal Staff means employees of the municipality and its departments.

Notice of Intent (NOI) means a notification of intent to seek coverage under this general permit, to discharge stormwater into waters of the State of West Virginia.

NPDES means National Pollutant Discharge Elimination System, a provision of the Clean Water Act which prohibits the discharge of pollutants into waters of the United States. This federally mandated permit program is used for regulating point source discharges.

Outfall means the point source where the MS4 discharges from a pipe, ditch or other discreet conveyance directly or indirectly to water of the State of West Virginia, or to another MS4.

Planning documents are documents a municipality or jurisdiction uses for planning. They include, but are not limited to; comprehensive or master plans, subdivision ordinances, general land use plan, zoning code, transportation master plan, specific area plans, such as sector plan, site area plans, corridor plans, or unified development ordinances.

Pollutants of Concern are those pollutants which cause a water body to be placed on the Section 303(d) list of impaired waters.

Qualifying Local Program means a WV DEP formally recognized state, municipal or county program that meets or exceeds the provisions of WV DEP stormwater construction program in accordance with 40 CFR 122.44(s).

Rainfall and Rainwater Harvesting is the collection, conveyance, and storage of rainwater. The scope, method, technologies, system complexity, purpose, and end uses vary from rain barrels for garden irrigation in urban areas, to large-scale collection of rainwater for all domestic uses.

Receiving waters or receiving water means the 'water resources' that receive the discharge from the permittee.

Runoff Reduction practices and/or techniques are the collective assortment of stormwater practices that reduce the volume of stormwater from discharging off site. These include stormwater practices that infiltrate, evapotranspirate and reuse stormwater on site.

Secretary means the Secretary of the West Virginia Department of Environmental Protection, or his/her designated representative.

Site Registration Application means the forms designed by the Director for the purpose of obtaining coverage under the small MS4 general permit. The information contained on the site registration application once approved becomes the "stormwater management program" for the permittee.

Soil amendments are components added to in situ or native soils to increase the spacing between soil particles so that the soil can absorb and hold more moisture. The amendment of soils changes various other physical, chemical and biological characteristics so that the soils become more effective in maintaining water quality.

Source control stormwater management means practices that control stormwater *before* pollutants have been introduced into stormwater.

Stormwater Hotspots are commercial, industrial, institutional, municipal, or transportation related operations that may produce higher levels of stormwater pollutants, and/or present a higher potential risk for spills, leaks, or illicit discharges. Hotspots may include: gas stations, petroleum wholesalers, vehicle maintenance and repair, auto recyclers, recycling centers and scrap yards, landfills, solid waste facilities, wastewater treatment plants, airports, railroad stations and associated maintenance facilities, and highway maintenance facilities.

Stormwater Pollution Prevention Plan (SWPPP) means the erosion and sediment control plan for a construction site.

Stormwater Management Practice means practices that manage stormwater, including structural and vegetative components of a stormwater system.

Total Maximum Daily Load (TMDL): A calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. A TMDL is the sum of individual wasteload allocations for point sources (WLA), load allocations for nonpoint sources and natural background (LA), and must consider seasonal variation and include a margin of safety. The TMDL comes in the form of a technical document or plan. (40 CFR 130.2 and 130.7)

Treatment control stormwater management means practices that 'treat' stormwater after pollutants have been incorporated into the stormwater.

Wasteload allocation (WLA): The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Water Quality Treatment means any passive or active process that removes pollutants from stormwater, and/or prevents pollutants from encountering stormwater.

Water Resources, 'Water' or 'Waters' means any and all water on or beneath the surface of the ground, whether percolating, standing, diffused or flowing, wholly or partially within this state, or bordering this state and within its jurisdiction, and includes, without limiting the generality of the foregoing, natural or artificial lakes, rivers, streams, creeks, branches, brooks, ponds (except farm ponds, industrial settling basins and ponds and water treatment facilities), impounding reservoirs, springs, wells, watercourses and wetlands.

Appendix C

I. MANAGEMENT CONDITIONS:

1. Duty to Comply
a) The permittee must comply with all conditions of this permit. Permit noncompliance constitutes a violation of the CWA and State Act and is grounds for enforcement action; for permit modification, revocation and reissuance, suspension or revocation; or for denial of a permit renewal application.
b) The permittee shall comply with all effluent standards or prohibitions established under Section 307(a) of the CWA for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.
2. Duty to Reapply
If the permittee wishes to continue an activity regulated by this permit after the expiration date of this permit, the permittee must apply for a new permit at least 180 days prior to expiration of the permit.
3. Duty to Mitigate
The permittee shall take all reasonable steps to minimize or prevent any discharge in violation of this permit, which has a reasonable likelihood of adversely affecting human health or the environment.
4. Permit Actions
This permit may be modified, revoked and reissued, suspended, or revoked for cause. The filing of a request by the permittee for permit modification, revocation and reissuance, or revocation, or a notification of planned changes or anticipated noncompliance, does not stay any permit condition.
5. Property Rights
This permit does not convey any property rights of any sort or any exclusive privilege.
6. Signatory Requirements
All applications, reports, or information submitted to the Chief shall be signed and certified as required in Title 47, Series 10 , Section 4.6 of the West Virginia Legislative Rules.
7. Transfers
This permit is not transferable to any person except after notice to the Chief. The Chief may require modification or revocation and reissuance of the permit to change the name of the permittee and incorporate such other requirements as may be necessary. .
8. Duty to Provide Information
The permittee shall furnish to the Chief, within a reasonable specified time, any information which the Chief may request to determine whether cause exists for modifying, revoking and reissuing, suspending, or revoking this permit, or to determine compliance with this permit. The permittee shall also furnish to the Chief, upon request, copies of records required to be kept by this permit.
9. Other Information
Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application or in any report to the Chief, it shall promptly submit such facts or information.
10. Inspection and Entry
The permittee shall allow the Chief, or an authorized representative, upon the presentation of credentials and other documents as may be required by law, to:
a) Enter upon the permittee's premises in which an effluent source or activity is located, or where records must be kept under the conditions of this permit;
b) Have access to and copy at reasonable times, any records that must be kept under the conditions of this permit;
c) Inspect at reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit; and
d) Sample or monitor at reasonable times, for the purposes of assuring permit compliance or as otherwise authorized by the State Act, any substances or parameters at any location.
11. Permit Modification
This permit may be modified, suspended, or revoked in whole or in part during its term in accordance with the provisions of Chapter 22-11-12 of the Code of West Virginia.
12. Water Quality
The effluent or effluents covered by this permit are to be of such quality so as not to cause violation of applicable water quality standards adopted by the Environmental Quality Board.
13. Outlet Markers
A permanent marker at the establishment shall be posted in accordance with Title 47, Series 11, Section 9 of the West Virginia Legislative Rules.
14. Liabilities
a) Any person who violates a permit condition implementing sections 301, 302, 306, 307, 308, 318, or 405 of the Clean Water Act is subject to a civil penalty not to exceed $10,000 per day of such violation. Any person who willfully or negligently violates permit conditions implementing sections 301, 302, 306, 307, or 308 of the Clean Water Act is subject to a fine of not less than $2,500 nor more than $25,000 per day of violation, or by imprisonment for not more than 1 year, or both.
b) Any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.
c) Any person who knowingly makes any false statement, representation, or certification in any record or other document submitted or required to be maintained under this permit, including monitoring reports or reports of compliance or noncompliance shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.
d) Nothing in I.14 a), b), and c) shall be construed to limit or prohibit any other authority the Chief may have under the State Water Pollution Control Act, Chapter 22, Article 11.

II. OPERATION AND MAINTENANCE:

1. Proper Operation and Maintenance
The permittee shall at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with the conditions of this permit. Proper operation and maintenance also includes adequate laboratory controls, and appropriate quality assurance procedures. Unless otherwise required by Federal or State law, this provision requires the operation of back-up auxiliary facilities or similar systems which are installed by the permittee only when the operation is necessary to achieve compliance with the conditions of the permit. For domestic waste treatment facilities, waste treatment operators as classified by the WV Bureau of Public Health Laws, W. Va. Code Chapter 16-1, will be required except that in circumstances where the domestic waste treatment facility is receiving any type of industrial waste, the Chief may require a more highly skilled operator.

2. Need to Halt or Reduce Activity Not a Defense
It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of the permit.

3. Bypass
a) Definitions
(1) "Bypass" means the intentional diversion of waste streams from any portion of a treatment facility; and
(2) "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which causes them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.
b) Bypass not exceeding limitations. The permittee may allow any bypass to occur which does not cause effluent limitations to be exceeded, but only if it also is for essential maintenance to assure efficient operation. These bypasses are not subject to the provision of II.3.c) and II.3.d) of this permit.
c) (1) If the permittee knows in advance of the need for a bypass, it shall submit prior notice, if possible at least ten (10) days before the date of the bypass;
(2) If the permittee does not know in advance of the need for bypass, notice shall be submitted as required in IV.2.b) of this permit.
d) Prohibition of bypass
(1) Bypass is permitted only under the following conditions, and the Chief may take enforcement action against a permittee for a bypass, unless;
(A) Bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;
(B) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate backup equipment should have been installed in the exercise of reasonable engineering judgement to prevent a bypass which occurred during normal periods of equipment downtime or preventative maintenance; and
(C) The permittee submitted notices as required under II.3.c) of this permit.
(2) The Chief may approve an anticipated bypass, after considering its adverse effects, if the Chief determines that it will meet the three conditions listed in II.3.d.(1) of this permit.

4. Upset
a) Definition. "Upset" means an exceptional incident in which there is unintentional and temporary noncompliance with technology-based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventative maintenance, or careless or improper operation.

b) Effect of an upset. An upset constitutes an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limitation if the requirements of II.4.c) are met. No determination made during administrative review of claims that noncompliance was caused by upset, and before an action for noncompliance, is final administrative action subject to judicial review.

c) Conditions necessary for a demonstration of upset. A permittee who wishes to establish the affirmative defense of upset shall demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:
(1) An upset occurred and that the permittee can identify the cause(s) of the upset;
(2) The permitted facility was at the time being properly operated;
(3) The permittee submitted notice of the upset as required in IV.2.b) of this permit.
(4) The permittee complied with any remedial measures required under I.3. of this permit.

d) Burden of proof. In any enforcement proceeding the permittee seeking to establish the occurrence of an upset has the burden of proof.

5. Removed Substances
Where removed substances are not otherwise covered by the terms and conditions of this permit or other existing permit by the Chief, any solids, sludges, filter backwash or other pollutants (removed in the course of treatment or control of wastewaters) and which are intended for disposal within the State, shall be disposed of only in a manner and at a site subject to the approval by the Chief. If such substances are intended for disposal outside the State or for reuse, i.e., as a material used for making another product, which in turn has another use, the permittee shall notify the Chief in writing of the proposed disposal or use of such substances, the identity of the prospective disposer or users, and the intended place of disposal or use, as appropriate.

III. MONITORING AND REPORTING

1. Representative Sampling
Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity.

2. Reporting
a) Permittee shall submit, according to the enclosed format, a Discharge Monitoring Report (DMR) indicating in terms of concentration, and/or quantities, the values of the constituents listed in Part A analytically determined to be in the plant effluent(s). DMR submissions shall be made in accordance with the terms contained in Section C of this permit.
b) Enter reported average and maximum values under "Quantity" and "Concentration" in the units specified for each parameter, as appropriate.
c) Specify the number of analyzed samples that exceed the allowable permit conditions in the columns labeled "N.E." (i.e., number exceeding).
d) Specify frequency of analysis for each parameter as number of analyses/specified period (e.g.,3/month is equivalent to 3 analyses performed every calendar month). If continuous, enter "Cont.". The frequency listed on format is the minimum required.

3. Test Procedures
Samples shall be taken, preserved and analyzed in accordance with the latest edition of 40 CFR Part 136, unless other test procedures have been specified elsewhere in this permit.

4. Recording of Results
For each measurement or sample taken pursuant to the permit, the permittee shall record the following information.
a) The date, exact place, and time of sampling or measurement;
b) The date(s) analyses were performed;
c) The individual(s) who performed the sampling or measurement;
d) The individual(s) who performed the analyses; if a commercial laboratory is used, the name and address of the laboratory;
e) The analytical techniques or methods used, and
f) The results of such analyses. Information not required by the DMR form is not to be submitted to this agency, but is to be retained as required in III.6.

5. Additional Monitoring by Permittee
If the permittee monitors any pollutant at any monitoring point specified in this permit more frequently than required by this permit, using approved test procedures or others as specified in this permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the Discharge Monitoring Report Form. Such increased frequency shall also be indicated. Calculations for all limitations which require averaging of measurements shall utilize an arithmetic mean unless otherwise specified in the permit.

6. Records Retention
The permittee shall retain records of all monitoring information, including all calibration and maintenance records and all original chart recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for the permit, for a period of at least three (3) years from the date of the sample, measurement, report or application. This period may be extended by request of the Chief at any time.

7. Definitions
a) "Daily discharge" means the discharge of a pollutant measured during a calendar day or within any specified period that reasonably represents the calendar day for purposes of sampling. For pollutants with limitations expressed in units of mass, the daily discharge is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurement, the daily discharge is calculated as the average measurement of the pollutant over the day.
b) "Average monthly discharge limitation" means the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.
c) "Maximum daily discharge limitation" means the highest allowable daily discharge.
d) "Composite Sample" is a combination of individual samples obtained at regular intervals over a time period. Either the volume of each individual sample is proportional to discharge flow rates or the sampling interval (for constant volume samples) is proportional to the flow rates over the time period used to produce the composite. The maximum time period between individual samples shall be two hours.
e) "Grab Sample" is an individual sample collected in less than 15 minutes.
f) "is" = immersion stabilization - a calibrated device is immersed in the effluent stream until the reading is stabilized.
g) The "daily average temperature" means the arithmetic average of temperature measurements made on an hourly basis, or the mean value plot of the record of a continuous automated temperature recording instrument, either during a calendar month, or during the operating month if flows are of shorter duration.
h) The "daily maximum temperature" means the highest arithmetic average of the temperatures observed for any two (2) consecutive hours during a 24 hour day, or during the operating day if flows are of shorter duration.
i) The "daily average fecal coliform" bacteria is the geometric average of all samples collected during the month.
j) "Measured Flow" means any method of liquid volume measurement, the accuracy of which has been previously demonstrated in engineering practice, or which a relationship to absolute volume has been obtained.
k) "Estimate" means to be based on a technical evaluation of the sources contributing to the discharge including, but not limited to pump capabilities, water meters and batch discharge volumes.
l) "Non-contact cooling water" means the water that is contained in a leak-free system, i.e., no contact with any gas, liquid, or solid other than the container for transport; the water shall have no net poundage addition of any pollutant over intake water levels, exclusive of approved anti-fouling agents.

IV. OTHER REPORTING

1. Reporting Spills and Accidental Discharges
Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities or penalties established pursuant to Title 47, Series 11, Section 2 of the West Virginia Legislative Rules promulgated pursuant to Chapter 22, Article 11.

Attached is a copy of the West Virginia Spill Alert System for use in complying with Title 47, Series 11, Section 2 of the Legislative rules as they pertain to the reporting of spills and accidental discharges.

2. Immediate Reporting
a) The permittee shall report any noncompliance which may endanger health or the environment immediately after becoming aware of the circumstances by using the Agency's designated spill alert telephone number. A written submission shall be provided within five (5) days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the noncompliance and its cause; the period of noncompliance, including exact dates and times, and if the noncompliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent recurrence of the noncompliance.
b) The following shall also be reported immediately:
(1) Any unanticipated bypass which exceeds any effluent limitation in the permit;
(2) Any upset which exceeds any effluent limitation in the permit; and
(3) Violation of a maximum daily discharge limitation for any of the pollutants listed by the Chief in the permit to be reported immediately. This list shall include any toxic pollutant or hazardous substance, or any pollutant specifically identified as the method to control a toxic pollutant or hazardous substance.
c) The Chief may waive the written report on a case-by-case basis if the oral report has been received in accordance with the above.
d) Compliance with the requirements of IV.2 of this section shall not relieve a person of compliance with Title 47, Series 11, Section 2.

3. Reporting Requirements
a) Planned changes. The permittee shall give notice to the Chief of any planned physical alterations or additions to the permitted facility which may affect the nature or quantity of the discharge. Notice is required when:
(1) The alteration or addition to a permitted facility may meet one of the criteria for determining whether a facility is a new source in Section 13.7.b of Series 10, Title 47; or
(2) The alteration or addition could significantly change the nature or increase the quantity of pollutants discharged. This notification applies to pollutants which are subject neither to effluent limitations in the permit, nor to notification requirements under IV.2 of this section.
b) Anticipated noncompliance. The permittee shall give advance notice to the Chief of any planned changes in the permitted facility or activity which many result in noncompliance with permit requirements.
c) In addition to the above reporting requirements, all existing manufacturing, commercial, and silvicultural discharges must notify the Chief in writing as soon as they know or have reason to believe:
(1) That any activity has occurred or will occur which would result in the discharge, on a routine or frequent basis, or any toxic pollutant which is not limited in the permit, if that discharge will exceed the highest of the following "notification levels":
(A) One hundred micrograms per liter (100 ug/l);
(B) Two hundred micrograms per liter (200 ug/l) for acrolein and acrylonitrile; five hundred micrograms per liter (500 ug/l) for 2,4-dinitro phenol; and for 2-methyl 4,6-dinitrophenol; and one milligram per liter (1 mg/l) for antimony;
(C) Five (5) times the maximum concentration value reported for that pollutant in the permit application in accordance with Section 4.4.b.9 of Series10, Title 47.
(D) The level established by the Chief in accordance with Section 6.3.g of Series 10, Title 47;
(2) That any activity has occurred or will occur which would result in any discharge (on a non-routine or infrequent basis) of a toxic which is not limited in the permit, if that discharge will exceed the highest of the following "notification levels":
(A) Five hundred micrograms per liter (500 ug/l);
(B) One milligram per liter (1 mg/l) for antimony;
(C) Ten (10) times the maximum concentration value reported for that pollutant in the permit application in accordance with Section 4.4.b.7 of Series 10, Title 47;
(D) The level established by the Chief in accordance with Section 6.3.g of Series 10, Title 47.
(3) That they have begun or expect to begin to use or manufacture as an intermediate or final product or by-product of any toxic pollutant which was not reported in the permit application under Section 4.4.b.9 of Series 10, Title 47 and which will result in the discharge on a routine or frequent basis of that toxic pollutant at levels which exceed five times the detection limit for that pollutant under approved analytical procedure.
(4) That they have begun or expect to begin to use or manufacture as an intermediate or final product or by-product of any toxic pollutant which was not reported in the permit application under Section 4.4.b.9 of Series 10, Title 47 and which will result in the discharge on a non-routine or infrequent basis of that toxic pollutant at levels which exceed ten times the detection limit for that pollutant under approved analytical procedure.

4. Other Noncompliance
The permittee shall report all instances of noncompliance not reported under the above paragraphs at the time monitoring reports are submitted. The reports shall contain the information listed in IV.2.a). Should other applicable noncompliance reporting be required, these terms and conditions will be found in Section C of this permit.

Appendix D

Designation Criteria for small MS4s with a population greater than 1,000.

The DWWM will use the following designation criteria to evaluate and determine if the subject MS4s require permit coverage:

1. Discharge to sensitive waters

2. High growth or growth potential

3. High population density

4. Contiguity to an urbanized area

5. Significant contributor of pollutants to waters of the State

6. Ineffective protection of water quality by other programs

Appendix E

Sediment and Erosion Control BMP manuals:

1. West Virginia BMP manual; http://www.wvdep.org/dwwm/stormwater/BMP/index.html

2. Maryland Soil Erosion and Sediment Control BMP manual; http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/erosionsedimentcontrol/standards.asp

3. Virginia Erosion and Sediment Control Handbook; http://www.dcr.virginia.gov/soil_&_water/e&s-ftp.shtml

4. USEPA has a listing of available state stormwater manuals here; http://yosemite.epa.gov/R10/WATER.NSF/0/17090627a929f2a488256bdc007d8dee?OpenDocument

5. West Virginia Department of Transportation, Division of Highways, Erosion and Sediment Control Manual, March 1, 2003. http://www.wvdot.com/engineering/TOC_engineering.htm

Effects of Lawn Fertilizer on Nutrient Concentration in Runoff from Lakeshore Lawns, Lauderdale Lakes, Wisconsin

Introduction

Transport of nutrients (primarily forms of nitrogen and phosphorus) to lakes and resulting accelerated eutrophication are serious concerns for planners and managers of lakes in urban and developing suburban areas of the country. Runoff from urban land surfaces such as streets, lawns, and rooftops has been noted to contain high concentrations of nutrients; lawns and streets were the largest sources of phosphorus in residential areas (Waschbusch, Selbig and Bannerman, 1999). The cumulative contribution from many lawns to the amount of nutrients in lakes is not well understood and potentially could be a large part of the total nutrient contribution.

Why study runoff from lawns?

The shorelines of many lakes are already highly developed, and the potential water-quality effects of this development are increasing. Many lawn-care professionals and homeowners hold a common belief that runoff from lawn surfaces is minimal and that phosphorus movement from lawns is not a problem (Barth, 1995). The homeowners' goal to maintain lush green lawns may conflict with the lake manager's goal to minimize nutrient inputs. In cooperation with the Lauderdale Lakes Lake Management District and the Wisconsin Department of Natural Resources, the U.S. Geological Survey (USGS) conducted a study during 1999–2000 to determine the magnitude of nutrient runoff from nearshore residential lawns surrounding a lake and to determine whether fertilizer application and the type of fertilizer (regular or nonphosphorus types) affect the amount of nutrients in runoff from lawns. Such information is important for developing stormwater best-management practices and for developing or improving shoreland zoning ordinances and other local regulations to protect or improve the water quality of lakes (Wisconsin Department of Natural Resources, Wisconsin Shoreland Management Program, http://www.dnr.state.wi.us/org/water/wm/dsfm/shore/title.htm, accessed February 8, 2002).

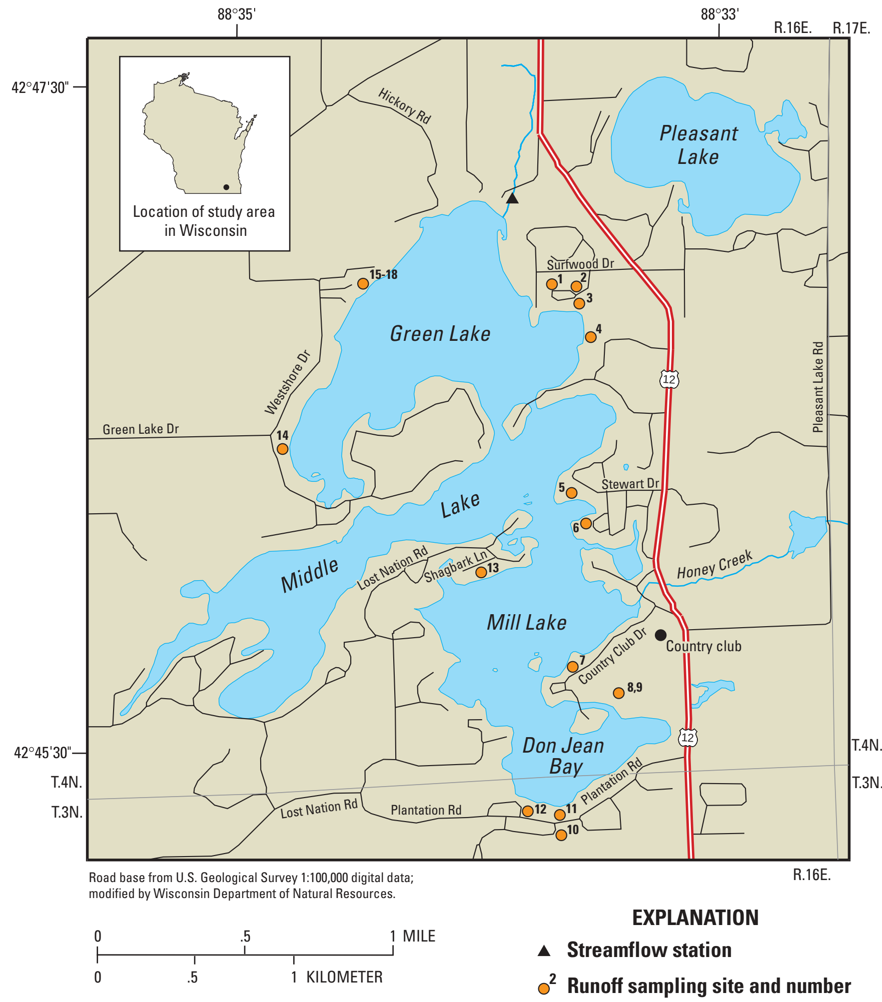

Figure 1. Site locations surrounding Lauderdale Lakes, Wis.

The study area was located at Lauderdale Lakes in Walworth County, a chain of lakes in the more populated southeastern part of Wisconsin (fig. 1). The 15-mile shoreline of the lakes is about 70 percent developed, primarily as single-family housing, and is the focus for additional residential development. Most of the lakefront homes have sloping lawns that are maintained to the water's edge (fig. 2). Information about the specific sources and amounts of phosphorus entering the lakes was needed to develop a plan for reducing the input of phosphorus. The lakes are phosphorus limited, meaning that phosphorus is the nutrient limiting plant growth and affecting lake productivity. A previous study (Garn and others, 1996) found that surface-water inflow from the small nearshore contributing drainage area accounted for only 4 percent of the water inflow to the lake but represented 51 percent of the total annual phosphorus input from all sources. The Lake Management District is in the process of installing

Figure 2. Lakeshore development and lawns at Lauderdale Lakes, Wis.

Figure 3. Tube-type lawn sampler (site 2).

and implementing various measures to reduce the phosphorus input to the lakes, among which is a “lake-friendly” fertilizer program that encourages residents to apply nonphosphorus turf fertilizer. The Lake Management District has been supplying residents with phosphorus-free fertilizer for purchase for about 3 years, and data were needed to evaluate the effectiveness of the program.

Equipment and Methods

In 1999 and spring 2000, lawn samplers designed to collect surface runoff were installed using methods described in Waschbusch, Selbig, and Bannerman (1999, p. 7). The samplers collect runoff through two 5-foot pieces of 1/2-inch-diameter PVC tubing placed flush with the surface of the ground, on a sloping lawn, with an angle of about 150 degrees between the two tubes (fig. 3). Runoff entered the tubing through a 1/8-inch slot cut at intervals along the length of the tube; each tube was then wrapped with fiberglass screen to prevent insects and large debris from entering. The tube was held in place on the lawn surface with wire staples. At the end of each tube, a connecting piece of 1/2-inch silicone tubing directed the collected runoff into a covered 1-quart glass jar placed in the ground in a 4-inch-diameter protective PVC sleeve with a cover.

During the summer of 2000, the original sampler design was modified to increase sample volumes at sites that did not generate sufficient runoff samples and to minimize contamination problems caused by insects and earthworms entering the samples despite the fiberglass screen. One variation to increase runoff-collection efficiency was to enlarge the slots cut in the pipes to 1/4-inch. Another technique used at sites with the least runoff production was to replace the tubing with two lengths of 4-foot-long plastic lawn edging that directed runoff toward the collecting jar (fig. 4); this solution was more effective at increasing captured runoff and minimizing contamination than increasing the slot size.

Clean sample bottles were placed in the lawn samplers before each expected storm or at about 2-week intervals when sites were inspected if there was no rain. Samplers were cleaned and rinsed with deionized water

Figure 4. Edging-type lawn sampler (site 5).

during each visit to remove any accumulated dirt or debris. Notes were kept on volume of runoff in the collection bottle; color and noticeable sediment, debris, or insects in the bottle; and site condition. Sample bottles were collected as soon as possible after each storm (usually within 1 to 5 days) and brought to Madison, where the contents were filtered with a 0.45-micrometer filter, preserved with sulfuric acid, and then delivered to the Wisconsin State Laboratory of Hygiene for nutrient analyses. Samples were analyzed according to standard laboratory methods (Wisconsin State Laboratory of Hygiene, written commun., 2001) for concentrations of total phosphorus (TP), total dissolved phosphorus, total Kjeldahl nitrogen (TKN), dissolved ammonia nitrogen, and dissolved nitrate plus nitrite nitrogen. When insufficient sample volume was collected from a storm to analyze for all nutrients, analyses were done first for total phosphorus.

Description of Sampling Sites

The Lauderdale Lakes are a chain of three interconnected lakes with a surface area of 807 acres. The lakes are ground-water drainage lakes in which more than 90 percent of the water inflows are from ground water and direct precipitation. Some surface water enters the lakes by way of a few ephemeral drainageways or as overland flow from the nearshore area. Lake and drainage-basin characteristics are described in detail by Garn and others (1996). Lakeshore developments include about 1,010 single-family homes, of which about 30 percent are year-round residences. Other developments include a golf course, a boat marina, and two recreational camps.

In the lakeshore area within 300 feet of the shoreline, soils consist primarily of the Casco-Rodman Complex (60 percent of the area), Rodman-Casco Complex (12 percent of the area), and Casco-Fox Silt Loam (6 percent of the area). The Casco-Rodman Complex is found on 20–30 percent slopes; surface textures range from loam to silt loam, and subsoils are clay loam to sandy loam. The Rodman-Casco Complex is found on slopes of 30 to 45 percent formed in loamy deposits over sand and gravel. The Casco-Fox soils are found on slopes of 6 to 12 percent and have a silt loam texture (Haszel, 1971). Soil disturbance can be severe during building construction in suburban areas, commonly resulting in subsoil compaction by heavy equipment followed by layering with topsoil. Such disturbance has the potential for greatly increasing runoff and nutrient losses.

Samplers were installed at 18 locations along the lakeshore (fig.1), representing different types of lawn-fertilizer use, undeveloped areas, and one area of mixed land use (part agricultural, ditched paved roads, and lawns). Sites were grouped into three categories: regular-fertilizer sites, nonphosphorus-fertilizer sites, and unfertilized sites. Samplers were installed at 12 sites and operated during the growing season in 1999. In 2000, six additional sites were installed, including two samplers in a swale. Samplers were installed at seven lawn sites where traditional fertilizer was applied, three sites where nonphosphorus fertilizer was applied, and six control sites where no fertilizer was applied (three steep, wooded sites; two lawns; and an undeveloped grass field). Much of the area is wooded, and many of the lawns have an overhead canopy of hardwood trees. Two samplers were installed in a swale area on the south side of Mill Lake (Don Jean Bay) that collected mixed runoff from an agricultural field, lawns, and streets. The drainage area of the upgradient sampler was 8 acres and of the downgradient sampler was 38 acres, of which about 25 percent was cropland.

Property owners were asked to participate in the runoff study. It was assumed that most lawn fertilizer users followed usual manufacturer recommendations of four applications per season made in about April–May, June–July, August–September, and October at 3 to 3.5 pounds per 1,000 square feet. Homeowners applying regular fertilizer fertilized their lawns two or more times per year. Each participant’s property was inspected to ensure that lawn slope was at least 20 feet long, grade was at

Table 1. Physical characteristics of sampling sites at Lauderdale Lakes, Wis. [P, phosphorus; ppm, parts per million; %, percent, turf-quality values are defined in text; ft^2, square feet; --, no data]

Site ID	Station number	Site type	Soil type/texture[a]	Soil P concentration[b] (ppm)	Slope (%)	Vegetative cover density (%)	Turf quality	Runoff area (ft^2)	Number of samples	Percentage of storm events
Regular fertilizer application sites										
2	424652088333901	Wooded lawn	Hebron loam, gravelly	68	21	65	6	150	10	67
3	424650088333501	Lawn	Hebron loam	32	9	90	8.5	180	8	80
5	424616088334201	Wooded lawn	Casco-Rodman loam-silt loam	66	20	100	9	114	8	33
8	424541088334602	Golf course lawn	Casco-Rodman loam-silt loam	35	20	100	9.5	250	15	63
9	424541088334601	Golf course lawn	Casco-Rodman loam-silt loam	78	24	100	9.5	186	9	54
10	424514088334001	Swale	Casco-Fox silt loam	--	5	--	--	8 acres	9	69
11	424518088334301	Swale	Casco-Fox silt loam	--	4	--	--	38 acres	10	77
12	424519088334101	Lawn	Casco-Fox silt loam	28	16	100	10	104	1	8
15	424654088343103	Lawn	Fox silt loam	11	11	60	6	152	5	24
Nonphosphorus-fertilizer application sites										
6	424611088334001	Wooded lawn	Casco-Rodman loam-silt loam	20	14	80	7.5	250	18	67
13	424603088340201	Wooded lawn	Casco-Rodman loam-silt loam	21	34	60	5	140	15	54
14	424623088345101	Wooded lawn	Casco-Rodman loam-silt loam	70	14	85	8	225	8	30
Unfertilized sites										
1	424652088334401	Grass field	Fox sandy loam	65	9	100	7	128	2	13
4	424643088333601	Wooded lawn	Casco-Rodman loam-silt loam	38	12	85	8	188	6	47
7	424543088334001	Wooded lawn	Casco-Rodman loam-silt loam	14	22	70	6	209	12	46
16	424654088343101	Wooded	Rodman-Casco loam/sand,gravel	28	41	95	1	200	9	33
17	424654088343102	Wooded	Rodman-Casco loam/sand,gravel	24	33	95	1	300	13	48
18	424654088343104	Wooded	Rodman-Casco sandy, gravelly	16	30	65	2	140	7	28

[a]From Haszel, 1971.

[b]50–75 ppm P optimum recommendation for turfgrass. Analysis by Soil and Plant Laboratory, University of Wisconsin, Madison.

least 5 percent, and sample catchment area was not affected by runoff from rain gutters, driveways, or other lawns or sources. A soil sample collected at the time of sampler installation was analyzed for soil texture, pH, and phosphorus content by the University of Wisconsin Soil and Plant Analysis Laboratory. A visual vegetative soil-cover density, in percent, and a turf-quality rating were assigned to each lawn during visits. Turf quality was based on a 1 to 10 scale: for example, a score of 10 represented 100 percent best-quality green grass cover, 5 represented 50 percent grass cover with bare spots, weeds, and dead grass providing additional cover, and 1 indicated no turfgrass cover, with dead grass, weeds, and other vegetation providing primary soil cover. The more heavily fertilized sites (5, 8, 9, 12) had the best turf-quality ratings. Various physical characteristics of the sampling sites are summarized in table 1.

Nutrient Concentration in Runoff

Rainfall and Runoff

Long-term precipitation records from the National Weather Service stations at Whitewater (about 9 miles northwest of Lauderdale Lakes) and Lake Geneva (about 13 miles southeast) were used to estimate rainfall at Lauderdale Lakes (National Oceanic and Atmospheric Administration, 1999–2000). Data from a recording rain gage at a USGS streamflow-gaging station at Jackson Creek near Elkhorn (9 miles south) was used after the rain gage was installed on May 25, 1999. Rainfall was above the 1961-90 average for April, May, and June 1999 and near or below average the remainder of the season. In 2000, rainfall amounts for May, June, and September were substantially above average (fig. 5). Ten runoff events occurred from 12 storms in the 1999 sampling season and 13 runoff events occurred from 15 storms in 2000; generally, the storms in 2000 were larger than those in 1999. A storm event was defined as more than 0.3 inches of rain, and a runoff event as one that resulted in at least two runoff samples with sufficient volume for analysis (about 100 ml). A summary of the storm dates and precipitation amounts is given in table 2.

Although measurement of quantity of runoff was not part of this study, a qualitative evaluation of runoff may be obtained by comparing the

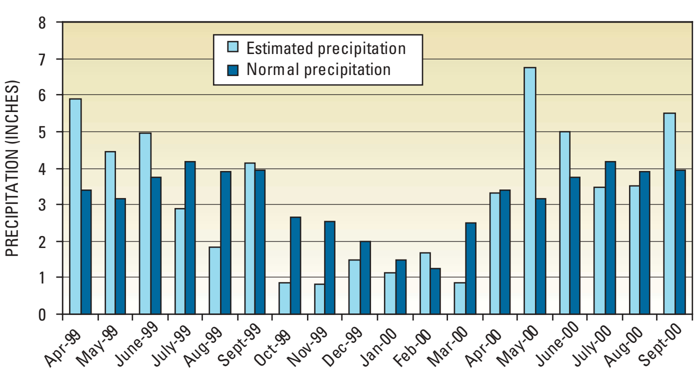

Figure 5. Estimated monthly precipitation at Lauderdale Lakes, Wis., during 1999–2000 compared to normal monthly precipitation.

Table 2. Storm information and number of sites with runoff samples at Lauderdale Lakes, Wis., 1999–2000 [est, estimated]

Storm number	Storm start date	Total precip amount (inches)	Number of sites with runoff samples
99S1	4/9/1999	0.86 [a]	4
99S2	4/22/1999	3.73 [a]	9
99S3	5/12/1999	0.63 [a]	3
99S4	5/16/1999	0.80 [a] est	4
99S5	5/17/1999	0.66 [a] est	3
99S6	6/1/1999	0.70	8
99S7	6/10/1999	3.35	6
99S8	7/17/1999	1.11	4
99S9	8/13/1999	0.37	5
99S10	9/27/1999	3.66	11
00S1	2/21/2000	2.0 [b]	11
00S2	4/19/2000	2.59	2
00S3	5/9/2000	1.36	9
00S4	5/18/2000	1.95	5
00S5	5/27/2000	3.85	14
00S6	6/11/2000	1.95	9
00S7	7/2/2000	1.40	12
00S8	7/10/2000	1.33	5
00S9	7/31/2000	1.62	3
00S10	8/5/2000	1.17	16
00S11	8/17/2000	0.70	5
00S12	9/11/2000	1.94	17
00S13	9/22/2000	1.89	9

[a] Measured at Whitewater.

[b] From 6 inches snowmelt and light rain.

Figure 6. Site 12 at Lauderdale Lakes, Wis.—an example of high-quality turfgrass.

number of sites where runoff was sampled for each storm (table 2) and the number of storms sampled at each site (table 1). The magnitude of runoff is dependent on a combination of factors including rainfall amount and intensity, soil-surface storage and detention, and infiltration rate. Infiltration is affected by soil type, vegetative cover, slope, and other factors (Haan, Barfield, and Hayes, 1994, p. 52–54). In general, sites with dense vegetative cover and coarse soils with high infiltration rates produced less runoff. Specifically, site 12 of the fertilized sites (fig. 6), which had the best-quality turf and fertilizer applications of 4 times per year, produced the least runoff (only 8 percent of all storms). Other sites (5, 8, 9) with high turf quality and density produced more frequent runoff samples, possibly because of steeper slopes or other factors. At six of the lawn sites, more than 50 percent of the storm events produced runoff.

The phenomenon of soil-water repellency, or hydrophobicity, was observed at many of the lawn sites, especially after dry periods. Water repellency of soils reduces affinity to water so that the soil resists wetting, thus reducing infiltration capacity, decreasing plant growth, and increasing surface runoff. The phenomenon has been widely accepted as a problem for many soils in seasonally dry climates. Soils with grass cover in temperate climates have recently been found to develop resistance to wetting—a common problem known as “localized dry spot” on golf courses (Doerr, Shakesby and Walsh, 2000; Kostka, 2000). Therefore, water repellency could be an additional factor influencing runoff from residential lawn soils (L.F. DeBano, University of Arizona, oral commun., 2001). At Lauderdale Lakes, there was also some indication that lawn shading by trees and less frequent use of fertilizer (sites 6, 7, and 13) resulted in less dense and patchy turf cover, increasing runoff. In ongoing turf studies at the University of Wisconsin (W.R. Kussow, Department of Soil Science, written commun., 2000), researchers found that not fertilizing turfgrass caused thinning of the turf, increased the amount of runoff, and increased nitrogen and phosphorus loss. Generally, the percentage of storms resulting in surface runoff from many of the lawns was higher than expected. Runoff from lawns may occur more frequently than previously thought because of the complex interaction of many factors.

Nutrient Concentrations in Runoff and Effects of Fertilizer Use

Summary statistics of nutrient concentrations measured in runoff from different site categories are given in table 3 and compared in figure 7. Detailed data for each of the sites were published annually in the U.S. Geological Survey Water-Data Reports (Holmstrom and others, 2000; Garn and others, 2001). There was a wide range in concentration of most nutrients among storms during the study period. Given this variability, geometric means or medians are more meaningful for comparison because they are better estimates of central tendency than arithmetic means. The nonparametric Kruskal-Wallis test was used to test for overall differences in concentration distributions, and the Wilcoxon rank sum test was used to test

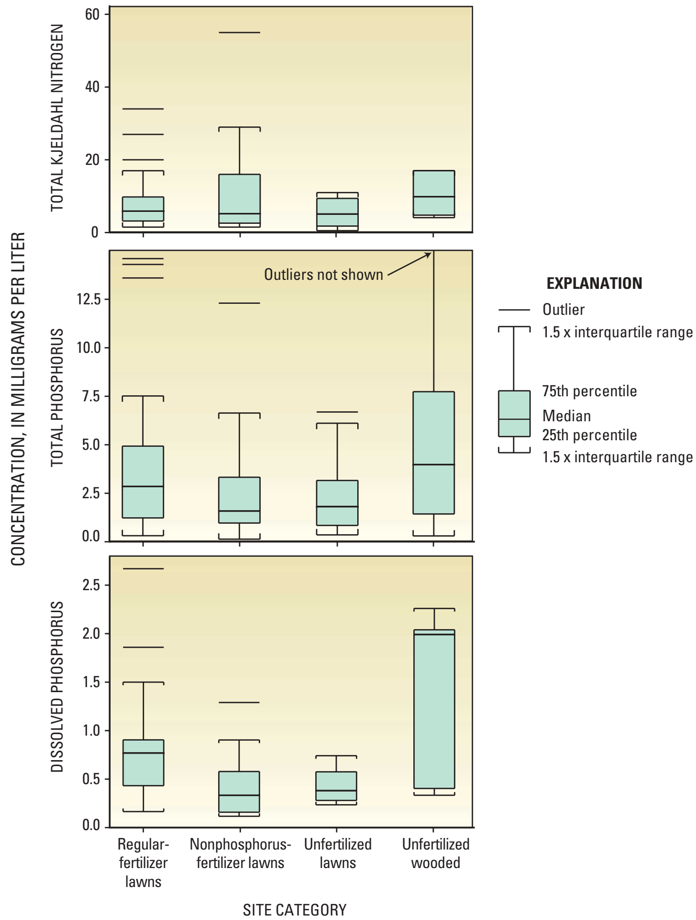

Figure 7. Nutrient concentrations in runoff from different categories of sampling sites at Lauderdale Lakes, Wis.

for differences in medians between pairs of lawn categories (P.W. Rasmussen, Wisconsin Department of Natural Resources, written commun., 2001). A confidence level of 10 percent ($p = 0.10$) was chosen to evaluate the results of the statistical tests. The difference in medians for samples from two different lawn categories was considered statistically significant if p values were less than 0.10.

A quality-control study was done to determine nutrient-concentration effects of grass clippings, earthworms, and insects that managed to get into water samples. All of these contamination sources had a large effect by increasing nitrogen and phosphorus concentrations. Samples that were affected by these contamination sources, identified from field notes, were excluded from data analysis, but the exclusions did not significantly change the overall results.

No significant differences in concentration among lawn categories were found for any of the nitrogen species. Fertilizer use did not affect total nitrogen concentrations in runoff. In addition, nitrite plus nitrate concentrations in runoff were generally low.

Dissolved phosphorus concentrations were significantly different ($p = 0.02$) among the lawn categories. Moreover, the median concentration of dissolved phosphorus from regular-fertilizer sites (0.77 milligram per liter (mg/L)) was significantly greater than that from nonphosphorus-fertilizer sites (0.33 mg/L) and unfertilized lawn sites (0.38 mg/L). Total phosphorus in runoff from regular-fertilizer sites compared to nonphosphorus-fertilizer and to unfertilized-lawn sites had p-values of 0.11 and 0.14, respectively. Thus, median total phosphorus concentrations were not significantly different at $p < 0.1$. Dissolved phosphorus was a fraction of total phosphorus, and its concentrations ranged from 22 to 45 percent of total phosphorus for all lawn categories.

Figure 8. Dense understory vegetation on wooded slope of sites 16 and 17 at Lauderdale Lakes, Wis.

The median dissolved phosphorus concentration in lawn runoff from regular-fertilizer sites was twice that for unfertilized and nonphosphorus-fertilizer sites. Runoff from lawn sites with nonphosphorus-fertilizer applications had a median dissolved phosphorus and total phosphorus concentration that was similar to unfertilized sites. Dissolved phosphorus in runoff is important because it is readily available for plant growth. Although not significant at $p < 0.1$, lawn sites with regular fertilizer applications had a median total phosphorus concentration in runoff that was 1.6 times that for unfertilized sites and 1.8 times that for nonphosphorus-fertilizer sites.

In comparison with other studies, phosphorus concentrations in lawn runoff at Lauderdale Lakes were slightly higher than concentrations found in runoff from urban lawns in Madison, Wis. (Waschbusch, Selbig and Bannerman, 1999), but were similar to those in lawn runoff from suburban lawns in Minneapolis/St. Paul, Minn. (Barten and Jahnke, 1997). Surprisingly, nutrient concentrations in runoff from the unfertilized, steep, wooded hillsides (sites 16, 17, and 18) were higher than those from the lawn sites and thus were separated from the unfertilized lawn sites in the data comparisons. These wooded sites (fig. 8) may be different from other wooded sites because of their steep slopes, thick surface organic and litter layer, and dense understory vegetation (crown vetch) planted for erosion control. Waschbusch, Selbig, and Bannerman (1999) found a direct relation between phosphorus concentration and percentage of overhead tree canopy that could affect source-area concentrations. In the Lauderdale Lakes study, however, all lawn categories contained sites with overhead tree canopy, and the lawn sites treated with regular fertilizer had the fewest trees; therefore, differences between regular-fertilizer sites and the other lawn sites could be even greater if there was an effect from tree cover.

Total phosphorus concentration in lawn runoff had a significant ($p = 0.08$) relation to soil-phosphorus concentration (table 1); total dissolved phosphorus had no significant relation. The low category of soil-phosphorus concentration (0 to 24 parts per million (ppm)) had a significantly lower median concentration of total phosphorus in lawn runoff (about half) than the medians from medium (25-65 ppm) or high (66 ppm or more) soil-phosphorus concentration lawns. There was no significant difference between runoff concentrations from medium and high soil-phosphorus concentration lawns. Barten and Jahnke (1997) also found a significant difference in concentration of phosphorus in runoff from different categories of lawn soil fertility. In their study, total and soluble reactive phosphorus concentrations in runoff from high soil-phosphorus concentration lawns were twice as large as the concentrations in runoff from low soil-phosphorus concentration lawns.

Median nutrient concentrations from the Don Jean Bay swale area with mixed land use were more similar to those from the unfertilized wooded sites and fertilized lawn sites than to those from other lawn sites (table 3). The range in concentrations for ammonia nitrogen and total Kjeldahl nitrogen in runoff from the swale, however, was greater than those for the other sites.

Although it was not within the scope of this study to measure runoff volumes from each of the sites and quantify the mass of nutrients transported offsite, the concentration data will be useful for future computations of unit-area loads (that is, mass of a particular nutrient species per unit contributing area). Concentrations of nutrients from lawns observed in this

Table 3. Statistical summary of nutrient concentrations in runoff from different site categories, Lauderdale Lakes, Wis. [n, number of samples; TKN, total Kjeldahl nitrogen; NO_2, nitrite nitrogen; NO_3, nitrate nitrogen; TP, total phosphorus; Diss P, dissolved phosphorus; all concentrations in milligrams per liter]

	Ammonia N	TKN	$NO_2 + NO_3$	TP	Diss P
Regular-fertilizer lawn sites					
Geometric mean	1.11	5.9	0.09	2.57	0.7
Median	1.07	5.9	0.12	2.85	0.77
Mean	2.18	8.6	0.17	4.02	0.93
Max	14.5	34	0.56	23.2	3.32
Min	0.05	1.5	0.01	0.31	0.17
n	23	23	23	58	23
Nonphosphorus-fertilizer lawn sites					
Geometric mean	1	6.5	0.14	1.89	0.34
Median	0.93	5.2	0.14	1.58	0.33
Mean	3.95	12.2	0.57	3.3	0.45
Max	36.2	55	5.22	23.5	1.29
Min	0.04	1.5	0.14	0.14	0.12
n	14	14	14	38	15
Unfertilized lawn sites					
Geometric mean	0.76	4.08	0.12	1.73	0.4
Median	0.63	5.1	0.14	1.81	0.38
Mean	1.12	5.85	0.17	2.33	0.43
Max	2.98	11	0.4	6.69	0.74
Min	0.22	0.53	0.01	0.36	0.23
n	9	9	9	19	8
Unfertilized wooded sites					
Geometric mean	2.95	12.7	0.16	3.52	1.04
Median	4.38	9.8	0.24	3.98	1.99
Mean	5.33	29.3	0.9	6.78	1.4
Max	11.6	130	2.24	30.6	2.26
Min	0.41	4.1	0.01	0.3	0.33
n	5	6	5	28	5
Don Jean Bay swale sites					
Geometric mean	3.48	14.5	0.06	2.46	0.49
Median	3.96	19	0.04	2.66	0.41
Mean	11.91	31.3	0.15	3.55	0.91
Max	88.1	160	0.6	9.07	3.33
Min	0.56	2	0.01	0.37	0.18
n	11	11	10	19	9

study are much greater (by 3 to 5 times) than the estimated concentrations used to calculate total phosphorus load from surface runoff to Lauderdale Lakes in a previous study by Garn and others (1996, p. 16). All of the nutrient load from lawn runoff may not actually reach or be deposited in the lake because of varying flowpaths, soil permeability, breaks in slope, vegetative buffers, and other obstructions; however, in many cases, lawns extend and slope continuously to the water's edge to provide a direct source of loading.

The annual phosphorus load from the nearshore area of Lauderdale Lakes may be greater than the 430 pounds previously estimated. Using a revised median concentration of 2.3 mg/L for surface runoff from an estimated 220 acres of developed shoreline (67 percent of shoreline) within 200 feet from the edge of water, annual total phosphorus load from residential lawns could be as much as 370 pounds (assuming all of the phosphorus reaches the lake). If a delivery of 50 percent of the load is assumed, and the total surface-water load is recomputed using the surface runoff values from the previous study, the total annual surface-water load from the nearshore drainage area would be 620 pounds, which represents 60 precent of the total annual phosphorus input from all sources. Studies at Lauderdale Lakes and several other ongoing studies by the USGS in Wisconsin will provide additional information on the effects of lawns and shoreline development on nutrient loads to lakes.

Limitations of Results

- Many runoff samples (about 30 percent) overflowed the collecting bottle and may not be truly representative of the mean concentration from each storm. According to T.D. Stuntebeck (U.S. Geological Survey, unpub. data, 2002), overflow samples for suspended solids and total phosphorus had higher concentrations than those from samples that did not overflow the container, but the opposite was true for dissolved phosphorus. Barten and Jahnke (1997) also found that overflow samples had lower concentrations for some constituents. Overflow occurred, however, for all categories of sites, and differences noted could potentially be even greater.
- The number of samples for some categories was relatively small for rigorous statistical analysis, and the small numbers could lead to inconsistencies among comparisons for different pairs of categories.
- Nutrient-concentration data are for onsite runoff and should be used with caution when making offsite interpretations. Not all of the nutrient load from lawn runoff may actually enter the lake.
- Some changes in nutrient species composition affecting dissolved constituents may have occurred in those samples that were not collected within 2 days after a storm.

Conclusions

- A high percentage of storms resulted in surface runoff from many of the lawns. Runoff from lawns may occur relatively frequently, more than 50 percent of the storms for many lawns.
- Fertilizer use did not affect nitrogen concentrations in runoff. Nitrite plus nitrate concentrations in runoff were generally low.
- Total phosphorus concentration in lawn runoff was directly related to the phosphorus concentration of lawn soils.
- Dissolved phosphorus concentrations were significantly different among the lawn categories; the median from regular-fertilizer sites was twice that from unfertilized or nonphosphorus-fertilizer sites.
- Runoff from lawn sites with nonphosphorus fertilizer applications had a median total phosphorus concentration that was similar to that of unfertilized sites, an indication that nonphosphorus fertilizer use may be an effective, low-cost practice for reducing phosphorus in runoff.

Acknowledgments

Thanks are extended to Scott Mason of the Lauderdale Lakes Lake Management District for his assistance in this study; to the lakeshore homeowners that allowed us to install sampling equipment in their lawns; and to the Wisconsin Department of Natural Resources, Lake Protection Grant Program.

References Cited

Barten, J.M., and Jahnke, Ethan, 1997, Suburban lawn runoff water quality in the Twin Cities Metropolitan Area, 1996 and 1997: Maple Plain, Minn., Hennepin Regional Park District, Water Quality Management Division, 17 p.

Barth, C.A., 1995, Nutrient movement from the lawn to the stream: Center for Watershed Protection, Watershed Protection Techniques v. 2, no. 1, pp. 239–246.

Doerr, S.H., Shakesby, R.A. and Walsh, R.P.D., 2000, Soil water repellency—its causes, characteristics, and hydro-geomorphological significance: Earth-Science Reviews, v. 51, no. 1, p. 33–65.

Garn, H.S., Olson, D.L, and Ellefson, B.R., 2001, Water-resources data for Wisconsin, water year 2000: U.S. Geological Survey Water-Data Report WI-00-1, 560 p.

Garn, H.S., Olson, D.L., Seidel, T.L., and Rose, W.J., 1996, Hydrology and water quality of Lauderdale Lakes, Walworth County, Wisconsin, 1993–94: U.S. Geological Survey Water-Resources Investigations Report 96-4235, 29 p.

Haan, C.T., Barfield, B.J., and Hayes, J.C., 1994, Design hydrology and sedimentology for small catchments: San Diego, Academic Press, 588 p.

Haszel, O.L., 1971, Soil survey of Walworth County, Wisconsin: U.S. Department of Agriculture, Soil Conservation Service, 107 p.

Holmstrom, B.K., Olson, D.L, and Ellefson, B.R., 2000, Water-resources data for Wisconsin, water year 1999: U.S. Geological Survey Water-Data Report WI-99-1, 578 p.

Kostka, S.J., 2000, Amelioration of water repellency in highly managed soils and the enhancement of turfgrass performance through the systematic application of surfactants: Journal of Hydrology, v. 231/232, p. 359–368.

National Oceanic and Atmospheric Administration, 1999–2000, Climatological Data—Wisconsin, published monthly, 36 p.

Waschbusch, R.J., Selbig, W.R., and Bannerman, R.T., 1999, Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin, 1994–95: U.S. Geological Survey Water-Resources Investigations Report 99-4021, 47 p.

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A REVIEW OF LOW IMPACT DEVELOPMENT POLICIES: REMOVING INSTITUTIONAL BARRIERS TO ADOPTION

Commissioned and Sponsored by:
California State Water Resources Control Board Stormwater Program
And
The Water Board Academy

Project Officer:
Greg Gearheart, P.E.

December 2007

The Low Impact Development Center, Inc.

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EXECUTIVE SUMMARY

Managing stormwater runoff has historically presented technical challenges because of its diffuse and episodic nature, the range of pollutants requiring treatment, and the volume of runoff resulting from changes in land cover. Complicating the technical challenges is a regulatory environment that has been based on presumptive minimum treatment standards and has not effectively promoted innovative treatment approaches. Recent research and pilot applications have demonstrated efficient approaches to control and treat stormwater runoff and have removed many of the technical barriers. However, regulatory and institutional barriers still exist and can prevent application of effective control programs.

This analysis reviewed the State of California's primary mechanisms of regulating stormwater runoff and considered how low impact development (LID) approaches could be used for compliance purposes. A review of the country's more progressive regulatory approaches is also included to illustrate requirements or incentives for LID or other innovative treatment programs. California has already made steps toward a regulatory system that encourages better treatment performance and the application of LID; the State Water Resources Control Board's recent emphasis on limiting hydromodification impacts (changes in a site's runoff and transport characteristics) from development will create the framework for broader adoption of LID. In addition, the Porter-Cologne Act (commonly referred to as the California Water Code) allows the Water Boards broad discretion to implement innovative natural resource protection programs because it allows the regulation of any activity or factor that affects water quality and is not narrowly focused on end-of-pipe treatment.[1]

INTRODUCTION

When the Clean Water Act (CWA) was amended in 1987, a federal mandate to manage and control stormwater was established.[2] The past 20 years have witnessed significant shifts in the science and regulatory environment of municipal and post-construction runoff control. The recent movement to address stormwater on a watershed basis by limiting hydromodification and the volume of discharges is a departure from the convention of peak flow limitation and flood control. Advances in understanding the relationship between hydromodification and stream health and the science to preserve or restore water quality have greatly outpaced the changes in the regulatory environment and institutional structures that influence stormwater programs, neither of which having ever fully matured to achieve water quality or environmental goals.

With the technical approach coming into focus, the regulatory system needed to foster and propel these new strategies has not yet been developed. The intent of regulatory compliance is not necessarily meeting resource objectives. Regulations often set a minimum benchmark of environmental effort and often are not or cannot be designed to fully achieve water quality objectives. Maximum extent practicable or water quality standards along with other programs and efforts are used to augment regulations to achieve the full desired environmental outcome. Designing regulations and integrating them with other programs to achieve desired outcomes and benefits is critical to improving stormwater management.

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[1] California Water Code sections 13000, 13050(i), 13140, 13142, 13241.
[2] 40 CFR 122.26

Several states, including California, have begun to evaluate the regulatory changes that are required and the impacts that they will have on the success of their programs. This effort is one step in that process. This paper will focus on municipal and post-construction runoff and review the regulatory and institutional structure that influences stormwater control in California. It will also evaluate new programs and efforts aimed at improving stormwater management. Lastly it will evaluate policy and program options that could further advance the implementation of comprehensive water programs.

BACKGROUND

The diversity of climatic and geographic conditions within California has influenced the structure of the State's water agencies. The State Water Resources Control Board (SWRCB), created in 1967, has water allocation and water quality protection responsibilities. Nine Regional Water Quality Control Boards (RWQCBs), established along major watershed boundaries, have development and enforcement responsibilities of water quality objectives and implementation plans. The U.S. Environmental Protection Agency (EPA) has authorized the State to administer the National Pollutant Discharge Elimination System (NPDES) program, which uses statewide and regional programs to fulfill the mandated requirements. Municipal NPDES permits are issued by the Regional Boards.

The Porter-Cologne Water Quality Control Act, passed in 1969 and predating the CWA, is the main statute that governs water quality control in the state. Porter-Cologne subjects any activity or factor that affects water quality to regulation and covers point and non-point sources. By looking comprehensively at influences on water quality, not only are pollutant discharges subject to regulation, but also parameters such as flow or riparian or land use changes that can impose physical or temperature impacts.[3] Porter-Cologne applies to all waters of the state including wetlands and groundwater. It also establishes the tenant that waste discharges to state waters are a privilege and not a right.[4,5]

Through Porter-Cologne the SWRCB and RWQCBs are provided:[6]

1. Planning authority to designate beneficial uses of State waters, establish water quality objectives, and develop implementation programs to meet water quality objectives and designated uses.
2. Permitting authority.
3. Enforcement authority to ensure permit compliance.

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[3] J. M. Gerstein, et al., *State and Federal Approach to Control of Nonpoint Sources of Pollution*, University of California Cooperative Extension, August 2005.
[4] State Water Resources Control Board, *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*, May 20, 2004.
[5] When the 1987 amendments to the CWA designated municipal stormwater runoff as a point source, regulation of stormwater came under the provisions of the National Pollutant Discharge Elimination System (NPDES) program. California, like other states, has a defined institutional and regulatory separation between municipal stormwater and other non-point sources that are influenced by Porter-Cologne.
[6] State Water Resources Control Board, *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*, May 20, 2004.

With this authority, the SWRCB is responsible for setting statewide policy and regulations, in addition to developing statewide water quality control plans. Based on the SWRCB policies, the nine RWQCBs develop individual water quality control plans, referred to as Basin Plans. Once developed, the basin plans must be approved by the SWRCB, the Office of Chief Council, and the U.S. EPA.[7] The coordinated efforts between the State and Regional Boards constitute the primary mechanism through which the State addresses point and nonpoint source pollution and implements its control program. The SWRCB also has the authority to adopt statewide water quality control plans, like the California Ocean Plan, the Plan for California's Nonpoint Source Pollution Control Program, and the California Thermal Plan. The Ocean Plan contains a prohibition of any discharge of waste (e.g., stormwater) to waters designated as Areas of Special Biological Significance (ASBS).

In addition to the framework above, a number of other regulatory agents and programs (e.g., the California Water Boards and CWA 401 Certification, the California Coastal Commission and the Coastal Zone Act Reauthorization Amendments) also directly impact stormwater discharges in the state. Although not discussed in detail, the requirements of these programs work in concert with the stormwater program and can lead to more stringent pollutant discharge limitations in runoff.

NPDES Permits

Construction General Permit

The SWRCB last issued statewide general NPDES stormwater permits for designated construction activities in 1999 (SWRCB Order 99-08-DWQ). This permit contains minimum requirements to control post-construction runoff. Page 79 of SWRCB Order 99-08-DWQ states:

> *10. Post-Construction Storm Water Management*
>
> *The SWPPP shall include descriptions of the BMPs to reduce pollutants in storm water discharges after all construction phases have been completed at the site (Post-Construction BMPs). Post-Construction BMPs include the minimization of land disturbance, the minimization of impervious surfaces, treatment of storm water runoff using infiltration, detention/retention, biofilter BMPs, use of efficient irrigation systems, ensuring that interior drains are not connected to a storm sewer system, and appropriately designed and constructed energy dissipation devices. These must be consistent with all local post-construction storm water management requirements, policies, and guidelines. The discharger must consider site-specific and seasonal conditions when designing the control practices. Operation and maintenance of control practices after construction is completed shall be addressed, including short-and long-term funding sources and the responsible party.*

[7] State Water Resources Control Board, *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*, May 20, 2004.

While this language describes LID techniques, there is no level of compliance specified. The standard for the Construction General Permit is Best Available Technology economically achievable/ Best Conventional pollutant control Technology (BAT/BCT).[8] However, since it is not easy to apply a technology standard to the practice of minimizing land disturbance, this permit language is difficult to enforce. Municipal permits have the standard of Maximum Extent Practicable (MEP) which lends itself more naturally to specifying and enforcing a level of compliance for low impact development.

In March 2007 the SWRCB released a preliminary draft NPDES stormwater permit for construction activities as part of the Reissuance process of SWRCB Order 99-08-DWQ. This preliminary draft permit contains much more specific requirements for post-construction stormwater runoff. If approved, the new permit would establish statewide post-construction runoff standards. This would significantly alter the existing framework that relies on the municipalities to address post-construction runoff and leaves the unincorporated areas of the State largely unaddressed. The draft permit requires mitigating hydromodification by maintaining pre-development hydrologic characteristics on a site.[9]

<u>Municipal Phase I Permits</u>

The Regional Boards are currently using their authority to issue municipal separate storm sewer system (MS4) permits to address post-construction runoff.[10] Each Regional Board issues individual MS4 NPDES stormwater permits to their qualifying or designated Phase I permittees. At a minimum these require the MS4 permittees to develop and implement plans such as Standard Urban Storm Water Mitigation Plans (SUSMPs) that address new development and redevelopment projects that disturb more than one acre.[11,12] For example, the SUSMPs in the Los Angeles Water Board jurisdiction establish which types of development will be required to implement stormwater controls and the control, pollutant removal, site design, and maintenance requirements. The Los Angeles County SUSMP stipulates the following runoff requirement:[13]

> *Post-development peak stormwater runoff discharge rates shall not exceed the estimated pre-development rate for developments where the increased peak stormwater discharge rate will result in increased potential for downstream erosion.*

This language, which is typical for many municipal stormwater permits in California and the country, establishes the regulated physical stormwater parameter as the *rate* of discharge. This definition is typically based on one or more single peak storm events rather than continual flow information from runoff events. The SUSMP regulatory construct is in line with the historical

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[8] State Water Resources Control Board, National Pollutant Discharge Elimination System General Permit for Storm Water Discharges Associated with Construction Activity, Water Quality Order 99-08-DWQ, p.1.

[9] State Water Resources Control Board, Draft National Pollutant Discharge Elimination General System General Permit Number CAR000002, Waste Discharge Requirements For Discharges Of Storm Water Runoff Associated With Construction Activity, March 2007.

[10] Personal communication, Eric Berntsen, State Water Resources Control Board, April 2007.

[11] Memo from the SWRCB Office of Chief Counsel on SWRCB Order WQ 2000-11: SUSMP, Craig M. Wilson, December 26, 2000.

[12] Los Angeles County Urban Runoff and Stormwater NPDES Permit, Standard Urban Stormwater Mitigation Plan, March 2000.

[13] Ibid.

thinking about stormwater impacts that postulated that the velocity of stormwater was the main factor impacting receiving stream quality and channel impacts. This primary requirement along with site design and treatment requirements form the range of requirements necessary to be satisfied for new development and redevelopment.

Municipal Phase II Permit

The SWRCB adopted a statewide General Phase II MS4 Permit in April, 2003 (SWRCB Order No. 2003-0005-DWQ). The permit contains similar post-construction language to Phase I permits.

The Central Coast Water Board requires municipalities, via the General Phase II MS4 Permit, to minimize negative impacts on aquatic ecosystems and degradation of water quality to the maximum extent practicable by incorporating LID methodology into new and redevelopment ordinances and design standards, unless permittees can demonstrate that conventional BMPs are equally effective, or that conventional BMPs would result in a substantial cost savings while still adequately protecting water quality and reducing discharge volume. In order to justify using conventional BMPs based on cost, permittees must show that the cost of low impact development would be prohibitive because the “cost would exceed any benefit to be derived.” (State Water Resources Control Board Order No. WQ 2000-11). The Central Coast Water Board has determined that conventional site layouts, construction methods, and stormwater conveyance systems with “end-of-pipe” basins and treatment systems that do not address the changes in volume and rates of storm water runoff and urban pollutants (including thermal pollution) do not meet MEP standards.[14]

HYDROMODIFICATION

Changes in land cover are the cause of hydromodification: changes in a site’s runoff and transport characteristics. Impervious surfaces, compacted soils, deforestation, and topographic modifications alter the distribution and flow of water across a site. Infiltration, interception, and evapotranspiration are diminished and a greater percentage of precipitation is converted to overland flow. These changes impact the water balance on site, less water infiltrates and is available for groundwater recharge or shallow subsurface flows that constitute the base flows of receiving streams. In addition, the increased volume of overland flow imparts physical impacts on receiving streams and transports pollutants that have collected on impervious surfaces.[15]

The effects of hydromodification can be demonstrated on a hydrograph, a representation of a site’s stormwater discharge with respect to time. The hydrograph in Figure 1 shows development’s impact on a site’s runoff. Individual points on the curve represent the rate of stormwater discharge at a given time. The graph shows that development and corresponding changes in land cover result in greater discharge rates, greater volume, and a shorter time to reach the maximum discharge rate (referred to as time of concentration, T_c). In a natural or pre-

[14] Central Coast Water Board Low Impact Development web page, How LID is currently required: http://www.waterboards.ca.gov/centralcoast/stormwater/low%20impact%20devel/lid_index.htm (accessed November 2007).

[15] U.S. EPA, *Protecting Water Quality from Urban Runoff*, Nonpoint Source Control Branch, EPA-841-F-03-003, February 2003.

development condition the initial rainfall is absorbed by the soil and vegetation. Once these are saturated, or the initial losses are satisfied, runoff occurs. In the post-development condition there is generally a much shorter time before runoff begins because of connectivity of impervious and developed areas and the loss of vegetative cover.

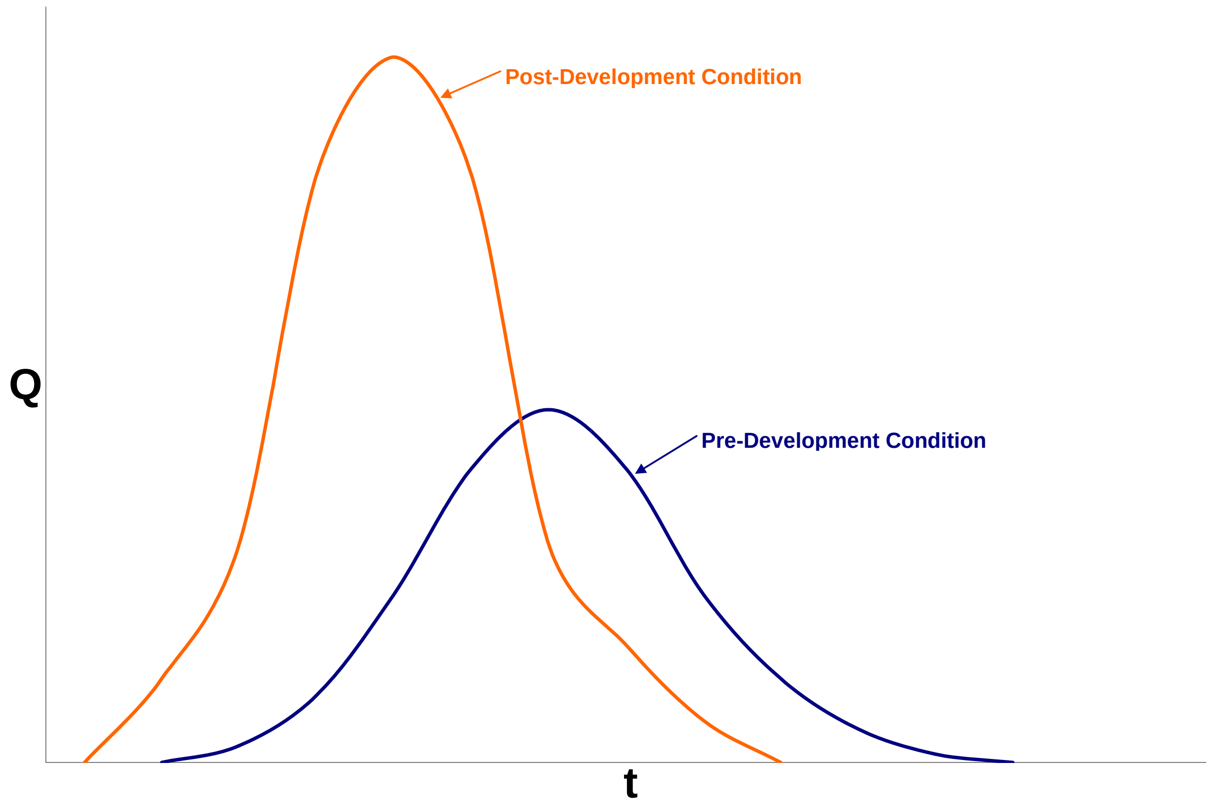

Figure 1. Hydrographs showing development's impact on runoff.
(Q = volumetric flow rate; t = time)

The area under the hydrographs represents the total volume of stormwater discharged. Along with the increased rate of discharge is an increased volume of discharge after development. The first analyses of these hydrograph impacts produced the consensus that the maximum rate of discharge was the critical parameter for protecting the integrity of receiving streams. The result of this concept was a regulatory structure, like those witnessed in many SUSMPs, that establishes requirements for the peak rate of discharge. Figure 2 shows how the post-development hydrograph responds to this type of regulatory structure.

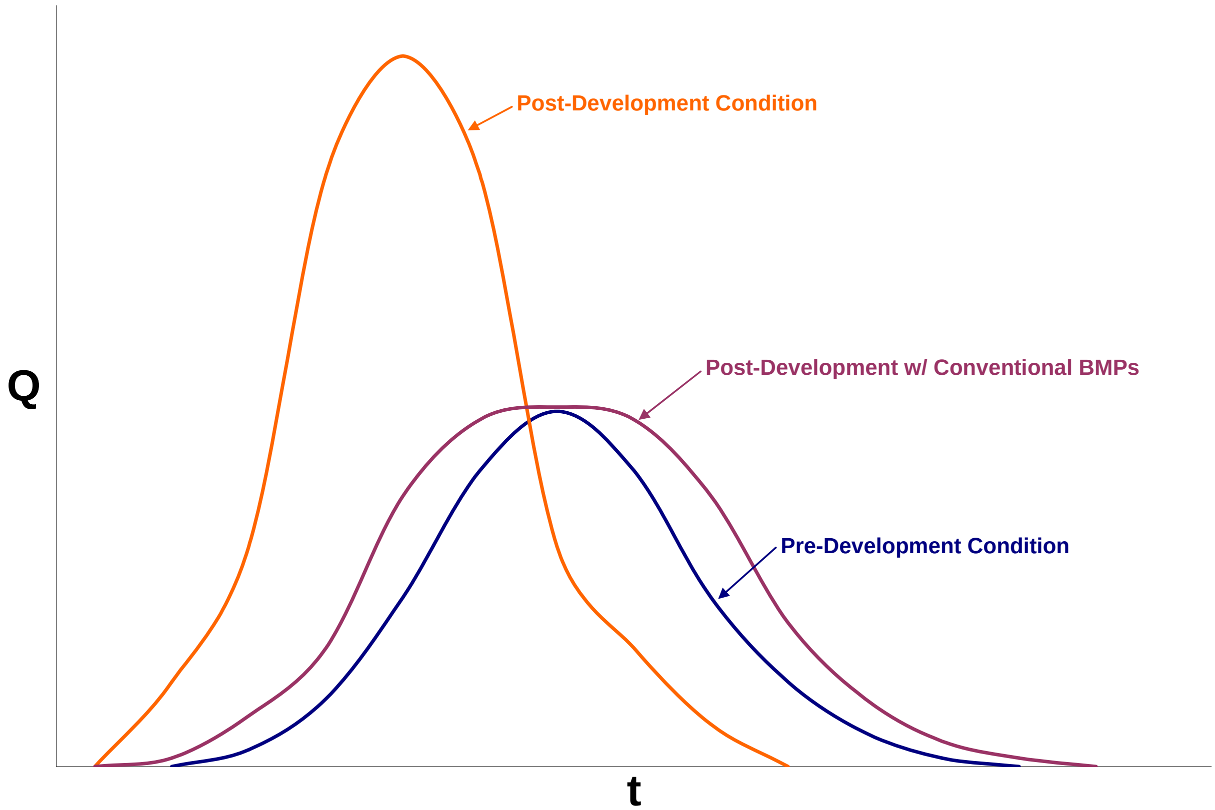

Figure 2. Post-development hydrograph response to conventional BMPs.
(Q = volumetric flow rate; t = time)

As Figure 2 illustrates, although the post-construction rate of stormwater discharge is equivalent to the pre-construction rate, it is sustained for a longer period of time and the total volume and energy of stormwater discharged, when compared to pre-development, is greater. This hydrograph response illustrates one reason why stormwater control efforts have been largely unsuccessful. Even when peak discharge rates are matched, the increased volume of stormwater delivers more energy and an increased amount of pollutants to the receiving stream when compared to pre-developed conditions. This result demonstrates the inefficiencies of the prevailing regulatory system and helps to predict that this type of framework will be unlikely to ultimately achieve water quality goals.

A regulatory system that attempts to address this deficiency and reduce the increase in the volume of stormwater discharge will propose a standard that stipulates that the rate of post-construction discharge will be equal not only to the pre-development peak rate, but also as every point-in-time along the hydrograph. This approach, a version of which is presented in the draft Construction stormwater NPDES permit, results in the hydrograph response represented in Figure 3.

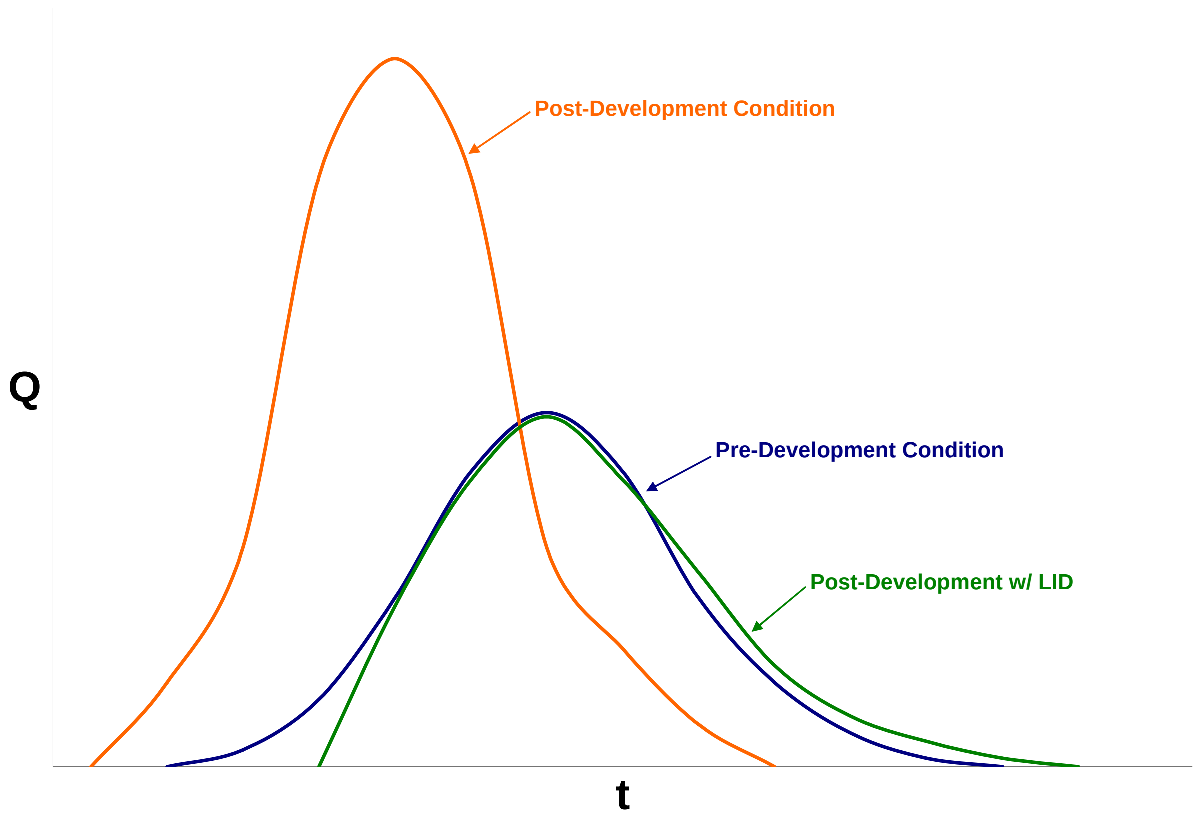

Figure 3. Post-development hydrograph response to LID controls.
(Q = volumetric flow rate; t = time)

Low Impact Development's Influence on Hydromodification

Traditionally, a wastewater collection and treatment system approach has been applied to stormwater management. End-of-pipe treatment and control technologies have been the predominate methods of stormwater control. However, this system of control essentially concedes the inevitability of hydromodification; that the only control options are those that deal with the consequences of development without addressing the root causes of the problem. To be fair, many stormwater management plans and manuals address site design, source control, and pollution prevention strategies. Mostly though, these are presented as "add-on" options that may be done above the standard end-of-pipe controls. The regulatory mandates still largely preserve the centralized collection and treatment system of control.

Over the past decade, LID has emerged as an alternative management approach. Rather than centralized, end-of-pipe controls, LID relies on an integrated system of decentralized, small-scale control measures. These measures range from site design practices to technology driven LID BMPs. The underlying principle of LID is that undeveloped land does not present a stormwater runoff or pollution problem. The evolved natural hydrology of any given site manages water in the most efficient manner. This most often translates to high rates of infiltration, vegetative interception, and evapotranspiration.

LID attempts to offset the inevitable consequences of development and changes in land cover by preserving or mimicking natural hydrology. It is a source control option that minimizes stormwater pollution by recognizing that the greatest efficiencies are gained by minimizing stormwater generation. This is a process that begins with functional conservation of watershed resources, reducing impacts of development, and then using innovative management practices to meet the stormwater objective; it is not the use of the management practices alone. Site preservation practices coupled with small-scale BMPs that rely on the environmental services of vegetation and soils or systems that mimic these services comprise the control approach of LID. These practices, taken in aggregate, limit the observed hydromodification on a developed site and present a more comprehensive and beneficial control approach.

Needing to be addressed, however, is the lag in broad LID implementation. Even though it has been demonstrated as an attractive strategy, its application is limited and has not yet been fully integrated. Several barriers have generally slowed and hampered greater LID adoption. Bureaucratic inertia involving the entrenchment of prevailing conventional practices, institutional structures, and regulatory shortfalls are the prime barriers preventing a broad shift in stormwater management philosophy. Of these, regulatory structure is the most critical barrier. If regulations are crafted appropriately and call for proper environmental performance, a significant catalyst for overcoming the other barriers will be created and facilitate further institutional changes.

To appropriately implement LID it is important to assess its role in water quality protection. LID is one part of a toolkit that can be used to better manage natural resources and limit the pollution delivered to waterways. It is not independent of watershed planning and to gain optimal benefits LID needs to be integrated with appropriate land use programs. LID by itself will not deliver the water quality outcomes desired; it does provide enhanced stormwater treatment and mitigate excess volume and flow rates. However, if not integrated in a comprehensive fashion, LID techniques can end up as a series of uncoordinated innovative BMPs that have limited water quality benefit.

The potential of LID is maximized when it is used in conjunction with other conservation and planning approaches. Programs like Smart Growth are the first step of the process. Before LID is used, decisions about where and how to develop within the watershed need to be evaluated to limit water quality impacts. Once these decisions are made, LID can then be used to mitigate the impacts of the development. Coordinating and integrating LID with Smart Growth and other innovative land use approaches will limit conversions in land cover, preserve natural watershed areas, and maximize the management of stormwater runoff. In urbanized areas, LID can be coordinated with green building and redevelopment efforts and it can be used to augment infrastructure projects by enhancing capacity. Retrofitting LID in urban locations provides opportunity to provide multiple environmental, social, and infrastructure benefits.

REGULATORY CLIMATE

Stormwater presents a significant challenge for establishing efficient and effective regulations. Its episodic and dynamic nature is the polar opposite of the largely predictable and constant nature of municipal and industrial wastewater discharges that have been such a large focus of the regulatory and permit efforts of the past decades. Incorporating stormwater into these programs has been an institutional and technological challenge.[16] The resulting approach to stormwater control has been an adoption and reliance on minimum control measures that are implemented to demonstrate compliance with stormwater management plans. Discharge flow limitations and water quality criteria are often required and influence the selection of control measures. Even with the best efforts of these programs, water quality and use designations of waters nationwide are still well short of their intended goals.

The prevailing problem is that the current construct of many stormwater regulations do not require the use of the best available technologies and do not address hydromodification. This regulatory shortfall has hampered innovative applications of new technologies and an institutional shift in the practice of stormwater management. In California and other locations around the country, innovative practices are being adopted with increasing frequency. In certain instances innovation and implementation are outpacing regulatory programs and driving the revision of regulations; in others, innovative regulations have been adopted to establish environmental performance criteria that provide a significant incentive to adopt new control strategies. In either case, the resulting regulatory and incentive structures are informative for new program development.

A critical differentiation in regulatory application exists and will be presented in the examples in the following section. Minimizing and mitigating hydromodification is a critical performance criterion for Greenfield development. Undisturbed, Greenfield sites still possess natural hydrologic characteristics and attributes that can be used to inform appropriate control and mitigation strategies. Development or redevelopment of previously developed urban areas will require surrogate performance criteria. The natural hydrology of these areas has largely been lost due to the impacts of decades or centuries of urbanization. Linking performance criteria to hydrology in these areas is not as practical as Greenfield sites, but other approaches are used to approximate the desired outcomes of limited runoff volumes and pollutant loads.

POLICIES AND PROGRAMS

The following examples demonstrate how various jurisdictions have crafted their regulations to mitigate hydromodification or an increase in the volume of stormwater discharge.

- **401 Certifications**

  Section 401 of the CWA grants each state the right to ensure that the State's interests are protected concerning any federally permitted activity occurring in or adjacent to Waters of the State. In California, the Regional Water Quality Control Boards (Regional Boards) are the agency mandated to ensure protection of the State's waters. If a proposed project requires a U.S. Army Corps of Engineers CWA Section 404 permit, or involves dredge or fill activities that may result in a discharge to U.S. surface waters and/or "Waters of the State" the project proponent is required to obtain a Clean Water Act (CWA) Section 401 Water

[16] The NPDES program is not the only available avenue for regulating stormwater discharges. Other federal, state, and local water policies or programs offer significant opportunity for the development of comprehensive stormwater programs. In some cases, these provisions have influenced stormwater management, but municipal stormwater control is still largely driven by the NPDES program.

Quality Certification and/or Waste Discharge Requirements (Dredge/Fill Projects) from the Regional Board, verifying that the project activities will comply with state water quality standards.[17]

Section 401 gives the Regional Boards the authority to consider the impacts of the entire project and require mitigation for volume, velocity, and pollutant load of the discharge from new outfalls to surface waters. Some Regional Boards that have large areas not covered by Phase I or II Municipal permits, require low impact development and hydromodification mitigation consistent with municipal post-construction design standards.

- **404 Compliance**

Section 404 of the CWA regulates fill and disturbance of wetlands and waters of the United States. The US Corps of Engineers, Norfolk District, (which has permit review responsibilities) encourages 404 compliance with the use of LID principles. Projects applying for a permit are required to demonstrate that they have avoided and minimized impacts to jurisdictional areas to the maximum extent practicable. For unavoidable impacts, projects may be required to provide compensatory wetland mitigation. The Norfolk District office considers LID practices as partial mitigation, provided that there is no project-specific loss of wetland acreage.

This allowance is intended to minimize impacts that the Corps has witnessed to wetlands and streams that are associated with conventional stormwater management facilities. Therefore, the Corps allows consideration of LID BMPs (e.g., swales, bioretention facilities) as viable alternatives to in-channel or in-wetland stormwater basins. The initiative's goal is to reduce the number and size of conventional stormwater facilities impacting wetlands or waters of the U.S. In addition, the emphasis on LID design and BMPs is intended to ensure that the post-development and pre-development hydrographs are similar to reduce wetland impacts and maintain pre-development groundwater recharge.

- **Preliminary Draft California NPDES Construction General Permit for Stormwater Discharges**

The preliminary draft revised General Permit, released for comment in March 2007, included for the first time post-construction stormwater control performance standards.[18] Previously post-construction language was difficult to enforce as the standard of BAT/BCT was not easily applied to low impact development practices. If accepted, the draft permit will establish consistent state-wide post-construction standards that can be enhanced or augmented by the Regional Boards. The permit stipulates several performance standards for new development and redevelopment as identified below.

[17] North Coast Water Board, 401 Certification web page: http://www.waterboards.ca.gov/northcoast/programs/wqwetcert.html, (accessed November 2007).
[18] State Water Resources Control Board, National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges - Associated Construction and Land Disturbance Activities, March 2, 2007.

1. *The discharger shall, through the use of non-structural and structural measures, ensure that the post-development runoff volume approximates the pre-project runoff volume for areas covered with impervious surfaces...*
2. *For projects whose disturbed project area exceeds two acres, the discharger shall preserve the post-construction drainage divides for all drainage areas serving a first order stream or larger and ensure that post-project time of concentration is equal or greater than pre-project time of concentration.*
3. *For projects whose disturbed project area exceeds 50 acres, the discharger shall preserve pre-construction drainage patterns by distributing their non-structural and structural controls within all drainage areas serving first order streams or larger and ensuring that post-project time of concentration is equal to or greater than pre-project time of concentration.*

The regulatory approach of the draft permit is one of volume and time of concentration control. Pre-development site hydrology must be evaluated and guides post-construction performance objectives. The pre-development water balance must be approximated so that there is no increase in the volume of runoff that leaves the site. In addition, while the regulation expressly permits the use of both non-structural and structural controls, it is likely that achieving the hydrologic objectives of the standard will require a significant reliance on LID techniques.

- **Santa Clara Valley Hydromodification Management Plan**

The RWQCB, San Francisco Bay Region, requires stormwater programs to develop and implement hydromodification management plans (HMPs). The Santa Clara Valley Urban Runoff Pollution Prevention Program was the first permit to include the new HMP requirements.[19] The Program's hydromodification control standard requires that those who discharge stormwater manage increases in peak runoff flow and increased runoff volume where the increased volume or flow can cause erosion or siltation problems. The implemented HMP limits post-construction runoff to pre-construction rates and/or durations.[20]

Performance criteria to demonstrate compliance with the hydromodification control standard are also presented in the permit. The first of which is that the project shall use stormwater controls to maintain pre-construction stream erosion potential.[21] The second requires that post-construction stormwater discharge rates and flow durations be equivalent to pre-construction values for flows from 10% of the 2-year peak flow up to the full 10-year peak flow.[22]

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[19] Santa Clara Valley Urban Runoff Pollution Prevention Program, Hydromodification Management Plan – Final Report, April 21, 2005.
[20] Ibid.
[21] Erosion potential is a measure of how a site's runoff hydraulically impacts a receiving stream. Greater volumes of stormwater released at greater rates and for longer durations impart greater physical impacts on receiving streams.
[22] Santa Clara Valley Urban Runoff Pollution Prevention Program, Hydromodification Management Plan – Final Report, April 21, 2005.

Santa Clara's HMP is an interesting case because the language differs greatly from conventional stormwater control regulations. By requiring quantification of the erosion potential of a site, the HMP directly addresses both the rate and volume of discharge. This requirement, coupled with flow duration criteria for small storms up to the 10-year storm, will require sites to maintain the pre-development hydrograph for a large percentage of storm events post construction.

This regulatory construct is efficient for several reasons. A great majority of stormwater regulations contain requirements for peak control only. As discussed in the background of this report, controlling only that single parameter is not sufficient to adequately protect receiving stream water quality because increased stormwater volumes and extended durations contribute larger mass loads of pollutants and impart greater physical impacts. By establishing discharge performance criteria for the volume, rate, and duration, these standards are more protective and demonstrate the full complement of factors that require control to limit the physical impacts of stormwater discharges.

Also important is the range of storms for which the duration of discharge must be controlled. Stormwater regulations routinely pick two design storms (often the two and 10 year events) for which peak flow rate requirements are established. The consequence of this is that no control is provided for the most frequently occurring small storms that are less than the two year event. Research shows that post-construction discharges from these small, frequent storms have much greater physical impacts than originally thought. Along this same line is the ability to effectively manage dry flows which can constitute a significant portion of runoff and pollutant transport in many areas of California. The duration control criterion recognizes the impacts of these small storms and established performance criteria designed to mitigate these effects.

- **San Diego County Phase I MS4 Permit**

In January 2007, the San Diego Regional Water Quality Control Board reissued the Phase I Municipal Stormwater Permit for San Diego County.[23] The permit has specific requirements for the implementation of low impact development BMPs and a Hydromodification Management Plan. Not only does the permit specify that LID is required to meet MEP for retail gas outlets and heavy industry meeting certain criteria, but also the permit requires all new and redevelopment projects to implement LID BMPs where feasible.

Priority Development Projects, a subset of development projects with a particular potential threat to water quality, as specified in the permit, are required to implement LID in the following ways:

[23] California Regional Water Quality Control Board, San Diego Region, Order No. R9-2007-0001, NPDES NO. CAS0108758, Water Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems Draining the Watersheds of the County of San Diego, the Incorporated Cities of San Diego County, the San Diego Unified Port District, and the San Diego County Regional Airport Authority.

1. Draining a portion of the site's impervious areas into pervious areas prior to discharge to the MS4.[24]
2. Properly designing and constructing the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas.
3. Constructing a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces.

Another set of LID BMP requirements apply to Priority Development Projects where feasible:

1. Conserve natural areas, including existing trees, other vegetation, and soils.
2. Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised.
3. Minimize the impervious footprint of the project.
4. Minimize soil compaction.
5. Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions).

Permittees are then given the responsibility of defining the applicability and feasibility of LID BMPs. They are required to establish minimum standards to maximize the use of LID practices and principles as a means of reducing stormwater runoff. This includes siting, design, and maintenance criteria for each LID BMP to ensure that they are constructed correctly and are effective at pollutant removal and/or runoff control. Additionally, prior to occupancy of a Priority Development Project, the LID BMPs must be inspected to verify compliance with specifications. Education concerning how to implement LID BMPs into the local regulatory programs and methods of minimizing impacts to receiving waters as a result of development is required for municipal personnel and development planning staff.

The permit's hydromodification requirements also apply to all Priority Development Projects. Each permittee must develop and apply criteria for priority projects so that runoff discharge rates, durations, and velocities are controlled to maintain or reduce downstream erosion conditions and protect stream habitat.

The Hydromodification Management Plan (HMP) must include:

1. A stability standard for channel segments which receive urban runoff discharges.
2. A range of runoff flows for which post-project runoff flow rates and durations shall not exceed pre-project runoff flow rates and durations.
3. Hydrologic control measures so that post-project runoff flow rates and durations do not exceed pre-project runoff flow rates and durations, and do not result in channel conditions which do not meet the channel standard.

[24] "Portion" corresponds with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.

4. Other performance criteria (numeric or otherwise) as necessary to prevent urban runoff from increasing erosion of channel beds and banks, silt pollutant generation, or other impacts to beneficial uses and stream habitat due to increased erosive force.
5. A review of pertinent literature.
6. A protocol to evaluate potential hydrograph change impacts to downstream watercourses.
7. A description of how the HMP requirements will be incorporated into the local approval processes.
8. The identified range of runoff flows to be controlled expressed in terms of peak flow rates of rainfall events.
9. Criteria for selection and design of management practices and measures to control flow rates and durations and address potential hydromodification impacts.
10. Technical information supporting standards and criteria proposed.
11. A description of inspections and maintenance to be conducted for management practices and measures to control flow rates and durations and address potential hydromodification impacts.
12. A description of pre- and post-project monitoring and other program evaluations to be conducted to assess the effectiveness of implementation of the HMP.
13. Mechanisms for addressing cumulative impacts within a watershed on channel morphology.
14. Information on evaluation of channel form and condition, including slope, discharge, vegetation, underlying geology.

Until the HMP is completed, the permit requires that interim criteria for projects disturbing 50 acres or more be established and implemented. The interim hydromodification criteria must contain a range of runoff flow rates for which Priority Development Project post-project runoff flow rates and durations shall not exceed pre-project runoff flow rates and durations.

While the San Diego Permit requirements have not been in effect long enough to draw conclusions about its implementation success, the concepts of:

- Including both LID and hydromodification requirements to address both on-site and receiving water concerns;
- Requiring the permittees to clearly define BMP feasibility in an effort to ensure maximum implementation;
- Including an education component for municipal staff to aid program implementation and consistency;
- Requiring inspection of management measures to ensure proper construction and long-term effectiveness; and
- Including interim requirements to implement until the more detailed plans have been approved.

The permit language and concepts are robust and specifically delineate LID and performance criteria requirements that are likely to lead to enhanced water quality protection and improvement.

- **Ventura County Draft Phase I MS4 Permit**

The August 2007 draft of the Ventura County Municipal Stormwater Permit also includes LID and hydromodification requirements.[25] The New Development and Redevelopment Criteria specify that all new and redevelopment shall integrate low impact development principles into project design. Permittees have 365 days to develop an LID technical guidance document for planners and developers that includes objectives and specifications for the integration of LID strategies, including:

1. Site assessment;
2. Site planning and layout;
3. Vegetative protection, re-vegetation, and maintenance;
4. Techniques to minimize land disturbance;
5. Techniques to implement LID measures at various scales;
6. Integrated water resources management practices;
7. LID design and flow modeling guidance;
8. Hydrologic analysis; and
9. LID credits.

In addition, the permit requires an LID training program for builders, design professionals, regulators, resource agencies, and stakeholders that addresses the integration of LID at various scales.

The permit's hydromodification control criteria require all new and redevelopment projects to implement control measures that prevent down stream erosion by maintaining the project's pre-development stormwater runoff flow rates and durations. The permit requires that the Erosion Potential (E_p) in streams be maintained at a value of 1, unless an alternative value is shown to be protective. The permit specifies a preference for LID strategies.

The Southern California Storm Water Monitoring Coalition is currently developing a regional methodology to eliminate adverse impacts from urbanization. The objectives for the Hydromodification Control Study (HCS) are:

1. Establishment of a stream classification for Southern California streams.
2. Development of a deterministic or predictive relationship between changes in watershed impervious cover and stream-bed/stream bank enlargement.
3. Development of a numeric model to predict stream bed/stream bank enlargement and evaluate the effectiveness of mitigation strategies.

Until the HCS is completed, permittees are required to implement the following interim hydromodification criteria:

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[25] California Regional Water Quality Control Board, Los Angeles Region, Waste Discharge Requirements for Storm Water (Wet Weather) and Non-Storm Water (Dry Weather) Discharges from the Municipal Separate Storm Sewer Systems within the Ventura County Watershed Protection District, County of Ventura and the Incorporated Cities therein, August 28, 2007.

1. Projects disturbing land area of less than fifty acres must implement hydromodification controls such that the 2-year 24-hour storm event post-development hydrograph peak flow and volume will match within one percent of the 2-year 24-hour storm event pre-development peak flow and volume hydrograph.
2. Projects disturbing land areas of fifty acres or greater shall develop and implement a Hydromodification Analysis Study that demonstrates that post-development conditions are not expected to alter the duration of sediment transporting flows in receiving waters. The HAS must demonstrate that the selected hydromodification control BMPs will maintain an E_p value of 1 unless an alternative value can be shown to be protective.

Once the HCS is completed, permittees must develop Hydromodification Control Plans (HCPs) that are watershed specific and identify:

1. Stream classifications;
2. Flow rate and duration control methods;
3. Sub-watershed mitigation strategies; and
4. Stream restoration measures which will maintain the stream and tributary E_p at 1 unless an alternative value can be shown to be protective.

In addition, the HCP must contain the following elements:

1. Hydromodification management standards;
2. Natural drainage areas and hydromodification management control areas;
3. New development and redevelopment projects subject to the HCP;
4. Description of authorized hydromodification management control BMPs;
5. Hydromodification management control BMP design criteria;
6. For flow duration control methods, the range of flows to control for, and goodness of fit criteria;
7. Allowable low critical flow, Q_c, which initiates sediment transport;
8. Description of the approved hydromodification model;
9. Any alternate hydromodification management model and design;
10. Stream restoration measures design criteria;
11. Monitoring and effectiveness assessment; and
12. Record keeping.

The permit requires that verification of maintenance provisions be provided for the hydromodification controls for all new and redevelopment projects and that LID and hydromodification measures be inspected to ensure proper installation prior to the issuance of occupancy certificates. The permit also specifies that the permittee implement a tracking system, and an inspection and enforcement program for new and redevelopment post-construction stormwater BMPs.

While this permit is still in draft form and has not yet been adopted, it has a broad scope of requirements. The permit requires:

- An LID Technical Guidance document;
- An LID training program;
- A Hydromodification Control Plan;
- Interim hydromodification criteria;
- Verification of maintenance provisions for hydromodification controls;
- A tracking, inspection, and enforcement program for post-construction stormwater BMPs; and
- Inspection of LID and hydromodification measures prior to the issuance of occupancy certificates.

This permit does not allow for a feasibility assessment for its LID requirements. It requires that all new and redevelopment projects integrate LID principles into project design and that the permittee develop a LID Technical Guidance document that includes the specifications for the integration of LID strategies.

- **New Jersey Stormwater Management Rules**

New Jersey's new stormwater requirements adopted in 2004 contain specific criteria for infiltration and the rate and volume of discharge.[26] The state establishes groundwater recharge requirements with the following performance standards.

1. *…that the site and its stormwater management measures maintain 100 percent of the average pre-construction groundwater recharge volume for the site; OR*
2. *…that the increase of stormwater runoff volume from pre-construction to post-construction for the two-year storm is infiltrated.*

The recharge provisions contain exemptions for the defined "urban redevelopment area," hot spots, and industrial stormwater exposed to source material.[27] These provisions are complemented by runoff quantity requirements.

1. *…that post-construction runoff hydrographs for the two, 10, and 100-year storm events do not exceed, at any point in time, the pre-construction runoff hydrographs for the same storm events; OR*
2. *…that there is no increase, as compared to the pre-construction condition, in the peak runoff rates of stormwater leaving the site for the two, 10, and 100-year storm events and that the increased volume or change in timing of stormwater runoff will not increase flood damage…; OR*
3. *…that the post-construction peak runoff rates for the two, 10, and 100-year storm events are 50, 75, and 80 percent, respectively, of the pre-construction peak runoff rates…*

In addition to the hydrologic performance standards, water quality standards requiring 80% total suspended solids (TSS) removal for the water quality design storm of 1.25 inches in two hours is also required. The New Jersey standards took important steps forward with their primary hydrologic requirements. Maintaining groundwater recharge rates or infiltrating the

[26] "Stormwater Management Rule," *New Jersey Register*, N.J.A.C., Vol. 7, No. 8 (February 2, 2004).
[27] Ibid.

post-construction volume increase for the two year storm addresses one of the significant impacts of development – lost infiltration and groundwater recharge. Establishing these requirements will help to maintain pre-development water balance on the site.

Most importantly the primary runoff volume language requiring the post-construction hydrograph to match the pre-development hydrograph at each and every point does not allow an increase in the volume of stormwater discharged. This is not only an environmentally protective standard, but it would necessarily encourage wide adoption of non-structural controls and LID.

- **Portland Stormwater Requirements**

Portland's stormwater requirements are a good example of urban standards. Hydrology is not as much of a driving factor with urbanized areas as natural hydrology has been greatly altered and is likely not replicable in many instances because of factors such as existing utilities, density, soil compaction, fill materials, and existing historical contamination. Portland also has a combined sewer system and has a great interest in reducing stormwater inflow into the system.

The city's code requires on-site stormwater management for new development and redevelopment, and encourages the use of green infrastructure techniques to meet this objective.[28] In addition, new city-owned buildings are required to have a green roof covering 70% of the roof area. As an incentive for other buildings, a zoning bonus that allows additional square footage is available for those that install a green roof. The city will also allow up to a 35% discount in the stormwater utility for properties with on-site stormwater management.[29] This provides an incentive for existing properties to retrofit with on-site controls.

These are some of the most progressive urban stormwater standards in the country. They establish defined performance criteria based upon retention of stormwater and are a departure from many urban models whose aim is to provide water quality treatment for the first-flush of stormwater. Existing urban areas are often confronted by infrastructure capacity and maintenance concerns in addition to water quality requirements. Limiting the volume of stormwater discharged is a critical factor in addressing these issues. By also encouraging the use of green infrastructure, Portland is adopting a policy that will yield multiple environmental benefits in additional to providing stormwater retention.

- **Seattle Green Factor**

Adopted in January 2007, the Green Factor is an alternative approach for urban stormwater control. The Green Factor is a landscaping requirement in neighborhood business districts that stipulates that 30% of a site must be vegetated. This system encourages multiple layers of visible plantings and plantings in the public rights-of-way adjacent to the properties. The

[28] Portland City Code Chapter 17.38, Policy Framework, Appeals, and Update Process.
[29] C. Kloss and C. Calarusse, *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows*, Natural Resources Defense Council, June 2006.

system is flexible and weights different landscaping practices according to their effectiveness. The square footage of each practice is multiplied by its green factor and then aggregated with the score of each additional practice to satisfy the requirements. For example, asphalt and concrete have a green factor of 0, permeable pavements 0.6, and green roofs 0.7. Bonuses are also provided for utilizing rain water harvesting and low water-use plants.[30]

This regulatory construct is interesting because it is not stormwater specific, nor does it contain specific discharge performance requirements. However, because of the practices selected for green factors and the benefits gained by adding vegetation and other green infrastructure practices, this policy will beneficially impact the volume of stormwater runoff. It is similar to the Green Area Ratio program in Berlin, Germany that has been a catalyst for encouraging green roof installation and the preservation or creation of other green spaces. The downside to this approach is that stormwater benefit may not be as great as stormwater specific performance requirements because of the flexibility in selecting green options. However, this is a progressive, multi-benefit/multi-pollutant policy approach.

This approach also provides an opportunity to assess appropriate amounts of vegetative cover in urban areas and the benefits gained from a comprehensive greening program. Analysis of this program can determine the environmental benefits with respect to the urban aesthetics desired. In addition, this type of system lends itself to a trading scheme where vegetative cover percentages can be increased in one area to offset a lack elsewhere or to provide enhanced performance in a critical or sensitive area.

- **Washington D.C. Anacostia Redevelopment Standards**

The area along the Anacostia River in Washington, DC (hereafter, the District) is slated for major redevelopment in the coming years. The Anacostia is one of the most polluted rivers in the country with a significant amount of this pollution contributed by stormwater runoff and combined sewer overflows. The District realized that the redevelopment presented an opportunity to revitalize a historically neglected portion of the city and established social, economic, and environmental benchmarks for the development area.

A comprehensive set of environmental standards was developed that included provisions for: (1) integrated environmental design; (2) stormwater; (3) green building; and (4) site planning and preservation. Like Portland’s standards, natural hydrology is not as much a consideration as stormwater volume retention to limit discharges from the MS4 system and combined sewer overflows. The stormwater standards adopted serve as another example of an innovative urban application.

The stormwater control requirements stipulate on-site retention of the first inch of rainfall for new development and redevelopment and water quality treatment for up to the two-year storm volume along with a stated preference for vegetated controls. Where it is not technically feasible for on-site retention of stormwater, an off-set provision allows developers to provide off-site mitigation for 1½ times the volume that could not be provided

[30] Seattle Municipal Code, SMC 23.47A, Council Bill Number: 115746, Ordinance Number: 122311.

for the developed area or to pay into a dedicated stormwater fund for twice the cost of an equivalent volume reduction.[31] The off-set provision was modeled after other environmental off-set provisions and intended to provide an incentive to maximize on-site treatment.

These standards are considered some of the most progressive in the country. The driving focus was to significantly decrease stormwater inflow into the collection system and provide enhanced water quality treatment for any discharge while also supporting a green building and sustainability focus within the city. The stormwater standards were used as a platform to provide not only advanced stormwater control, but also encourage the integration of green space throughout an urban redevelopment to gain the associated social, economic, and multi-media environmental benefits.

- **Maryland Stormwater Act of 2007**

The Maryland Stormwater Act was passed by the General Assembly in April 2007 and signed into law by the Governor. The new act stipulates that Environmental Site Design (ESD) using LID practices is the preferred stormwater control method in the State and must be utilized as the first control option for new development projects.[32] Only after the developer or designer can demonstrate that they have used ESD to the maximum extent practicable are they permitted to use conventional stormwater controls.

This is more of a command-and-control regulatory construct mandating the use of a particular stormwater control system. However, because of the expansive list of LID BMPs and techniques, there is a great deal of flexibility built into the regulation. It also provides alternative options when site constraints may limit ESD's ability to achieve the stormwater management requirements. A significant benefit of this new policy is the understood preference for a new stormwater control regime based on LID principles that signals a departure from the standard methods of stormwater control.

An additional benefit of the new legislation is that it moves the State program to a more performance based system of stormwater management. Moving away from minimum treatment standards for selecting end-of-pipe BMPs and towards a system of integrated site design principles begins to allow the regulatory system to address overall site performance and function.

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[31] Anacostia Waterfront Corporation, *Final Environmental Standards*, June 1, 2007.
[32] *Maryland Stormwater Management Act of 2007*, Senate Bill 784 / House Bill 786, (available at http://mlis.state.md.us/2007RS/billfile/sb0784.htm).

CONCLUSIONS AND RECOMMENDATIONS

The State of California has a well developed institutional framework that can aid the development of a comprehensive LID program. Many steps already taken by the State have established the necessary performance criteria needed for broader LID adoption. The draft general Construction permit establishes volume limitations for post-construction runoff rather than the traditional approach of limiting flow rate. Preserving pre-construction runoff volumes will require the use of site design approaches and LID that will limit stormwater generation and maximize natural hydrologic processes for treatment.

In addition, the San Francisco Region's requirement for hydromodification plans places the emphasis on in-stream impacts of stormwater runoff and the need to develop programs that effectively manage the increased volume and flow that contribute to these impacts. The critical link in both of these approaches is that they require stormwater volume to be limited. Establishing a performance criterion for volume will more than likely require LID or other similar approaches that limit the conversion of precipitation to runoff.

Importantly, the institutional structure within the State can function to efficiently promote the adoption of innovative control approaches. The coordinated efforts of the State Board establishing broad policy approaches and the Regional Boards setting additional requirements within their watersheds when needed allows for alternative and evolving regulatory approaches, as highlighted by the examples above. Critical to this is the authority granted by the Porter-Cologne Act to regulate any activity or factor that impacts water quality. This stipulation gives the State broad authority to assess the cause of stormwater runoff and pollution and develop strategies to mitigate the originating cause. This condition exceeds that of many states that are limited by choice or statute to manage stormwater as a waste product while giving limited attention to the upstream factors that affect runoff. The planning and permitting authority that exists in the State and Regional Boards allows for the development of comprehensive control requirements that maximize vegetation, natural systems, and LID.

Important to the successful application of LID, is evaluating how it will be used for new development and redevelopment or urban retrofit. The pre-draft of the Reissuance of the Statewide construction general permit and the hydromodification management plans apply to new development and redevelopment and assess pre-development hydrologic conditions. Matching pre-development hydrologic conditions is a fair method in Greenfield development and redevelopment situations where determinations of pre-development conditions can be made and will help to decrease the pollution impact of new development across the state.

However, existing development exerts a tremendous pollution impact largely due to the resulting, developed landscape and its associated runoff characteristics. Addressing it by matching pre-development hydrology may not always be possible because many urban areas lack land for stormwater control and natural hydrology has been altered so significantly. In these instances, the urban stormwater regulations in Portland and Washington, D.C. that require volume retention can serve as appropriate models. These regulations do not focus on the natural function of a site, but rather attempt to limit runoff as a means of pollution prevention and enhancing infrastructure capacity. The desired outcome is the same as the hydromodification approaches, but the assessment and control requirements are structured differently to account for urban conditions.

The important concept across all of these approaches is that the regulations established a performance requirement to limit the volume of stormwater discharges. The fact that volume is the critical regulatory requirement instead of maximum flow rate leads to greater adoption of LID and vegetated systems. The City of Salinas and the Central Coast Regional Water Quality Control Board found that ordinances that only encourage LID adoption had little voluntary implementation, but ordinances that require LID have resulted in more widespread implementation.[33]

Regulations can address new development or redevelopment but LID retrofits are also a critical need on existing development to mitigate existing stormwater pollution. Appropriately structured incentive programs can encourage LID adoption outside of a regulatory structure and reduce stormwater volume. Portland uses the potential for a discount from its stormwater utility fee to create an incentive for existing properties to retrofit to on-site stormwater controls. The recurring financial benefits that can be gained from a one-time capital investment and limited maintenance requirements can entice owners to adopt on-site practices that otherwise may not have.

Utility fees or other dedicated funding can serve multiple purposes. Portland's utility fee funds its program and provides an incentive for volume reductions. The off-set fee that is permissible in the Anacostia portion of Washington creates a revenue stream that the city can use for installations within right-of-ways or city owned property. To be effective for both purposes, a fee must be structured and valued to provide sufficient programmatic funding and allow for a fee discount sufficient to create an incentive. Washington's preference is for on-site controls, so the required off-set fee is based upon twice the cost to manage the volume of stormwater to encourage the maximization of on-site options.

LID is also a complement to other land use planning or environmental programs. The water quality benefits of Smart Growth programs can be enhanced by using LID. LID can also be used within the Leadership in Energy and Environmental Design (LEED®) system to gain points for environmentally sensitive design. Many LID practices provide benefits like energy conservation or other site design benefits in addition to stormwater control that can contribute to the overall LEED® rating of a project.

The State and Regional Boards have begun to implement policies that will encourage LID practices. These policies will likely lead to broader implementation of distributed, on-site stormwater techniques. Other policy options that have been adopted in other jurisdictions have the potential to augment California's existing efforts and develop a more robust regulatory system. The institutional framework within the State allows for regulatory innovation and should provide the necessary platform for a water resources program that fully incorporates LID.

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[33] Chris Conway, et al., *Technical Memorandum to the Central Coast Regional Water Quality Control Board and the City of Salinas – Model Low Impact Development (LID) Ordinance for Salinas and the Central Coast,* Kennedy/Jenks Consultants, January 22, 2007.

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TO: Chairman Wright and San Diego Regional Water Quality Control Board Members

FROM: Catherine George Hagan, Senior Staff Counsel
Office of Chief Counsel

DATE: 5 November 2009

SUBJECT: Regulatory Authority for Imposing Numeric Effluent Limits on Dry Weather, Non-Storm Water Discharges, in Municipal Storm Water Permits

At the July 1, 2009, San Diego Regional Board Meeting, Regional Board members received public comments regarding the inclusion of regulations specific to non-storm water discharges in Tentative Order No. R9-2009-002, the reissuance of National Pollutant Discharge Elimination System (NPDES) Waste Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer Systems (MS4s) draining the watersheds of Orange County within the San Diego Region (South Orange County Municipal Storm Water Requirements). At the July meeting, Regional Board members requested that Board Counsel respond to public comments and Board member questions regarding the Regional Board regulation of non-storm water discharges. Commenters assert that the definition of "storm water" in the federal regulations includes drainage and surface runoff entirely unrelated to precipitation events. They also comment that regardless of whether a discharge is composed entirely of storm water or non-storm water, any pollutants discharged *from* an MS4 are subject to the maximum extent practicable (MEP) standard and related iterative process, despite the Clean Water Act's (CWA) requirement that discharges of non-storm water into an MS4 be "effectively prohibited." As a result, commenters assert that numeric effluent limitations on dry weather, non-storm water discharges are inappropriate. Board members also sought clarity on the claims by copermittees that many provisions in the Tentative Order are unfunded state mandates, requiring reimbursement by the State. This memorandum addresses both the non-storm water and unfunded mandate issues.

I. Regulatory Background

The Clean Water Act (CWA) employs the strategy of prohibiting the discharge of any pollutant from a point source into waters of the United States unless the discharger of the pollutant(s) obtains a NPDES permit pursuant to Section 402 of the Clean Water Act. The 1987 amendment to the CWA includes provision 402(p) that specifically addresses NPDES permitting requirements for storm water discharges from MS4s. Section 402(p) prohibits the discharge of pollutants from specified MS4s to waters of the United States except as authorized by an NPDES permit and identifies two substantive standards for MS4 storm

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water permits. MS4 permits (1) “shall include a requirement to effectively prohibit non-stormwater discharges into the storm sewers[ ]” and (2) “shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or State determines appropriate for the control of such pollutants.” (CWA Section 402(p)(3)(B)(ii-iii).)

On November 16, 1990, USEPA published regulations addressing storm water discharges from MS4s. (Vol. 55 Federal Register (Fed. Reg.) 47990 and following (Nov. 16, 1990).) The regulations establish minimum requirements for MS4 permits, and generally focus on the requirement that MS4s implement programs to reduce the amount of pollutants found in storm water discharges to the maximum extent practicable. However, the regulations also require the MS4’s program to include an element to detect and remove illicit discharges and improper disposal into the storm sewer. (40 CFR § 122.26(d)(2)(iv)(B).) “Illicit discharges” defined in the regulations is the most closely applicable definition of “non-storm water” contained in federal law and the terms are often used interchangeably. The State Water Board has concluded that “U.S. EPA added the illicit discharge program requirement with the stated intent of implementing the Clean Water Act’s provision requiring permits to ‘effectively prohibit non-storm water discharges.’” (State Board Order WQ 2009-0008 (*County of Los Angeles)*, p. 4.)

II. Definition of Storm Water and Non-Storm Water

Federal regulations define “storm water” as “storm water runoff, snow melt runoff, and surface runoff and drainage.” (40 C.F.R. § 122.26(b)(13).) While “surface runoff and drainage” is not defined in federal law, USEPA’s preamble to the federal regulations demonstrates that the term is related to precipitation events such as rain and/or snowmelt. (55 Fed. Reg. 47990, 47995-96.) For example, USEPA states: “In response to the comments [on the proposed rule] which requested EPA to define the term ‘storm water’ broadly to include a number of classes of discharges which are not in any way related to precipitation events, EPA believes that this rulemaking is not an appropriate forum for addressing the appropriate regulation under the NPDES program of such non-storm water discharges . . . . Consequently, the final definition of storm water has not been expanded from what was proposed.” (*Ibid.*) The State Water Board recently considered and rejected in its precedential *Los Angeles County* order, WQ 2009-0008, the very arguments made here by commenters that storm water includes dry weather flows, completely unrelated to precipitation events. The State Water Board concluded that “U.S. EPA has previously rejected the notion that ‘storm water,’ as defined at 40 Code of Federal Regulations section 122.26(b)(13), includes dry weather flows. In U.S. EPA’s preamble to the storm water regulations, U.S. EPA rejected an attempt to define storm water to include categories of discharges ‘not in any way related to precipitation events.’ [Citations.]” (*County of Los Angeles,* Order WQ 2009-0008, p. 7.)

The storm water regulations themselves identify numerous categories of discharges including landscape irrigation, diverted stream flows, discharges from potable water sources, foundation drains, air conditioning condensation, irrigation water, springs, water from crawl space pumps, footing drains, lawn watering, individual residential car washing, and street wash water as "non-storm water." While these types of discharges may be regulated under storm water permits, they are not considered storm water discharges. (40 CFR § 122.26(d)(2)(iv)(B).) Applicable regulations do not prohibit these and other categories of non-storm water discharges that are not expected to be a source of pollutants. But where, as in the Tentative Permit, certain categories of non-storm water discharges have been identified by the municipality to be sources of pollutants, they are no longer exempt and become subject to the effective prohibition requirement in section 402(p)(3)(B)(ii). This process would be wholly unnecessary if MEP were the governing standard for these non-storm water discharges.

Not only does a review of the storm water regulations and USEPA's discussion of the definition of storm water in its preamble to these regulations strongly support the interpretation that storm water includes only precipitation-related discharges, the Regional Board is bound to follow the State Water Board's interpretation of the definition of "storm water" set forth in the precedential State Water Board Order WQ 2009-0008 which rejects the commenters' interpretation. Therefore, while commenters assert that dry weather, non-precipitation related discharges are nonetheless storm water discharges (and therefore subject to the MEP standard in CWA section 402(p)(3)(B)(iii)), their interpretation is not supported and does not conform to applicable State Water Board precedent.

III. Non-Storm Water Regulation

Oral and written comments received by the Regional Board throughout this proceeding assert that the *discharge* of non-storm water, like storm water, from the MS4 is subject to the MEP standard and may not be regulated appropriately with numeric effluent limitations.
Several commenters assert that once pollutants contained in prohibited non-storm water enter the MS4, the MEP standard and related iterative approach to storm water regulation is the most stringent means available to require those discharges to comply with water quality standards. In other words, the commenters assert that it is inappropriate for a Regional Board to regulate non-storm water discharges with numeric effluent limitations. As explained below, this interpretation is incorrect. Building on the effective prohibition against non-storm water discharges, the Clean Water Act requirement to reduce pollutants discharged from the MS4 to the MEP standard necessarily is limited to storm water discharges.

The Clean Water Act's municipal storm water MEP standard does not require storm water discharges to strictly meet water quality standards, as is required for other NPDES permitted discharges. This distinction reflects Congress's recognition that variability in flow and intensity of storm events render difficult strict compliance with water quality standards by MS4 permittees. In describing the controls that permits must include to reduce pollutants in storm water discharges to the MEP, the statute states that the controls shall include: "management practices, control techniques and system, design and engineering methods, and such other provisions as the [permit writer] determines appropriate for the control of such pollutants." (CWA § 402(p)(3)(B)(iii).)

In contrast, non-storm water discharges from the MS4 that are not authorized by separate NPDES permits, nor specifically exempted, are subject to requirements under the NPDES program, including discharge prohibitions, technology-based effluent limitations and water quality-based effluent limitations. (40 C.F.R. § 122.44.) USEPA's preamble to the storm water regulations also supports the interpretation that regulation of non-storm water discharges through an MS4 is not limited to the MEP standard in CWA section 402(p)(3)(B)(iii):

> "Today's rule defines the term "illicit discharge" to describe any discharge through a municipal separate storm sewer system that is not composed entirely of storm water and that is not covered by an NPDES permit. Such illicit discharges are not authorized under the Clean Water Act. Section 402(p(3)(B) requires that permits for discharges from municipal separate storm sewers require the municipality to "effectively prohibit" non-storm water discharges from the municipal separate storm sewer…Ultimately, such non-storm water discharges through a municipal separate storm sewer must either be removed from the system or become subject to an NPDES permit." (55 Fed. Reg. 47990, 47995.)

USEPA has recently affirmed its support for the Tentative Order's regulatory approach to non-storm water discharges in comments submitted in this proceeding. As noted above, the State Water Board concluded in its recent Order WQ 2009-0008 that "U.S. EPA added the illicit discharge program requirement with the stated intent of implementing the Clean Water Act's provision requiring permits to 'effectively prohibit non-storm water discharges.'" (State Board Order WQ 2009-0008 (*County of Los Angeles)*, p. 4.) Along these same lines, the State Water Board also explained that "the Clean Water Act and the federal storm water regulations assign different performance requirements for storm water and non-storm water discharges. These distinctions in the guidance document . . . , the Clean Water Act, and the storm water regulations make it clear that a regulatory approach for storm water - such as the iterative approach we have previously endorsed - is not necessarily appropriate for non-storm water." (State Water Board Order WQ 2009-0008, *County of Los Angeles),* p. 9.)

Some commenters place extensive reliance on various State Water Board water quality orders, the State Water Board's expert storm water panel (also known as the "Blue Ribbon Panel") report entitled, *The Feasibility of Numeric Effluent Limits Applicable to Discharges of Storm Water Associated with Municipal, Industrial and Construction Activities* (June 2006), and other references, to assert that it is inappropriate to include numeric effluent limitations for dry weather non-storm water discharges from the MS4. It is important to note that the Blue Ribbon Panel neither considered nor made any determination on how non-storm water discharges from MS4s that adversely affect receiving waters are to be addressed. The discussion of the feasibility of numeric and/or narrative water quality-based effluent limitations and the MEP standard within these documents is applicable to discharges of storm water from MS4 systems, and does not pertain to non-storm water discharges from the MS4. Similarly, commenters also identify a superior court ruling in (*Cities of Arcadia, et al., v. State Water Resources Control Board* (Super. Ct. Orange County, 2007, No. 06CC02974)) (*Arcadia II*) to support its interpretation that numeric effluent limitations are not legally appropriate for the non-storm water discharges identified in the Tentative Order. Again, these references pertain to storm water and not non-storm water discharges and are inapposite here.

Federal law mandates that permits issued to MS4s must require management practices that will result in reducing storm water pollutants to the MEP yet at the same time requires that non-storm water discharges be effectively prohibited from entering the MS4.

Consistent with USEPA's position, the State Water Board has clearly indicated that Regional Boards are not limited by the iterative approach to storm water regulations in crafting appropriate regulations for non-storm water discharges. (State Water Board Order WQ 2009-0008, *County of Los Angeles),* p. 9.) The argument that non-storm water discharges, prohibited from entry into the MS4 in the first instance, should be held to comply with only the less stringent MEP standard developed for storm water discharges in recognition of the variable quality of storm events, is contrary to and potentially renders the "effectively prohibit" requirement in section 402(p)(3)(B)(ii) meaningless. While water quality based effluent limits, expressed as numeric effluent limitations, are not *required* to be imposed on dry weather, non-storm water discharges from the MS4, it is legally permissible to do so.[1]

IV. Water Code Section 13241

Many commenters assert that provisions in the Tentative Order, including NELs, storm water action levels (SALs), and implementation of the Baby Beach TMDL requirements, are new permit terms that exceed federal law. Therefore, the commenters argue that the Regional Board is required, but has failed, to consider Water Code section 13241 factors, including economic considerations, prior to approving any of these provisions. The City of Dana Point cites extensively to the California Supreme Court case, *City of Burbank v. State Water Resources Control Board, et al.* ((2005) 35 Cal.4th 613) (*Burbank*), particularly the concurring opinion of Justice Brown, as supportive of its assertions.

The *Burbank* court stated: "[Water Code s]ection 13377 specifies that wastewater discharge permits must meet the federal standards set by federal law. In effect, section 13377 forbids a regional board's consideration of any economic hardship on the part of the permit holder if doing so would result in the dilution of the requirements set by Congress in the Clean Water Act. That act prohibits the discharge of pollutants into the navigable waters of the United States unless there is compliance with federal law (33 U.S.C. § 1322(a)), and publicly operated wastewater treatment plants such as those before us here must comply with the act's clean water standards, regardless of cost [citations]. Because [Water Code] section 13263 cannot authorize what federal law forbids, it cannot authorize a regional board, when issuing a wastewater discharge permit, to use compliance costs to justify pollutant restrictions that do not comply with federal clean water standards." (*Burbank,* 35 Cal.4th at 625.)

While the Burbank decision does require an analysis of Water Code section 13241 factors when the state adopts permit conditions that are more stringent than federal law (*id. at 618*) the Tentative Order reflects that all of the challenged provisions are required to implement federal law. Thus, the Regional Board is not required to consider economic information to justify a "dilution of the requirements" established in federal law. Nonetheless, as staff has

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[1] Commenters have also claimed that TMDLs are inappropriately included as numeric effluent limitations on both dry and wet weather discharges. This is not the case. The Tentative Order requires the Copermittees to implement BMPs capable of achieving the interim and final Waste Load Allocations (WLA) and Numeric Targets in the approved TMDL. The BMPs apply to the discharges, while compliance with the WLAs and Numeric Targets occurs in receiving waters. Further, the Copermittees have 10 years to meet the final allocations and targets established for wet weather. Finally, these provisions within the Tentative Order comply with federal regulations [40 CFR 122.33(d)(1)(vii)(B)] by being consistent with the assumptions and requirements of the Waste Load Allocations of an adopted and applicable TMDL.

noted extensively in responses to comments, to the extent that economic information has been provided in connection with compliance and other costs associated with challenged permit provisions, staff has fully considered this information. Under these circumstances, the *Burbank* case does not require more.

V. Unfunded State Mandates

Both prior to and at the July 1, 2009, Regional Board meeting on an earlier version of the Tentative Order, commenters raised the issue of unfunded state mandates in connection with many of the proposed permit provisions. Board members indicated that they would appreciate clarification about the subject of unfunded state mandates. In recently submitted written comments, the City of Dana Point and others again assert that a number of the provisions in the Tentative Order go beyond what is required under federal law and therefore constitute unfunded state mandates that may not be imposed absent necessary funding first being made available to Permittees.

Commenters are correct that one factor to be considered in determining whether a requirement is an unfunded state mandate is whether the requirement goes beyond, or exceeds, what is required by federal law. However, the commenters are incorrect that the provisions in the Tentative Order exceed federal law. Moreover, there are a number of other factors that also must be established before a requirement will be found to be an unfunded state mandate warranting state reimbursement. Finally, unless and until a particular provision is determined by the State of California, Commission on State Mandates (Commission) to be an unfunded state mandate for which reimbursement is required, the Regional Board is not, as some commenters assert, precluded from adopting such provisions.

<u>State Mandate Law</u>

Article XIIIB, Section 6 of the California Constitution requires subvention of funds to reimburse local governments for state-mandated programs in specified situations. The process for establishing that a requirement is subject to reimbursement as an unfunded state mandate involves the filing by a local agency of a Test Claim with the Commission on State Mandates. There are several exceptions and limitations to the subvention requirements that provide bases for the Commission to determine that one or more provisions in a Test Claim are not subject to subvention. Article XIIIB, Section 6 provides, "Whenever the Legislature or any state agency mandates a new program or higher level of service on any local government, the State shall provide a subvention of funds to reimburse that local government for the costs of the program or increased level of service." Implementing statutes clarify that no subvention of funds is required if: (1) the mandate imposes a requirement that is mandated by a federal law or regulation and results in costs mandated by the federal government, unless the statute or executive order mandates costs that exceed the mandate in that federal law or regulation (Govt. Code, § 17556, subd. (c)); or (2) the local agency proposed the mandate (*id.*, subd. (a)); or (3) the local agency has the authority to levy service charges, fees, or assessments sufficient to pay (*id.*, subd. (d)).

Numerous judicial decisions have further defined limitations on the requirements for subvention of funds. Specifically, subvention is only required if expenditure of tax monies is required, and not if the costs can be reallocated or paid for with fees. *(County of Los Angeles v. Commission on State Mandates* (2003) 110 Cal.App.4th 1176; *Redevelopment Agency v. Commission on State Mandates* (1997) 55 Cal.App.4th 976.) In addition, reimbursement to local agencies is required only for the costs involved in carrying out functions peculiar to government, not for expenses incurred by local agencies as an incidental impact of laws that apply generally to all state residents and entities. Laws of general application are not entitled to subvention. *County of Los Angeles v. State of California* (1987) 43 Cal.3d 46. The fact that a requirement may single out local governments is not dispositive; where local agencies are required to perform the same functions as private industry, no subvention is required. *City of Richmond v. Commission on State Mandates* (1998) 64 Cal.App.4th 1190.

If the Commission determines that provisions in a permit in fact constitute reimbursable state mandates, the determination may be challenged through the judicial process. There also exists a Commission process for determining appropriate reimbursement of state mandates. If a determination that a provision constitutes an unfunded state mandate is upheld, the State likely would decide whether to reimburse the local agency for the program or the Regional Board could decide to withdraw a provision from a permit.

Recent Commission Proceedings

Recently, the Commission issued a Final Statement of Decision in a storm water permit Test Claim filed by the County of Los Angeles and several additional co-permittee test claimants. (*Municipal Storm Water and Urban Runoff Discharges,* 03-TC-04, 03-TC-19, 03-TC-20, and 03-TC-21 (Los Angeles Regional Water Quality Control Board Order No. 01-182 (July 31, 2009) (County of Los Angeles Test Claim).) In the Commission's Statement of Decision, the Commission found that all but one of the challenged provisions issued by the Los Angeles Water Board in its MS4 permit did not qualify as unfunded state mandates as they did "not impose costs mandated by the state within the meaning of article XIII B, section 6 of the California Constitution because the claimants have fee authority (under Cal. Const. article XI, § 7) within the meaning of Government Code section 17556, subdivision (d), sufficient to pay for the activities in those parts of the permit." (County of Los Angeles Test Claim, Statement of Decision, p. 2.)

As you know, on June 20, 2008, the County of San Diego filed a Test Claim with the State of California, Commission on State Mandates (Commission), challenging multiple provisions in Order No. R9-2007-001 (National Pollutant Discharge Elimination System (NPDES) No. CAS0108758), Waste Discharge Requirements for Discharges of Urban Runoff From the Municipal Separate Storm Sewer Systems (MS4s) Draining the Watersheds of the County of San Diego, the Incorporated Cities of San Diego County, the San Diego Unified Port District, and the San Diego County Regional Airport Authority), adopted on January 24, 2007 (2007 MS4 Permit). The County filed the Test Claim on behalf of 18 of the 20 MS4 Co-permittees (Claimants). Only the San Diego Unified Port District and the San Diego County Regional Airport Authority did not join in the Test Claim. The San Diego Water Board and State Water Board responded to the Test Claim. It is still pending and a draft staff analysis has not yet been issued for comment.

A similar process would need to be followed by the Orange County permittees in order to establish that any of the Tentative Order's provisions constitute unfunded state mandates entitling them to reimbursement by the state.

POLLUTION CONTROL HEARINGS BOARD
STATE OF WASHINGTON

PUGET SOUNDKEEPER ALLIANCE; PEOPLE FOR PUGET SOUND; PIERCE COUNTY PUBLIC WORKS AND UTILITIES DEPARTMENT; CITY OF TACOMA; PORT OF SEATTLE; SNOHOMISH COUNTY; CLARK COUNTY; PACIFICORP; and PUGET SOUND ENERGY, Appellants, v. STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY, Respondent, CITY OF SEATTLE; KING COUNTY; PORT OF TACOMA; PACIFICORP; PUGET SOUND ENERGY; STATE OF WASHINGTON, DEPARTMENT OF TRANSPORTATION, Intervenors.	FINDINGS OF FACT, CONCLUSIONS OF LAW, AND ORDER **PHASE I** PCHB NOS. 07-021, 07-026, 07-027 07-028, 07-029, 0-030, 07-037

These consolidated appeals involve the regulation of stormwater discharges from municipal storm sewer systems under a National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge General Permit (State Waste Permit). In these appeals, multiple parties challenge the validity of the Department of Ecology's (Ecology) 2007 Phase I Municipal Stormwater General Permit (Phase I Permit). This permit was issued pursuant to the

Federal Water Pollution Control Act, commonly known as the "Clean Water Act" (CWA), 33 U.S.C. § 1251 *et seq.* and the state Water Pollution Control Act, (WPCA), Chapter 90.48 RCW.

The Pollution Control Hearings Board (Board) held a multiple day hearing between April 29, 2008 and May 8, 2008. Attorneys Todd True and Jan Hasselman represented Appellants Puget Soundkeeper Alliance and People for Puget Sound (PSA). Attorney Tad H. Shimazu represented Appellant Pierce County. Assistant City Attorney Doug Mosich represented Appellant City of Tacoma. Attorneys Susan Ridgley and Tanya Barnett represented Appellant Port of Seattle. Catherine A. Drews and Elizabeth E. Anderson, Deputy Prosecuting Attorneys, represented Appellant Snohomish County. E. Bronson Potter, Senior Deputy Prosecuting Attorney and Rodney Swanson, Clark County Department of Public Works represented Appellant Clark County. Attorneys Loren R. Dunn and Blake Mark-Dias represented Appellants Pacificorp and Puget Sound Energy (Utilities). Ronald L. Lavigne, Senior Counsel, and Thomas J. Young, Assistant Attorney General represented Respondent Ecology. Assistant City Attorney Theresa R. Wagner represented Intervenor City of Seattle. Senior Deputy Prosecuting Attorney Joseph B. Rochelle and Deputy Prosecutor Verna P. Bromley represented Intervenor King County. Attorney Carolyn Lake represented Intervenor Port of Tacoma. Stephen Klasinski, Assistant Attorney General represented Intervenor Washington State Department of Transportation (WSDOT).

Chair, Kathleen D. Mix, William H. Lynch, and Andrea McNamara Doyle comprised the Board. Administrative Appeals Judge Kay M. Brown, presided for the Board. Randi Hamilton and Kim L. Otis of Gene Barker and Associates of Olympia, Washington provided court reporting services.

PROCEDURAL BACKGROUND

On January 17, 2007, Ecology issued the Phase I Permit for discharges from large and medium municipal separate storm sewer systems (called MS4s). The Phase I Permit went into effect on February 16, 2007.

PSA, Pierce County, City of Tacoma, Port of Seattle, Snohomish County, Clark County, and the Utilities appealed the Phase I Permit.[1] The Board conducted pre-hearing conferences, and entered pre-hearing orders for the Phase I Appeal. The parties raised multiple issues. The Board addressed many of these issues in a separate summary judgment order[2] and has resolved others through orders on summary judgment and after a hearing on the merits related to the Permit's Special Condition S4.[3] The parties also withdrew some of the issues. This decision resolves the remaining issues, which include the following:[4]

C. Special Condition 8 re: Monitoring (challenged only by Clark and Pierce County)[5]

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[1] City of Pacific (PCHB No. 07-031), Whatcom County (PCHB No. 07-032), and Sammamish Plateau Water & Sewer District (PCHB No. 07-024) filed additional appeals, but they are not part of this consolidated action.
[2] See Order on Dispositive Motions (Phase I Municipal Stormwater Permit), issued on April 7, 2008.
[3] See Order on Dispositive Motions: Condition S4, issued on April 2, 2008 and Findings of Fact, Conclusions of Law and Order, Condition S4, issued on August 7, 2008.
[4] The numbering of these issues was retained from the numbering system used in the Third Pre-Hearing Order issued on December 11, 2007.
[5] All of the permittee appellants initially raised issues related to the S8 monitoring provisions. These issues were resolved through an agreement between Ecology and all of the permittee appellants except Clark and Pierce County. *See* Ex. Ecy 11 (Phase I). The agreement also resolves issues raised by Snohomish County related to Special Condition S7.

1. Whether the requirements imposed in Special Condition S8 are lawful, practicable, reasonable, and/or designed to achieve the goals of the statutory municipal stormwater permit program?

3. Whether the monitoring requirements imposed in Special Condition S8 are overly broad, overly prescriptive, and cost-ineffective so that requiring implementation of such requirements as written is unlawful, impracticable, and/or unreasonable?

E. Issues Specific to the Ports of Seattle and Tacoma

5. Whether the requirement in Special Condition S6.E.7 to prepare and implement SWPPP(s) for "all Port-owned lands," regardless of their capacity to generate pollutants or other site-specific characteristics, is unlawful, unreasonable, unjust, or invalid?

F. Joint Environmental Legal Issues

1. Low-Impact Development:

   a. Does the permit fail to require maximum on site dispersion and infiltration of stormwater, through the use of "low impact development" techniques, basin planning, and other appropriate technologies, and if so, does that failure unlawfully cause or contribute to violations of water quality standards?
   b. Does the permit fail to require maximum onsite dispersion and infiltration of stormwater, through the use of "low impact development" techniques, basin planning, and other appropriate technologies, and if so, does that failure unlawfully allow permittees to discharge pollutants that have not been treated with all known available and reasonable methods of treatment ("AKART"), and/or fail to reduce the discharge of pollutants to the maximum extent practicable ("MEP")?

2. Existing Development:

   a. Does the absence of any standard and/or technology requirements for reducing stormwater discharges from existing development and existing stormwater systems unlawfully cause or contribute to violations of water quality standards?

b. Does the absence of any standard and/or technology requirements for reducing stormwater discharges from existing development and existing stormwater systems unlawfully allow permittees to discharge pollutants that have not been treated with AKART, and/or fail to reduce the discharge of pollutants to MEP?

3. Monitoring: Is the monitoring required under Permit Condition S.8 unlawful because it is inadequate to determine whether: (i) the permittee is in compliance with water quality standards; (ii) discharges are causing or contributing to violations of water quality standards; or (iii) discharges are being treated with AKART and/or MEP?[6]

4. Water Quality Standards Violations:

   a. Does the Phase I permit fail to ensure that discharges will not cause or contribute to violations of water quality standards?[7]

5. Compliance:

   a. Does the permit unlawfully provide for compliance with permit terms on a schedule that is indefinite and unenforceable, not as expeditious as possible, and/or in excess of statutory deadlines?
   b. Does the permit unlawfully allow a permittee to create and implement permit requirements without Ecology's oversight or involvement?

Based on pre-filed testimony, multiple days of sworn testimony of witnesses, extensive exhibits submitted into the record, and argument from counsel representing the numerous parties that participated in these consolidated appeals, and having fully considered the record, the Board enters the following decision:

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[6] PSA is not challenging the monitoring provisions of the permit. This issue is brought by the Utilities only.
[7] This issue also includes the issue originally stated as S4.6: Does the prohibition on violations of water quality standards contained in Permit Condition S4 unlawfully or unreasonably conflict with the other provisions of the permit?

SUMMARY OF THE DECISION

The Board concludes that the monitoring program established in Special Condition S8 and required of all permittees is a valid exercise of Ecology's technical expertise and discretion. (Issues C.1 and 3, and F.5). The Board upholds the permit term requiring that Stormwater Pollution Prevention Plans (SWPPPs) be prepared on all port-owned lands, but directs that Ecology modify the condition to exempt environmental mitigation sites owned by the Port of Tacoma from the SWPPP preparation requirement. (Issue E.5). The Board concludes that the Phase I Permit fails to require that the municipalities control stormwater discharges to the maximum extent practicable, and does not require application of all known, available, and reasonable methods to prevent and control pollution, because it fails to require more extensive use of low impact development (LID) techniques. (Issue F.1.b). To remedy this problem, the Board directs Ecology to make specific changes to some provisions in the permit, and also remands the permit with direction to Ecology to require the permittees to develop methods for use of low impact development at parcel and subdivision levels in their jurisdictions. The Board concludes that permittees must provide information in their annual report to Ecology on the extent to which basin planning is being undertaken or should be considered in their jurisdiction in order to assist with future phases of the permit. The areas identified should be relatively undeveloped where new development is occurring, and from which discharges may impact aquatic resources. The Board concludes that the structural stormwater control program provisions of the permit, as drafted, constitute impermissible self regulation. (Issues F.2 and F.5.b). To remedy this deficiency, the Board directs modification of the permit to require permittees to describe the prioritization of their selected structural control projects. The Board affirms the source control program requirements without change. Finally, the Board concludes that PSA and the Utilities failed to prove that any of the conditions of the permit violate the timing requirements of 33 U.S.C. § 1342 (p)(4)(A) (Issue F.5.a).

FINDINGS OF FACT

A. History of Phase I Permit

1.

Ecology developed the current Phase I Permit through an eight year long process. The 2007 Phase I Permit replaced the first municipal stormwater NPDES and State Waste Permits, which were issued in 1995 and expired in July of 2000. *Testimony of Wessel, Moore, Exs. Muni 0002, p. 17, 0006, 0007, 0008, 0009*.

2.

On January 19, 1999, Ecology filed a Notice of Intent to reissue the 1995 permits. *Ex. Muni 0002, p. 6*. Ecology formed an advisory committee, which included representatives from cities, counties, state and federal agencies, environmental groups, and the public, to assist with development of the revised permit. This committee met several times during 1999 and 2000. *Testimony of Wessel, Moore, Exs. Muni 0002, p. 6-7.* The 1995 Phase I Permit closely followed the EPA Phase I Regulations, which allowed the permittees to propose what was contained within their own stormwater programs. Ecology was dissatisfied with this approach and decided that more detailed requirements were needed for the 2007 Phase I Permit. *Testimony of Moore.*

3.

Completion of the new permit was delayed at several junctures as a result of a number of intervening events and shifting priorities, including the federal listing of Puget Sound Chinook Salmon in 1999, the adoption of EPA's Phase II rules, and Ecology's decision to revise the state's Stormwater Management Manuals and develop the first Phase II municipal stormwater permits in tandem with the Phase I permit update. *Testimony of Wessel, Moore, Exs. ECY 6 (Phase I), Muni 0002, p. 7.*

4.

In response to legislative interest in the new federal requirements for municipal stormwater permits, Ecology convened two advisory groups during the summer of 2003: one for Eastern Washington and one for Western Washington. Each advisory group submitted a report of its findings to Ecology in early December, 2003. Ecology developed its own recommendations and published these, together with the recommendations from both advisory groups, in a report to the Legislature dated January, 2004. *Testimony of Moore, Exs. ECY 6 (Phase I), Muni 0002, p. 7.*

5.

Ecology filed a notice of intent to issue the Phase I and Phase II Permits in June of 2004. The agency released the first preliminary draft of the Phase I Permit for public comment in May, 2005, and the first formal draft in February, 2006. *Exs. PSA 018, Muni-0100*. Ecology received and reviewed thousands of pages of public comment, and responded to those comments in a 205 page document when it released the revised, final permit in January, 2007. *Exs. Muni 002, p. 7-*

8, ECY 3 (Phase I). Ecology issued the Phase I permit, in its current form, on January 17, 2007. It became effective on February 16, 2007, and expires on February 15, 2012. *Ex. Muni 001, Testimony of Moore*.

B. Overview of the permit

6.

The Phase I Permit regulates discharges from municipal separate storm sewer systems (MS4s) owned or operated by the following large and medium municipalities statewide: City of Seattle, City of Tacoma, Clark County, King County,[8] Pierce County and Snohomish County.[9] It also allows coverage of "secondary permittees," including the Ports of Seattle and Tacoma, for discharges from other publicly owned or operated municipal separate sewer systems located within the primary permittee cities and counties. Secondary permittees as a group are subject to somewhat different terms under the permit than primary permittees, and the permit also has specific terms applicable only to the Ports of Seattle and Tacoma and not other secondary permittees. The Phase I permit does not cover direct discharges into waters of the state from privately owned stormwater systems, nor does it cover the storm sewers owned and operated by the Washington State Department of Transportation (WSDOT).[10] Unlike traditional NPDES permits, the Phase I permit is a "programmatic permit," meaning it requires the municipal

[8] King County Department of Metropolitan Services (METRO) is covered as a "co-permittee" with the City of Seattle for discharges from outfalls King County owns or operates in the City of Seattle. *Special Condition S1.C., Exs. Muni 0001, p. 1, Muni 0002, p. 21*.

[9] An MS4 consists of all of the conveyances, or systems of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs gutters, ditches manmade channels or storm drains) designed or used for collecting or conveying stormwater. By definition, these systems cannot be combined with sanitary sewer systems. *Exs. Muni 0001, p. 61, 63, Muni 0002, p. 22-24.*

[10] The Phase I permit does not cover the storm sewers owned and operated by the Washington State Department of Transportation (WSDOT). WSDOT's system is covered under an individual permit. *Ex. Muni 0002, p. 19, 21*.

permittees to implement area-wide stormwater management programs rather than establishing benchmarks or other numeric or narrative effluent limits for stormwater discharges from individual outfalls. *Testimony of Moore, Exs. Muni 0001, p. 1, 2, 60-65, Muni 0002, p 20-24*.

7.

The heart of the Phase I Permit requires that permittees implement a Stormwater Management Program (SWMP). Special Condition S5 contains the SWMP requirements for the primary permittees, and Special Condition S6 sets out the SWMP requirements for secondary and co-permittees. The required elements of the SWMP track closely with EPA's Part II Application rules but contain much more detailed minimum performance standards for the municipalities' programs. This approach avoids the need for separate review and approval by Ecology of each SWMP prior to coverage under the Phase I Permit. Instead, a permittee is required to submit the SWMP with the permittee's first year annual report. S5.A. *Testimony of Moore, Wessel; Exs. Muni 0001, p. 6-25; Muni 0002, p. 18, 28-42*.

8.

Ecology views these SWMP requirements, in the aggregate, to represent the MEP standard; that is, permittees who implement all of the program requirements in combination with one another are considered by Ecology to be reducing the discharge of pollutants to the maximum extent practicable, even though it may be possible for a permittee to do more in a specific program element or at a specific outfall if the individual requirements were evaluated in isolation from the rest of the program requirements. *Testimony of Moore.*

9.

Under Special Condition S5 the SWMP must include ten component parts, which are mandatory to the extent allowable under state and federal law. These program components address the following topics, and the minimum requirements for each are set out in S5.C. 1 through 10 of the Phase I Permit: (1) Legal authority; (2) System mapping and documentation; (3) Coordination; (4) Public involvement; (5) Controlling runoff from new development, redevelopment, and construction; (6) Structural stormwater controls (retrofits); (7) Source control for existing development; (8) Illicit connections, illicit discharge detection and elimination; (9) Operations and maintenance; and (10) Education and outreach. *Muni 0001, p. 6-25.*

10.

More specifically, S5.C.1 requires the permittee to demonstrate by the effective date of the Phase I Permit that it has the legal authority to control discharges to and from its MS4s. S5.C.2 requires the permittee to map, by specific dates, prescribed parts of its MS4. S5.C.3 requires the permittee to establish coordination mechanisms to remove barriers to stormwater management created by the need to coordinate efforts both internally within one governmental entity, and externally with jurisdictions that share drainage basins. S5.C.4 requires the permittee to provide ongoing opportunities for public involvement in its stormwater management program. S5.C.5 requires the permittee to develop a program to prevent and control impacts of runoff from new development, redevelopment, and construction activities. S5.C.6 requires the permittee to include a program to construct structural stormwater controls to prevent or reduce impacts from discharges from its MS4s. This element is applicable to existing development, as well as new development, and addresses impacts that are not already adequately controlled by other required actions under the SWMP. S5.C.7 requires the permittee to include a source control program for existing development that reduces pollutants in runoff from these areas. S5.C.8 requires the permittee to have an ongoing program to detect, remove and prevent illicit connections and illicit discharges, including spills, into its MS4s.[11] S5.C.9 requires the inclusion of a program to regulate maintenance activities and to conduct maintenance activities by the permittee that prevent or reduce stormwater impacts. S5.C.10 requires that the permittee's SWMP include an education program with the goal of reducing or eliminating behaviors and practices that cause or contribute to adverse stormwater impacts. The performance measures associated with S5.C.2 through 10 must be completed within specific time periods. *Testimony of Moore, Wessel, Exs. Muni 0001, p. 6-25, Muni 0002, p. 28-42*.

11.

Special Condition S6 (S6), which is similar but not identical to S5, establishes the components required for SWMPs from secondary permittees. Parts of this condition apply to all secondary permittees (S6.A, B and C), all secondary permittees other than the Ports of Seattle

[11] An illicit connection is any man-made conveyance that is connected to a MS4 without a permit, excluding roof drains and other similar type connections. An illicit discharge is any discharge to a MS4 that is not composed entirely of stormwater except discharges pursuant to a NPDES permit and discharges resulting from fire fighting activities. *Ex. Muni 0001, p. 61*.

and Tacoma (S6.D), and just the Ports of Seattle and Tacoma (S6.E). *Testimony of Moore, Exs. Muni 0001, p. 25-39, Muni 0002, p. 42-47*.

12.

Special Condition S8 (S8) addresses monitoring. It requires the primary permittees and the Ports to develop and implement long-term monitoring programs for the purpose of meeting two of the four monitoring objectives identified in the first round of the Phase I municipal stormwater permits issued in 1995: (1) estimating pollutant concentrations and loads from representative areas or basins; and (2) evaluating the effectiveness of selected Best Management Practices (BMP). The permit does not require monitoring to identify specific sources of pollutants or the degree to which stormwater discharges are impacting selected receiving waters and sediments. *Testimony of Moore, O'Brien, Exs. Muni 0001 p. 40-49; Muni 0002, p. 49-50*.

C. Monitoring provisions in S8

13.

Special Condition S8.C.1 specifies that the primary permittees' and the Ports' monitoring programs must contain three components: 1) stormwater outfall monitoring, which is intended to characterize stormwater runoff quantity and quality at a limited number of locations 2) Targeted stormwater management program effectiveness monitoring, which is intended to improve stormwater management efforts by evaluating at least two stormwater management practices that significantly affect the success of, or confidence in, stormwater controls, and 3) BMP evaluation monitoring, which is intended to evaluate the effectiveness and operation and maintenance requirements of stormwater treatment and hydrologic management BMPs. S8.D, E, and F set out the requirements for each of the three components. *Testimony of Moore, O'Brien, Exs. Muni 0001, p. 40-49; Muni 0002, p. 49-56*. A Quality Assurance Project Plan (QAPP) must be prepared for each of the components of the monitoring program in accordance with Ecology guidelines and submitted to Ecology for review. Ecology must review and approve the QAPPs for stormwater monitoring conducted under S8.D and F prior to monitoring. *Ex. Muni 0001, p. 40-41*.

14.

The first component of the Special Condition S8 monitoring involves outfall monitoring for the purpose of developing local knowledge of pollutant loads and average event mean concentrations from representative areas drained by MS4s. Developing a baseline of local data is important because some variations are emerging between stormwater characterization data from the Pacific Northwest and other areas around the county and world, with examples of both higher and lower concentration levels present regionally, differing from national averages. To accomplish this objective, the Permit requires permittees to select three sites that represent different land uses and then to monitor a certain percentage of storm events per year for a wide range of constituents and parameters. The permit requires storm events to be sampled using flow-weighted composite storm sampling. S8.D.2.b. The seasonal first-flush must be tested for toxicity. S8.D.2.d. Grab samples from each storm must be taken and tested for total petroleum hydrocarbon and fecal coliform bacteria, and one to three sediment samples must be collected each year at each site and analyzed for a variety of parameters. S8.D.2.e, f. *Testimony of O'Brien, Moore, Ex. Muni 0001, p. 41-45*.

15.

The number of samples is intended to establish a sufficient database from which to discern annual and seasonal loading trends over a long time period. Performing a toxicity test on the "seasonal first-flush storm" provides an annual worst case scenario. Ecology believes this data is necessary to evaluate whether stormwater management programs are making progress towards the goal of reducing pollutants discharged and protecting water quality. The data would also be useful when establishing Water Clean-up Plans (TMDLs) for water bodies not currently achieving water quality standards, and in other efforts to identify sources of toxicant loading to Puget Sound. *Testimony of O'Brien, Ex. Muni 0002, p. 49-53*.

16.

The second component of the S8 required monitoring, described in detail in S8.E, is the targeted stormwater management program effectiveness monitoring. In this section, each permittee must conduct monitoring designed to determine the effectiveness of (1) a targeted action (or narrow suite of actions) from their SWMP, and (2) achieving a targeted environmental outcome. The monitoring must, at a minimum, include stormwater, sediment or receiving water monitoring of physical, chemical and/or biological characteristics, and may also include other kinds of data collection and analysis. Ecology anticipates that the targeted environmental outcomes permittees will chose to evaluate will be measured in the receiving water and, therefore, may involve receiving water monitoring. *Testimony of O'Brien, Moore, Exs. Muni 0001, p. 45-46; Muni 0002, p. 53-54.*

17.

The third component of the S8 monitoring provisions is BMP effectiveness monitoring, the requirements of which are set out in S8.F. The purpose of this third component of the S8 monitoring is to develop local performance data on the effectiveness of specific treatment BMPs in reducing pollutant discharges and the effectiveness of various low impact development (LID) practices in reducing the quantity of runoff. This section requires the primary permittees and Ports to select and monitor two treatment BMPs in use at a minimum of two sites in their jurisdiction. S8.F.2. The permittees are also required to monitor the effectiveness of one flow reduction strategy[12] that is in use or planned for installation in their jurisdiction. S8.F.7. Though many of these treatment BMPs have been in common use for many years, and the 2005 Stormwater Management Manual for Western Washington relies on them as presumptively effective, Ecology has only incomplete information about their actual pollutant removal capabilities. *Testimony of O'Brien, Exs. Muni 0001, p. 46-47; Muni 0002, p. 54-56.*

18.

In the absence of local data, Ecology had relied on an existing national stormwater treatment BMP database, [13]as its primary source of BMPs for the 2005 Stormwater Management Manual for Western Washington (The Manual) *Testimony of O'Brien, Tobiason, Exs. PI 0059, 0060, 0064 and 0065.* The national database is of limited utility, however, in evaluating the

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[12] A flow reduction strategy is an approach that reduces the volume of runoff coming off a landscape. Ecology witness Ed O'Brien indicated in his testimony that this referred to the use of low impact development techniques.

[13] The purpose of the database, called the International Stormwater Treatment Database, is to facilitate understanding about how particular BMPs perform database and contains studies from both inside and outside the United States. *Testimony of O'Brien.*

effectiveness of BMPs because the performance of treatment BMPs varies greatly depending on specific design criteria, loading criteria, different rainfall patterns, and the types and sizes of solids to which a site gets exposed. These factors vary widely across the country, and therefore BMP performance data from one area is not always useful for another area. This has been a specific concern for Washington because, until recently, there has been little Washington data in the database. In some instances, this national database lacks also data quality, and relies on an insufficient number of samples at a particular site or from a particular BMP to be statistically useful. So, while there exists national data that allows Ecology to make some general assumptions about how well BMPs perform, Ecology still lacks site-specific, region-specific data to verify that the BMPs perform the way Ecology anticipates they will perform. As a result, Ecology required permittees to evaluate BMP effectiveness in an effort to learn and apply the information in future settings and permit iterations. *Testimony of O'Brien, Tobiason, Kibbey, Exs. PI 0059, 0060, 0064, 0065, Muni 0002, p.* 54-56.

19**.**

Ecology considered requiring receiving water monitoring in the Phase I Permit, but the municipalities as a group opposed the requirement. The 1995 Phase I Permit identified one monitoring objective as evaluating the degree to which stormwater discharges impact selected receiving waters and sediments, and Ecology concedes this continues to be a valid long-term objective for the municipal stormwater general permits. In the current iteration of the Phase I Permit Ecology decided, however, that receiving water monitoring data would not be the most helpful monitoring data because 1) receiving water monitoring data is more complex data to obtain, 2) samples can be hard to collect during storms, and 3) it is difficult to tie the receiving water data back to a specific discharger. Ecology agreed with the municipalities that certain receiving waters may receive pollution from multiple upland sources, and monitoring the receiving water would not provide permittees with useful data by which they could develop or tailor their stormwater management programs. Ecology also does not typically require receiving water monitoring under several other general stormwater discharge permits, including the construction and industrial permits, except for certain impaired water bodies where there have been violations of discharge limitations. *Testimony of Moore, O'Brien. Ex. Muni 0002, p. 49*.

20.

The monitoring required by S8 is primarily aimed at developing a uniform baseline of information about the pollutant loading discharging from MS4s, and evaluating the effectiveness of the BMPs that permittees use to control and reduce the pollutants discharging from those systems. Ecology determined this data will be the most useful for establishing what constitutes maximum extent practicable reduction in pollutants from MS4 discharges for future iterations of the municipal stormwater permits. Allowing some municipalities to opt out of these requirements, by substituting different kinds of monitoring, would reduce the robustness of the data set Ecology seeks for establishing this baseline for future permits. *Testimony of Moore, O'Brien.*

21.

Ecology intends to rely on its own monitoring programs, coordinated with and supplemented by other monitoring efforts, to accomplish the receiving water monitoring objectives identified in the 1995 permit. Ecology received an $800,000 state appropriation to begin work with a collaborative monitoring consortium to identify the elements of a comprehensive receiving water monitoring program, outside of the permit process. Such a monitoring consortium could more fairly distribute the cost of monitoring among all of the entities with an interest in receiving water data and form the basis for effective, region-wide monitoring of receiving water quality in relation to discharge points. Although Ecology is currently organizing the consortium, no water monitoring has been started to date through this program, and inadequate funding currently exists to do so. Outside the consortium, some receiving water monitoring occurs through statewide ambient water quality monitoring and pollutant specific monitoring where a water body is subject to a TMDL. *Testimony of Moore, O'Brien, Wessel*.

D. <u>Pierce and Clark Counties Monitoring Plans</u>

22.

Two primary permittees, Pierce and Clark Counties, already have water quality monitoring programs which differ significantly from the monitoring required in the Phase I Permit. The key difference between both of the counties' programs, and the Phase I Permit monitoring requirements, is that the county programs focus on monitoring in the receiving water environment. However, neither of the County programs monitors the chemical composition or toxicity of stormwater discharges from their MS4, nor relates stormwater management actions to a reduction in the pollutant characteristics of stormwater. *Testimony of Tobiason, O'Brien, Exs. PSA 018, PI 0042.*

23.

Pierce County began working with a consultant in 2004 to develop its monitoring program. The County developed the program based on the proposed monitoring requirements in an early draft of the Phase I permit, which included a receiving water monitoring component, as well as ongoing communications with Ecology personnel. The 2005 draft of the Phase I permit prescribed two of the five monitoring methods that Pierce County incorporated into its monitoring plan. *Ex. PI 0041*. Pierce County published its final program in March, 2007. *Testimony of Tobiason, O'Brien, Ex. PI 0042.*

24.

The overall goal of the Pierce County monitoring program is to implement a comprehensive monitoring program that will provide meaningful data to support the County's efforts to protect receiving waters from stormwater impacts. Although developed primarily in anticipation of the NPDES permit requirements, it also serves other county water quality objectives. In order to accomplish its goal, the program uses a three level receiving water monitoring approach. It includes long term status and trends monitoring, which includes a triad of bioassessments, physical channel characterization, and in-situ bioassays at existing County monitoring sites in selected streams, and may also include flow monitoring where gauges exist. Pierce County includes the sampling of the stream bottom as part of this long-term monitoring in order to determine the presence and health of benthic invertebrates. Monitoring benthic invertebrates provides a good indicator of watershed health because these organisms respond to physical and chemical stresses at the stream bottom. Pierce County applies these monitoring methods over a five year period to characterize the receiving waters in up to nine watersheds with regards to the receiving waters' physical stability, habitat, biological health, and susceptibility to toxicants in stormwater. This will enable Pierce County to prioritize responses to watersheds that exhibit vulnerability. It also includes targeted development monitoring, which compares upstream and downstream conditions to assess impacts of stormwater discharges on the receiving waters over finite periods before and after specific development. Targeted development monitoring includes continuous turbidity, conductivity and hydraulic stage monitoring and *in-situ* bioassay upstream and downstream of discharges from targeted development, and assessment of physical channel conditions downstream. Some aspects of the County's monitoring program, particularly the real-time data, will also assist the county in detecting spills and illicit discharges. The third level of receiving water monitoring included is a special studies monitoring. This method provides for adaptive management to be employed as needed on a site specific basis to develop cause-effect relationships that lead to focused stormwater management response. As part of this method, chemical analysis may be conducted if other programs indicate a need for such study to determine the cause of a problem discovered through receiving water monitoring. This is the only aspect of the Pierce County Program that provides for the use of chemical analysis. *Testimony of Tobiason, Kibbey, Exs. PI 0042, Ex. PI 0055, PI 0094.*

25.

Clark County, like Pierce County, has its own monitoring plan which is focused on receiving water monitoring. Clark County developed its plan in response to its first

NPDES/State Waste permit which was issued July, 1999 and expired December, 2000.[14] *Muni 0140, Special Condition S5.B.4, p. 7, 8.* Its plan has three elements: a long-term index site project, hydrologic monitoring, and a stormwater needs assessment program. The index site project involves nine stream stations which are influenced by stormwater, and a forested reference site. A suite of stream health characteristics are monitored at each site. Water quality monitoring takes place on a monthly basis. The hydrologic monitoring consists of monitoring stream flow continuously through the use of storm gauges at several locations, including some of the site index locations. The stormwater needs assessment program is a system created to make an assessment of needs for each sub-basin in the county that contains parts of the MS4. Currently, Clark County is in the process of completing reports on 12 urbanizing and rural sub-watersheds. *Testimony of Swanson, Ex. Muni 0140, p. 7-8.*

26.

The monitoring required under the Phase I Permit is fundamentally different than the monitoring contained in the Pierce and Clark County monitoring programs. The Counties' monitoring programs do not routinely look at the chemical content or toxicity of stormwater discharges, nor do they look at the effectiveness of treatment BMPs. *Testimony of O'Brien, Tobiason, Kibbey*.

[14] Clark County was not informed of the need to submit a permit application until January of 1995, because of confusion over whether Clark County met the requirements of the Phase I Permit, i.e. urbanized area with a population greater than 100,000. *Ex. Muni 0141, p. 8*.

27.

Ecology stated that it was extremely important to be able to answer whether our stormwater programs are adequate to protect aquatic resources and uses in its 2004 report to the Legislature. Therefore, Ecology included recommendations that certain types of environmental monitoring be conducted at the local and regional levels, including monitoring of the biological, chemical, and physical health of receiving waters. *Ex. ECY 6 (Phase I), p. 31-32*.

28.

Ecology does not oppose the Counties continuing on with their own monitoring programs in addition to the S8 monitoring. However, it has not allowed Pierce and Clark Counties to substitute their programs for the required S8 monitoring. Ecology witness Edward O'Brien did not rule out the possibility that Ecology could allow Pierce and Clark to substitute their monitoring programs for some parts of the required S8 monitoring. Pierce County witness Heather Kibbey testified that Pierce County could not afford to do both its receiving monitoring program and the required S8 monitoring. *Testimony of O'Brien, Tobiason, Kibbey*.

E. Ports

29.

One of the required elements of the SWMP for all Phase I permittees is the preparation of a stormwater pollution prevention plan (SWPPP). The permit requires all primary permittees to prepare SWPPS for "all heavy equipment maintenance or storage yards, and material storage facilities owned or operated by the Permittee(s)" that are not already covered by another stormwater discharge permit. S5.C.9.b.xi, p. 23, 24. The primary permittees are allowed 24 months to complete the development of their SWPPPs. The secondary permittees, other than the Ports, are required to prepare SWPPPS for "material storage areas, heavy equipment storage areas, and maintenance areas" not covered by another stormwater discharge permit. S6.D.6.a.vi, p. 32. Their SWPPPs must also be completed within three years from the date of permit coverage. *Testimony of Moore, Ex. Muni 0001, p. 23, 24, 32*. In contrast, the Ports' SWPPP preparation requirement, found in S6.E.7, requires the Ports to prepare SWPPPs "all Port-owned lands" that are not covered by another stormwater discharge permit. The Ports are allowed 24 months to develop and implement their SWPPPs. *Ex. Muni 0001, p. 38*.

30.

The Port of Seattle estimates this requirement will involve the preparation of SWPPPs for approximately 44 properties covering approximately 27 percent of its total Seaport acreage (286 acres).[15] Some of these sites include port-controlled and operated facilities with multiple tenants, such as Shilshole Marina and Fisherman's Terminal, and several others consist of tenant-controlled container areas. *Testimony of Guthrie, Exs. PI 0020, 0022*. The Port of Tacoma has identified several port-owned sites that are not covered by other stormwater discharge permits, some of which include buildings and parking lots leased to other businesses, others of which consist of environmental mitigation sites. *Testimony of Graves, Ex. PI 0039*.

31.

The Phase I fact sheet explains Ecology's general thinking regarding SWPPP preparation

[15] By agreement with Ecology, SWPPPs will not be required on "no discharge" properties, which include Port-owned parks and properties with connections to Metro Stormwater Conveyances.

for the primary permittees. It states:

> Ecology has determined that activities at certain sites owned or operated by permittees are potentially similar to activities at sites regulated under the Industrial Stormwater General Permit. For this reason this provision of the permit calls for developing Stormwater Pollution Prevention Plans (SWPPPs) for these sites.
>
> *Ex. Muni 0002, p. 41.*

32.

In the 2005 draft of the Phase I Permit, Ecology required SWPPP preparation for "all Port-owned lands with potential pollutant-generating sources." *Ex. PSA 018, p. 37*. The final permit eliminated the qualifier because Ecology expected that all port-owned lands would be pollutant-generating sources, although Ecology did not consider wetland mitigation areas owned by the Port of Tacoma when it made this decision. *Testimony of Graves*, *Moore*, *Exs. PSA 018, p. 37; PI 0022, 0025-0027*.

33.

The Port of Tacoma owns several environmental mitigation sites (i.e. wetlands). Most of these sites probably discharge directly to surface or ground waters of the state, and not to the MS4. For the ones that do discharge to the MS4, there is only a small potential that the discharges would carry pollutants. Therefore, preparation of SWPPPs on these sites is unlikely to result in any corresponding water-quality benefits. *Testimony of Moore, Graves.*

34.

Ecology also explains in the fact sheet its reasons for providing a slightly different standard for the Ports regarding SWPPP preparation. It states:

> Ecology has determined that special consideration is needed for the Ports of Seattle and Tacoma, distinguishing them from the broader group of Secondary permittees such as diking and drainage districts and public universities. These ports are both located on urban bays with documented water quality and sediment contamination problems that may be linked to stormwater discharges. The infrastructure in both Seattle and Tacoma is fairly old and the MS4s are heavily interconnected between each port and the respective city. Also, both ports lease properties to tenants, of whom many, but not all, are required to have coverage under the Industrial Stormwater General Permit. For these reasons this permit establishes SWMP components that are specific to these two entities.

Ex. Muni 0002, p. 43.

35.

In general, the permit has more requirements for primary permittees SWMPs than it does for the Ports. *Contrast* S5.C. 1 through 10 (establishing 10 components for primary permittees SWMPs) p. 6-25 with S6.E (establishing 7 components for Ports SWMPs) p. 32-39. The source control program for existing development, which is a component of both primary permittees and the Ports SWMPs, also imposes more requirements on the primary permittees than it does the Ports. *Contrast* S5.C.7, p. 13-15, with S6.E.7, p. 38-39. Further, the scope of the primary permittees source control obligation is much wider than that of the Ports, because the primary permittees are dealing with thousands of different sources, compared to a much more limited number for the Ports. Therefore, the Ports will be preparing a much smaller number of SWPPPs than the primary permittees. While Ecology suggests that the Guidance Manual for Preparation of SWPPPs for Industrial Facilities can be used to assist in preparation of Port SWPPPs, it also encourages the use of generic SWPPP provisions for sites grouped by type of activity, such as parking lots. *Testimony of Moore, Guthrie, Exs. Muni 0001, p. 6-25, 33-39, Muni 0002, p. 44, PI 0021*.

36.

The Port of Seattle expects its tenant businesses to be involved in the preparation of the required SWPPPs because they have the most familiarity with the pollution-generating activities and source control opportunities at the individual sites, but the port, in its role as property manager, will work cooperatively with tenants through its routine compliance assessment process. For example, it has already provided its tenants with templates for preparing the SWPPPs. This process will involve some cost and effort on the part of the tenants, but can also serve as an opportunity for educating and training tenants in issues related to stormwater management. *Testimony of Guthrie*. The Port of Tacoma intends to prepare the SWPPPS for its existing tenant facilities which will require the port to become better informed about the details of its tenant operations and pollutant-generating activities. For new facilities, the Port of Tacoma intends to direct tenants to prepare the SWPPPs. *Testimony of Graves*.

F. Low Impact Development (LID)

37.

The major contention of PSAs' challenge to the Phase I permit is that traditional structural engineered stormwater management practices are inadequate to address the municipal stormwater problem and that the Permit should have also required greater use of Low Impact Development (LID) practices on a broader and more comprehensive scale.

38.

In the Phase I Permit, Ecology chose to regulate stormwater discharges from new development and redevelopment primarily through the imposition of a flow control standard. S5.C.5.b.i. *Ex. Muni 0001, p. 9, Testimony of O'Brien*. The flow control standard generally requires new and redeveloped sites that discharge to surface waters to control the rate at which stormwater is released from their sites so that the discharges do not cause accelerated stream channel erosion. The flow control standard is not a LID concept, because, in contrast to LID techniques, it is based on the premise that there will be discharges of stormwater from particular sites, and it attempts to control the duration and frequency of high stormwater runoff flows. Conventional stormwater management criteria frequently incorporate a post development peak discharge rate for a 2- and 10-year storm event based upon possible property damage due to flooding and stream bank erosion. These are becoming more recognized as insufficient because they do not address the loss of storage volume to provide for groundwater recharge, they do not adequately protect downstream channels from accelerated erosion, and the inspection and maintenance costs are an increasing burden for local governments. The goal of LID, on the other hand, is to minimize or prevent entirely the discharge of stormwater from the site. While utilization of LID techniques may be useful (or even in some cases necessary) to meet the flow control standard on a particular site, the flow control standard does not require the use of LID techniques. *Testimony of O'Brien, Booth, Exs. ECY 4 (Phase I) p. 2-30 through 2-35, Ex. PSA-053, p. 7.*

39.

In order to meet the Permit's flow control standard(s), facilities must be engineered so that discharges are not predicted to exceed the predevelopment flow "durations" for a range of storm events. The Stormwater Management Manual gives detailed design specifications for sizing and constructing detention/retention facilities to meet the flow control standard. The Manual itself recognizes the shortcomings of the use of engineered stormwater conveyance, treatment and detention systems to control stormwater. It states, at page 1-25:

> [These techniques] can reduce the impacts of development to water quality and hydrology. But they cannot replicate the natural hydrologic functions of the natural watershed that existed before development, nor can they remove sufficient pollutants to replicate the water quality of pre-development conditions.

The primary focus of detention standards is on mitigating the worst impacts of large storm events. These standards have little or no effect on small storm events, which can also cause damaging increase in flows. Stated another way, the flow control standard addresses large stormwater flow rates only, which occur only a small percentage of time (1%), and provides only residual control to runoff the remainder of the time. *Testimony of O'Brien, Booth, Ex. ECY 4 (Phase I), p. 1-25, 2-30 through 2-35.*

40.

Another limitation of the flow control standard comes from a significant exception to the requirement to achieve pre-developed discharge rates for basins that have had at least 40 percent total impervious area since 1985. Phase I permit, Appendix 1, p. 25-27, and Manual, Section 2.5.7 Minimum Requirement # 7, pp. 2-33. For sites in these basins, the pre-developed condition to be matched is the existing land cover. Most areas located within the Seattle city limits, many areas within the City of Tacoma, and some areas in Bellevue and Everett would qualify for this exception. *Testimony of O'Brien, Booth, Exs. ECY 4 (Phase I), p. 2-33, Muni 0001, Appendix 1, p. 25-27.*

41.

The Phase I Permit defines LID as follows:

> stormwater management and land development strategy applied at the parcel and subdivision scale that emphasizes conservation and use of on-site natural features integrated with engineered, small-scale hydrologic controls to more closely mimic pre-development hydrologic functions.

Ex. Muni 0001, p. 62. Ecology adopted this definition from the Puget Sound Action Team's Low Impact Development Manual (PSAT Manual), which is a technical manual published in 2005 to "provide stormwater managers and site designers with a common understanding of LID goals, objectives, specifications for individual practices, and flow reduction credits that are applicable to the Puget Sound region." *Ex. PSA 050, p.2.*[16] Other definitions of LID offered in testimony at the hearing differ from this definition primarily in the scale of application of LID. Thomas Holz offers an almost identical definition to the one quoted above, but includes application at the watershed scale in addition to the parcel or subdivision scale. *Testimony of Holz, Ex. PSA 050, p.11.*

[16] The advisory committee for the development of the PSAT Manual included Edward O'Brien, Tom Holz, and Derek Booth. These three experts also testified at the Phase I hearing, *Testimony of Moore, Ex. PSA 050, Acknowledgements page and p. 2.*

42.

While specific definitions of LID may vary, the concept of LID is well-established, and the basic BMPs that constitute LID are well-defined. LID techniques emphasize protection of the natural vegetated state, relying on the natural properties of soil and vegetation to remove pollutants. LID techniques seek to mimic natural hydraulic conditions, reducing pollutants that go into stormwater in the first instance, by reducing the amount of stormwater that reaches surface waters. *Testimony of Horner, Booth, Holz.*

43.

LID techniques store, infiltrate and evaporate stormwater where it falls rather than collect and convey it to surface waters off site, and can be implemented at an individual development site level, as well as part of a broader strategy employed at a basin or watershed level. Site-level LID BMPs include, but are not limited to, maintenance of natural vegetation on site; reduction of impervious surfaces; protection of natural drainage patterns, use of minimal excavation foundations such as pin foundation for structures; use of vegetated swales to capture and retain runoff; use of green roofs, and storage and reuse of runoff. At a watershed or landscape scale, LID strategies can include basin planning, watershed-wide limits on imperviousness, and protection of sensitive areas like riparian zones, wetland and steep slopes. *Testimony of Holz, Booth, Ex. PSA 050.*

44.

Although many LID techniques are not new ideas (i.e. grass roofs, rain gardens), LID as a formal stormwater management concept was developed in the late 1980's. *Testimony of Booth,* *Holz.* Prince George's County, Maryland, a pioneer in the area of LID in the United States, began working on bioretention or rain gardens during the 1980's, and published a comprehensive LID technical manual and an accompanying volume providing detailed hydrologic analysis and computational procedures in 1999. *Exs. PSA 052 and 053*. Two federal agencies, the U.S. Department of Defense and Department of Housing and Urban Development, adopted LID Manuals in 2003 and 2004. *Exs. PSA 054 and 055*. The Puget Sound Action Team and the Washington State University Pierce County Extension published The PSAT Manual, a 247 page, comprehensive, technical guidance manual for the use of LID in the Puget Sound Area, in January of 2005 with funding provided by the Ecology. *Ex. PSA 050*. The PSAT Manual was intended to provide a menu of treatment options and direction for site design techniques, but it does not attempt to identify a performance standard for any of the included LID strategies. *Testimony of O'Brien*.

45.

The Environmental Protection Agency (EPA) has not required the use of LID in its stormwater rules or EPA permits, but it is increasingly supporting and encouraging the use of LID approaches in municipal stormwater programs on its website and thorough numerous publications. *See for example, Ex. PSA 057(EPA National Pollutant Discharge Elimination System (NPDES), Post-Construction Stormwater Management in New Development and Redevelopment)(posted on EPA's website); PSA Ex. 058, (EPA National Pollutant Discharge Elimination System (NPDES), Low Impact Development (LID) and Other Green Design Strategies)(posted on EPA's website); PSA 056 (EPA Fact Sheet for Stormwater Phase II Final*

Rule, Post-Construction Runoff Control Minimum Control Measure (Jan. 2000, rev'd 2005); Ex. PSA 066 (EPA Low Impact Development (LID), A Literature Review (Oct. 2000); Ex. PSA 059 (EPA 833-F-04-033, Resource List for Stormwater Management Programs (May 2004); Ex. PSA 060 (EPA National Management Measures to Control Nonpoint source Pollution for Urban Areas (Excerpts: Cover, Table of Content, Chapters 1-4, 10); Ex. PSA 061 (Memorandum from Benjamin Grumbles (Assistant Administrator, EPA) to EPA Regional Administrators Re: Using Green Infrastructure to Protect Water Quality in Stormwater, CSO, Nonpoint Source and Other Water Programs (Mar. 5, 2007); Testimony of Holz.

46.

Ecology's 2005 Stormwater Management Manual addresses the use of LID techniques in several ways, as part of the manual's Minimum Technical Requirements and Site Planning (Volume I), its Hydrologic Analysis and Flow Control Design/BMPs (Volume III), and its Runoff Treatment BMPs (Volume V). *Ex. ECY 4*.[17] One of the most significant changes during the 2005 update to the Manual included the addition of a "credit" system for projects that use LID techniques. *Ex. PSA 064*.

[17] The Manual is not a regulation but rather a guidance document that presents a presumptive approach to meeting requirements established through other means, such as permits. Washington is somewhat unique in its reliance on the Stormwater Management Manual for directing how stormwater management is to be conducted. *Testimony of Moore*. *Testimony of O'Brien*. The Manual represents Ecology's generalized determination of what constitutes AKART for stormwater management, without regard to how much horizontal development should be allowed (*i.e.*, whether a particular parcel, subdivision, or watershed should be developed or a particular project should be undertaken). The manual is also considered by the Department of Community, Trade, and Economic Development, the agency charged with state oversight of the implementation of the GMA, to constitute the best available science for use by local governments planning under the GMA. *Testimony of O'Brien*.

47.

Volume I covers several key elements of developing a stormwater site plan, including identifying the minimum requirements for stormwater management at all new development and redevelopment projects. Minimum Requirement #5, which directs on-site stormwater management for the purpose of using inexpensive practices on individual properties to reduce the amount of disruption of the natural hydrological characteristics of the site, requires the use of certain LID BMPs such as roof downspout control and dispersion and soil quality BMPs. This minimum requirement applies to single-family home sites and larger properties. *Testimony of O'Brien, Ex. ECY 4 (Phase 1), Vol I, at 2-26; Ex. Muni 0001, Appendix I at p.10 and 19*. The Phase I permit requires that permittees' local ordinances must meet Minimum Requirement #5, including requiring specified LID BMPs to reduce the hydrologic disruption of developed sites. *Testimony of O'Brien, Ex. Muni 0001, Condition S5.C.5 (at p. 9) and Appendix 1(at p.19).*

48.

Stormwater site planning requirements, also contained in Volume I, direct that site layouts minimize land disturbance and maximize on-site filtration by considering a number of LID strategies and techniques such as preserving areas with natural vegetation (especially forested areas) as much as possible, minimizing impervious areas, and maintaining and utilizing natural drainage patterns. *Testimony of O'Brien, Ex. ECY 4 (Phase I), Vol I, at 3-2.*

49.

Volume III of the Manual focuses primarily on BMPs to address the volume and timing of stormwater flows from developed sites, for the purpose of providing guidance on the estimation and control of stormwater runoff quantity. Appendix III-C of this volume is Ecology's guidance explaining how Low Impact Development techniques can be represented in approved runoff models so that their benefits in reducing surface runoff can be estimated and credited in the flow duration model. It identifies seven categories of LID techniques, including permeable pavements, vegetated roofs, rainwater harvesting, reverse slope sidewalks, minimal excavation foundations, and rain gardens, and lists the basic design criteria Ecology considers necessary in order to justify use of the suggested runoff credit. *Testimony of O'Brien, Ex. ECY 4 (Phase I), Vol III, at Appendix III-C.*

50.

Finally, Volume V of the Manual identifies and discusses BMPs designed to treat runoff to remove sediment and other pollutants at developed sites, for the purpose of providing guidance on the selection, design and maintenance of permanent runoff treatment facilities. LID techniques are included in both the basic and advanced treatment options available to developers, and the method for determining the treatment credits for each technique is explained. Chapter 5 of this volume is devoted to the methods for analysis and design of on-site LID BMPs that serve to both control runoff flow rates as well as provide runoff treatment and, since 2005, has directed readers to use the PSAT Manual for various LID BMPs. *Testimony of O'Brien, Ex. ECY 4, Vol V.*

51.

Ecology wrote the first draft of the current Phase I Permit in 1999. At that time, LID was recognized as a stormwater management strategy, but there was not the same body of work available on its use as there is today. Although much of the work and literature cited above post-dated the initial draft of the current Phase I Permit, Ecology recognized that a large body of work existed on LID as it finalized the Phase I permit. Despite the existence of many LID source or reference materials, Ecology believed that it could not at that time define minimum LID requirements, and was unable to define a regulatory performance standard to hold municipalities to, should LID requirements be imposed by the permit. The agency also recognized that local governments had adopted other land use and development standards that were obstacles to the implementation of LID on a broader scale. Some local governments also have limited experience with LID techniques and are reluctant to approve them. *Testimony of O'Brien*.

52.

Early drafts of the permit included requirements for basin or watershed planning as a LID technique. Use of a basin planning approach in the permit would, among other things, require municipalities to consider the effects of loss of impervious cover to water quality in larger, watershed, basin, and sub-basin areas (potentially measured in many square miles). The ideal area size for basin planning is two to ten acres. WRIA-scale (Water Resources Inventory Area) planning efforts are too large to address the impervious surface problem. *Testimony of Wessel*. Basin planning can also lead to the development of better site specific strategies, and some Ecology staff advocated for its inclusion into the Permit. *Testimony of O'Brien*.

53.

Ultimately, Ecology drafted a permit that requires municipalities to identify barriers to use of LID, and to take steps to also "allow" LID. Specific requirements for basin planning were not included in the final permit, although the Endangered Species Act listing of various salmon species, and efforts of the Puget Sound Partnership are reasons to reexamine the need for basin planning as a permit requirement. *Testimony of Wessel, Moore; Ex. PSA 31*. Ecology rejected basin or watershed planning as a permit requirement, in part because the agency could not require a comprehensive planning effort, given that not all jurisdictions within a given watershed or basin were covered by the Phase I permit. Ecology also concluded that imposing both site level LID and basin planning requirements would move the agency too far into the land use regulatory arena, although Ecology witnesses conceded that imposition of more detailed LID requirements and a basin planning process could be harmonized with a parallel Growth Management Act land use process, thereby elevating water quality as a growth management planning priority. *Testimony of Moore, Wessel, O'Brien*.

54.

Ecology stated in its 2004 report to the Legislature that:

> Compact style development, with a smaller footprint, reduced impervious surfaces, natural areas within the urban core, and improved water detention can help local communities meet the Growth Management Act's goals of accommodating growth while protecting the environment.

Ex. ECY 6 (Phase I), p. 31. This same 2004 report to the Legislature highlighted the importance of stormwater basin planning in areas which are relatively undeveloped where new development is occurring. Ecology stated that in these areas:

> site specific controls alone cannot prevent impacts and preserve aquatic resources. Recent research should be used to identify development strategies that may protect the resources. Scientific modeling of the basin can help predict the extent of potential

> impacts and the effectiveness of alternative land development options to help avoid or minimize those impacts.

Id. at 28. Ecology also recommended in its report to the Legislature that state and local governments consider basin planning to address the known shortcomings of the stormwater permits. Ecology stated that:

> Stormwater basin planning is needed to quantify flow-related impacts and sources of pollution to urban water bodies. This information is needed to target resources spent on structural and non-structural controls (such as maintenance and public education) so that goals for urban water bodies can be met. In many basins, this planning can be combined with the planning for new development described earlier.

Id. at 30. Other types of water quality planning are taking place on a WRIA basis. The Board finds that information developed by permittees regarding their use of basin planning, and its possible interface with other planning efforts, would be very valuable to Ecology in its development of the next phase of the Permit.

55.

The Phase I Permit includes several conditions that address LID in various ways, nearly all of which are in the nature of encouraging or promoting rather than requiring LID by municipalities. In contrast to other permit terms, the final permit does not require municipalities to implement ordinances or other measures to use LID as a primary tool to manage stormwater within their jurisdictions. *See* S5.C.5.b.i (allowing local governments to tailor certain requirements applicable to new development through the use of basin plans or other similar water quality and quantity planning efforts)*;* S5.C.5.b.iii (requiring SWMPs to allow non-structural preventative actions and source reduction approaches such as LID techniques)*;*

S5.C.6.a (stating that permittees should consider other means to address impacts from existing development "such as reduction or prevention of hydrologic changes through the use of on-site (infiltration and dispersion) stormwater management BMPs and site design techniques, riparian habitat acquisition, or restoration of forest cover and riparian buffers . . ."); S5.C.10.b.(3) and (4) (requiring the inclusion of LID techniques in education and outreach programs); S8.F.1 and 7 (requiring monitoring of the effectiveness of one flow reduction strategy that is in use or planned for installation in their jurisdiction); and Appendix 1 § 4.5 (imposing, as a minimum requirement, on-site stormwater management where feasible, including use of roof downspout controls and dispersion and soil quality BMPs or their functional equivalent).[18] *Exs. Muni 0001, p. 9, 10, 12, 24, 25, 46, 47, and Appendix 1, p. 19*.

56.

Some commentors on the draft Phase I Permit criticized the lack of more mandatory LID requirements. The National Marine Fisheries Service and the U.S. Fish and Wildlife Service (jointly the Services) offered comments on the Draft Phase I Permit in May, 2006. While they supported many elements of the draft Permit, the Services recommended that the Permit employ methods to help ensure that several LID projects are completed within the permit term and strongly encouraged the use of basin planning to make better linkage with salmonid recovery plans organized at the watershed level. *Ex. PSA 030*. EPA offered its comments on the draft Phase I Permit in October, 2006. *Ex. PSA 067*. While EPA praised many aspects of the permit, it also recommended strengthening the permit by "promot[ing] the implementation of low impact

[18] This same requirement is included in The Manual. *Ex. ECY 0004 (Phase I), Vol. 1, p. 2-26*.

development and non-structural best management practices," and "add[ing] a basin planning program requirement." Similarly, a group of Washington Scientists sent an "open letter" to Ecology on October 26, 2006, in which they criticized the draft Phase I Permit for its continued focus on "end of pipe" management of stormwater, emphasizing the need to preserve existing "least-disturbed" watersheds, to limit forest loss, and to halt runoff from new impervious areas in the Puget Sound Basin. They recommended broad application of LID principles within the context of land use planning and development regulations efforts to prevent runoff to surface water. *Ex. PSA 010.*

57.

Ecology staff who developed the Phase I permit, as well as a number of stormwater experts who testified before the Board, agreed that no one stormwater management technique could solve the problem of polluted runoff from municipal stormwater systems. Even the extensive use of site-level LID is not sufficient, on its own, to fully protect aquatic resources. Rather, a combination of aggressive use of LID techniques, best conventional engineering techniques to manage high flows (such as the flow duration standard), and land use actions to preserve a high percentage of native land cover, are necessary to reduce pollutants in stormwater to the maximum extent, and to preserve water quality. Although the there is considerable dispute about the attainable performance of particular LID strategies and engineering techniques, there is no dispute that *in combination* these approaches offer the best available, known and tested methods to address stormwater runoff. *Testimony of O'Brien, Holtz, Booth*.

58.

There are existing design criteria for many LID techniques, just as there are for traditional BMPs employed to manage stormwater run-off used at the parcel or subdivision scale (for example, pond size or thickness of a liner). These aspects of LID can be employed at a site specific level. However, at this time there are no universal or broadly endorsed performance standards for LID, at either the parcel, subdivision, or watershed scale. Nor were experts before the Board willing to endorse or recommend such standards from among the many potential options identified, although it was undisputed that any permit condition requiring permittees to meet a new stormwater performance standard based on LID would implicate many other local government regulatory schemes, and require modification to local government GMA planning processes and requirements, zoning and development regulations, and building codes. *Testimony of Holz*.

59.

A zero runoff outcome from the use of LID techniques is one such performance standard, but actions to meet that standard would implicate a range of land use planning actions and watershed level assessments. It is possible to create other, more specific performance standards for LID, although the process would involve time and effort. Other jurisdictions are currently using such standards, or have proposed standards for use. For example, jurisdictions can require that LID BMPs be designed in accordance with guidelines in technical manuals, impose specific minimum technical requirements for buildings or roads, require protection of a specific amount of native vegetation at the site or basin level, limit the amount of effective impervious surface, protect the natural hydrograph through various parameters, require maintenance of a certain percentage of predevelopment evapotranspiration capacity or minimize or eliminate surface runoff, or require that developers prioritize LID BMPs as the first choice before conventional BMPs. The Phase I Municipal Stormwater Permit for San Diego County, which was reissued in January, 2007, requires all new and redevelopment projects to implement LID BMPs where feasible. The Permittees are given the responsibility of defining the applicability and feasibility of LID BMPs, including the minimum standards to ensure maximum implementation. Another example of an NPDES permit from another jurisdiction that incorporates a LID performance criteria is the Ventura County MS4 Permit. This permit, which was in draft form at the time of the hearing, requires that developers prioritize LID BMPs as the first choice before conventional BMPS. *Testimony of Booth, Holz, Horner, Exs. PSA 048, p. 13-18; PSA 069, p. 49; PSA 070, 072, 080, Snohomish County Code 30.63C.*

60.

Requiring municipalities to impose parcel and subdivision-level LID best management practices represents a cost effective, practical advancement in stormwater management. Use of LID techniques at the parcel and subdivision level would not be feasible on every type of site, or under all rainfall conditions present in Western Washington. Use of LID techniques could in some instances allow pollutants to enter groundwater. LID BMPs require maintenance. All of these limitations are also applicable to the more traditional end of pipe BMPs. In fact, site attributes that make implementation of LID techniques difficult also typically make implementation of conventional techniques difficult. In the absence of watershed or basin level efforts to utilize LID, parcel and subdivision-level use of LID will be less effective in overall stormwater management efforts, but still a substantial advancement. *Testimony of O'Brien, Booth, Holz, Horner, Exs. ECY 3 (Phase I), p. 34-36, PSA 066, p. 2, 3.*

61.

In many cases, implementation of LID techniques on the ground for new or redevelopment, or even retrofitting existing development, is less costly, or no more costly, than conventional engineered BMPS. Structural stormwater controls, such as detention ponds, curbs, gutters and pipes, require significant hardware and capital investment. LID techniques eliminate or reduce the need for these structural controls by reducing the volume of water to be managed. LID techniques may also require less space than these traditional methods. *Testimony of Holz, Booth, Horner, Exs. PSA 047, p. 6-10, PSA 066, p.1, ECY 3 (Phase I), p. 35-36.*

62.

A major cost consideration in utilizing LID techniques at a site level is not the engineering or construction associated with the LID techniques, but rather the costs associated with navigating a system of regulation and development that was not created with LID in mind. To fully incorporate LID principles into this system will require review, consideration, and in some instances modification, of existing zoning and building regulations that create obstacles to the use of LID. Some examples of common local government ordinances that could make it difficult to utilize certain LID techniques include requirements related to road width, curbs and gutters, vegetation clearing, and parking spaces. *Testimony of Holz, Horner*. The cost of implementing LID across a broader land use spectrum, through basin or watershed planning is more speculative, and the Board was presented with no clear evidence on costs associated with broader scale implementation of LID in this manner. Although such planning is underway in certain areas, a longer public and political process could be expected to accompany such an effort.

63.

The cost of not expanding the application of LID strategies to manage municipal stormwater is very high. The biological health of Puget Sound is declining, and a significant cause of the decline is stormwater run-off. This decline carries with it a variety of environmental, economic, and social costs. *Ex. PSA 087, p. 1*. The Puget Sound Water Quality Plan, which is a plan mandated by the Legislature to be the state's long term strategy for protecting and restoring the Puget Sound, stated as early as 2000 that local governments needed to adopt ordinances that allow and encourage LID practices. *Ex. PSA 078, p. 101.* Many leading scientists concluded, in a paper submitted to the Puget Sound Partnership in July of 2007, that the problem of stormwater must be addressed in the land use context if the health of Puget Sound, the species that inhabit it, and its various important beneficial uses to the region, are to be protected and/or recovered. The group concluded that:

> We have well documented evidence that the impairment associated with stormwater runoff is primarily a **land use problem,** and that we cannot fully mitigate its effects if we approach it only site-by-site. <u>We know that the </u>problems must be addressed at a basin or landscape level-but we continue to manage land use and stormwater primarily on a site-by-site, end of pipe basis. At the same time, we also know that current site-by-site development techniques that result typically in wholesale loss of vegetation, compaction of native soils and connected impervious surfaces, can and should be improved upon significantly if we are to address stormwater problems.

Ex. PSA -012, p. 3 (emphasis in original).

64.

Recently, many local governments have begun incorporating LID techniques into their stormwater manuals, and/or adopting LID stormwater requirements. *Exs. PSA 072 (City of Olympia, Engineering Design and Development Standards, Ch. 9, Green Cove Basin); PSA 073 (Graham Community Plan, A Component of the Pierce County Comprehensive Plan, Excerpts: pp. Cover, Table of Contents, p. 70, 87, 109, 149, 208); PSA 074 (Gig Harbor Peninsula Community Plan, Excerpts: pp. cover, 29, 41, 63, 117, 210)*; *PSA 076 (King County, Washington, Surface Water Design Manual, Jan. 4, 2005, Excerpts: pp. cover, Table of Contents, 5-1 through 5-16); PSA 051 (Pierce County, Stormwater Management and Site Development Manual, Excerpts: Ch. 10, p. 10-1 to 10-82).*

65.

Examples of the approaches already being used by Phase I Permittees to encourage or require the use of LID techniques include reducing charges for surface water rates with the use of an approved LID stormwater and surface water runoff systems (*City of Tacoma, Ex. PSA 085, p. 4);* promoting LID during project scoping meetings with potential developers (*City of Tacoma, Ex. PSA 085, p. 4);* adopting LID Ordinances (*Snohomish County, PSA Ex. 077, p. 8);* incorporating LID Development Design concepts into existing regulations (*Snohomish County, Ex. PSA 077, p. 9*); and providing public outreach and education about LID (*City of Tacoma, Ex. PSA 085, p. 5, Snohomish County, Ex. PSA 077, p. 10-14, City of Seattle, Ex.PSA 079, p. 12, 13*). Other, more stringent examples include requiring project proponents to use LID techniques for all proposed Fully Contained Community developments in rural areas (*Snohomish County, Ex.*

PSA 077, p. 9); requiring LID for any UGA docket expansions proposals within the Little Bear Creek watershed (*Snohomish County, Ex. PSA 077, p. 10*); and requiring LID to be used on a large project in the Mill Creek pocket expansion (*Snohomish County, Ex. PSA 077, p. 9).*

66.

The Board finds that LID methods are at this time a known and available method to address stormwater runoff at the site, parcel, and subdivision level. Numerous reference documents, technical manuals, expert testimony, and Ecology's own Stormwater Management Manual, discussed above, support this finding. The Board also finds that LID methods are technologically and economically feasible and capable of application at the site, parcel, and subdivision level at this time. Because application of these methods at the basin and watershed level involves additional cost and practical considerations, we find Ecology must ready for the eventual use of this known and available method of stormwater treatment for future iterations of the permit, consistent with its obligation to impose increasingly stringent requirements on discharges covered by NPDES permits.

G. <u>Existing development</u>

67.

The Phase I Permit addresses stormwater runoff from existing development through the implementation of structural stormwater controls and source controls. Both of these are required components of Permittees' SWMPs, and the Permit includes minimum requirements for each which are based on EPA's stormwater rules.[19] *Testimony of Wessel, Ex. Muni 0001, p. 12-15, Ex. Muni 0002, p. 34-36*.

68.

The structural stormwater control program, also referred to as the "retrofit" component, is targeted at discharges not adequately controlled by other aspects of the SWMP. S5.C.6. Through this program, permittees must consider construction of stormwater control projects, as well as other means to address impacts to state waters caused by MS4 discharges. The permit directs that the program "shall consider the construction of projects such as: regional flow control facilities; water quality treatment facilities; facilities to trap and collect contaminated particulates, retrofitting of existing stormwater facilities; and rights-of-way, or other property acquisition to provide additional water quality and flow control benefits." The Permit also provides that permittees "should consider" other means to address impacts, including LID techniques such as "reduction or prevention of hydrologic changes through the use of on-site (infiltration and dispersion) stormwater management BMPs and site design techniques. . ." S5.C.6.a. *Testimony of Wessel, Ex. Muni 0001, p. 12, 13.*

69.

The permit establishes minimum performance measures for the structural stormwater control program, including development of the program within 1 year of the effective date of the

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[19] The Fact Sheet's reference to 40 C.F.R. 122.26(b)(2) appears to be a typographical error. Ecology's pre-hearing brief properly cites the applicable federal regulation for these program elements as 40 C.F.R. 122.26(d)(2). A portion of this federal rule, unrelated to municipal stormwater, was recently invalidated in Natural Resources Defense Council v. U.S. E.P.A., 526 F.3d 591 (9th Cir. 2008).

permit, and implementation of the program within 18 months from the effective date of the permit. S5.C.6.b.i. Permittees are required to provide a list of planned individual projects that are scheduled for implementation during the term of the permit. Municipalities are not required to prioritize the planned projects in any manner. Permittees are required to submit a description of their structural stormwater control program to Ecology along with the written documentation of their SWMP, but the permit does not set a minimum level of effort for this requirement or provide for Ecology review and/or approval of the structural stormwater control program. S5.C.6.b.ii. *Testimony of Wessel, Dalton, Ex. Muni 0001, p. 12, 13, Ex. Muni 0002, p. 35.*

70.

The requirements for the Source Control Program for existing development are set out in S5.C.7. Through this program, the permittee must "reduce" pollutants in runoff from areas that discharge to MS4s, through application of operational and structural source control BMPs, and if necessary treatment BMPs to pollution generating sources associated with existing land uses and activities. S5.C.7.a. The program required in this section also must include inspections, application and enforcement of local ordinances at applicable sites, and reduction of pollutants associated with application of pesticides, herbicides and fertilizer discharging to MS4s. S5.C.7.b.ii-iv. While reduction of pollutants is mandated, no objective standard is set for the amount of reduction, although Ecology must review and approve the source control program. S5.C.7.b.i. *Testimony of Wessel, Muni 0001, p. 13-15*. Under this section of the permit, permittees must also implement a progressive enforcement policy to assure compliance with stormwater requirements within a reasonable time period. S5.C.7.b.iv. *Testimony of Wessel, Ex. Muni 0001, p. 13-15*.

H. Timing of Compliance

71.

PSA challenges the validity of several Phase I Permit provisions on the grounds that they do not require implementation of the permit within three years. PSA provides several examples of permit conditions that allow implementation after three years. Some of these examples include S5.C.2.b.ii (requiring outfalls to be mapped no later than four years from the effective date of the permit); S5.C.8.b.vi (requiring screening for illicit discharges in portion of each jurisdictions to be completed within four years.); and S.5.C.9.b.ii (3) (allowing permittees up to four years after the effective date of the permit to develop a schedule to inspect treatment and flow control facilities). PSA also provides examples of conditions that impose duties that are tied to the expiration of the permit. Some examples of these conditions include Condition S6.A.3 (full development of the co-permittee and secondary permittees' SWMPs no later than 180 days prior to the expiration of the permit); and S6.D.1. a.ii (Secondary permittees shall label all inlets 180 days prior to expiration of the permit). *Ex. Muni 0001, p. 7, 18, 20-21, 25, and 27*.

72.

Any Conclusion of Law deemed to be a Finding of Fact is hereby adopted as such.

CONCLUSIONS OF LAW

1.

The Board has jurisdiction over the parties and the issues in the case pursuant to RCW 43.21B.110(1)(c). The burden of proof is on the appealing party(s) as to each of the legal issues, and the Board considers the matter *de novo*, giving deference to Ecology's expertise in administering water quality laws and on technical judgments, especially where they involve complex scientific issues. *Port of Seattle v. Pollution Control Hearings Board*, 151 Wn.2d 568, 593-594, 90 P.3d 659 (2004). Pursuant to WAC 371-08-540(2), "In those cases where the board determines that the department issued a permit that is invalid in any respect, the board shall order the department to reissue the permit as directed by the board and consistent with all applicable statutes and guidelines of the state and federal governments."

A. Monitoring (Issues C.1, C3, and F.3.)

2.

Two counties, Pierce and Clark, challenge the monitoring requirements imposed by Special Condition S8.[20] They contend that their own monitoring programs, which focus on receiving water monitoring, are more advanced than the monitoring required by S8. While they support Ecology's S8 monitoring approach as a starting point for municipalities that do not already have well developed receiving water monitoring programs, Pierce and Clark Counties

[20] Issues C.1 and C.3.

argue that compliance with the S8 monitoring will hinder their own efforts to protect water quality.

3.

The Utilities also challenge the validity of the S8 monitoring program. They contend that it is deficient because it does not require receiving water or "compliance" monitoring. They argue that receiving water monitoring is necessary to establish whether the permittees have complied with water quality standards and whether they have treated their discharges with AKART or to the maximum extent practicable.[21]

4.

WAC 173-226-090(1) establishes monitoring requirements for general waste discharge permits. The Board has concluded in its past decisions that this regulation provides Ecology with the discretion to impose *reasonable* monitoring requirements. WAC 173-226-090(1)*; Puget Soundkeeper Alliance v. Ecology,* PCHB Nos. 05-150, 0151, 06-034, -040 (Jan. 26, 2007) (CL 22). Further, since a decision pertaining to monitoring requirements in a general permit falls within an area of Ecology's technical expertise, and involves complex scientific issues, the agency's decision is entitled to deference. *Port of Seattle* at 593-594. The disagreement between appellants and Ecology reflects different sides of a long-standing debate regarding the relative merits of instream versus outfall monitoring, and the most advantageous sequencing of the two. *Ex. P1 0048*. It is clear there is no one right approach, as the type and timing of monitoring that is best

[21] Issue F.3.

in any given situation depends on the particular purpose, context, and available resources, among other factors.

5.

Neither the Utilities nor the Counties have cited to any law requiring the Phase I Permit to require receiving water monitoring. The federal stormwater rules require only that municipalities propose a monitoring program for the term of the permit, but list few specific requirements. 40 C.F.R. 122.26(d)(2)(iii)(D).[22] The Board concludes that Ecology's decision not to require receiving water monitoring during this permit cycle is lawful and reasonable. Ecology's decision to require monitoring designed to understand the pollutants discharging from MS4s, and to evaluate the effectiveness of the BMP's in use, will provide the most useful data to establish what constitutes maximum extent practicable reduction in pollutants in discharges from MS4s for future permits. Further, as pointed out by Ecology, the counties are not prohibited from conducting receiving water monitoring in addition to the S8 monitoring required under the permit. [23]

6.

In light of the discretion Ecology has in this area, the deference its technical decisions are entitled to, and the fact that the burden of proof rests on the party challenging the permit, neither the Counties nor the Utilities have presented a sufficient case to convince the Board that it should

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[22] A portion of this federal rule, unrelated to municipal stormwater, was recently invalidated in Natural Resources Defense Council v. U.S. E.P.A., 526 F.3d 591 (9th Cir. 2008).

[23] It is also possible that parts of the Pierce and Clark County programs could be used to satisfy the targeted effectiveness component of the S8 monitoring (S8.E). *Ex. Muni 0001, p. 45-46*. The Board encourages Ecology to work with Pierce and Clark Counties to find ways to make parts of their current monitoring programs satisfy some of the requirements under S8.

reverse Ecology's decision to select the S8 monitoring program and require all permittees to participate in it.

B. Ports (Issue E.5)

7.

The Ports contend that it is "unlawful, unreasonable, unjust, or invalid" to require them to prepare SWPPPs on all port owned land not covered by another discharge permit. The Ports argue that the primary permittees have to prepare SWPPPs only on areas on which industrial type activities occur (maintenance areas and material and heavy equipment storage) that are not covered by another discharge permit. The Ports assert that it is unreasonable to require SWPPPs without consideration to how property is used, it is unreasonably burdensome to the Ports because of the cost to prepare SWPPPs, and it is unnecessary because not all port-owned lands have polluting generating characteristics. The evidence presented, however, does not support these arguments.

8.

The evidence presented at the hearing establishes that lands owned by the Ports of Seattle and Tacoma are located close to vulnerable urban waters with documented water quality and sediment contamination problems. Almost all of the port-owned lands that discharge to MS4s have pollutant-generating characteristics. Therefore preparation of SWPPPs for these properties will have environmental benefits. The only exception is those few environmental mitigation sites owned by the Port of Tacoma. Most of these environmental mitigation sites probably do not discharge to the MS4s, and therefore would not require coverage under the Phase I Permit.

For the ones that do, however, there is no environmental benefit gained by requiring the preparation of a SWPPP, and it is appropriate to exempt these sites from preparation of SWPPPs.

9.

The Board concludes that it not an unreasonable burden to require the Ports to prepare a SWPPP for all port-owned lands which discharge to the MS4 and are not already covered by another discharge permit. Based on the permit's inventory of types of sites with potential pollutant generating sources (*Muni 0001, Appendix 8*), it was reasonable for Ecology to conclude that the Ports owned most or all of these type of pollution sources, and that the Ports needed to prepare plans to manage stormwater from such port-owned property. The Ports also have fewer requirements under the Phase I Permits than other primary permittees. They will have fewer SWPPPs to prepare than the primary permittees. For SWPPP preparation, they can use some generic conditions for sites with identical uses, such as commercial buildings or parking lots. This will reduce the amount of time it takes to prepare each SWPPP and the cost of preparation. The ports can also work cooperatively with their tenants who share some responsibility for the proper management of stormwater on port-owned properties, which will have the added environmental benefit of educating site operators about stormwater BMPs.

10.

The Board concludes that Special Condition S6.E.7, which requires the Ports to prepare SWPPPs on all port-owned lands is appropriate and valid. However, the permit should not mandate SWPPP preparation for environmental mitigation sites owned by the Port of Tacoma, as the Port of Tacoma has shown that such sites are unlikely to generate untreated stormwater pollution.

C. LID (Issue F.1.a & .b)

11.

The LID issues raised in this appeal involve the question of whether the Phase I Permit fails to meet the required treatment standard of reducing pollutants to the "maximum extent practicable"(MEP) and applying "all known, available and reasonable methods of treatment" (AKART), because the permit does not require more extensive use of LID techniques.

12.

The Board has previously ruled in this appeal (on summary judgment in the Special Condition S4 proceeding) the CWA requires that NPDES permits issued for discharges from MS4s must reduce pollution to the maximum extent practicable (the "MEP" standard). The Board also concluded the WPCA contains a similar requirement, in that all wastewater discharge permits must incorporate permit conditions requiring all known, available and reasonable methods of treatment to control the discharge of toxicants and protect water quality (the "AKART" standard). Order on Dispositive Motions: S.4 issued on April 2, 2008.

13.

The MEP standard in the CWA provides:

> Permits for discharges from municipal stormsewers . . . (iii) shall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants.

33 U.S.C. § 1342(p)(3)(B)(iii).

Neither Congress nor the EPA have defined the meaning of MEP in the municipal stormwater context, nor do the parties cite to federal court cases interpreting the MEP standard in the municipal stormwater context.[24] The Board, in a prior decision pertaining to the first round of the municipal stormwater permits, stated:

> The MEP standard is unique under water pollution laws and applicable only to municipal stormwater discharges. MEP reflects the difficulty of addressing stormwater on a system wide basis and the focus of regulating municipal stormwater discharges on prevention and control. This approach by its nature requires extensive planning and *prioritization* to achieve the underlying of goal of meeting water quality standards.

Save Lake Sammamish v. Ecology, PCHB Nos. 95-78 & 121, Order Granting Summary Judgment (Dec. 12, 1995) (emphasis added).

14.

The AKART standard originates in state law, but the Legislature has not explicitly defined the term. Ecology has incorporated the state AKART standard into several of its regulatory programs (*e.g.*, the state surface and ground water quality standards, state waste discharge and NPDES permit programs, sediment management standards, and domestic wastewater facilities regulations), and has defined the AKART standard through rulemaking. In the state's surface water quality standards, "AKART" is defined as "the most current methodology that can be reasonably required for preventing, controlling, or abating the

[24] The term "practicable" as used in a different section of the CWA, 33 USC § 1311(b)(1)(a), has been defined as meaning that technology is required unless the costs are "wholly disproportionate" to pollution reduction benefits. *Rybacheck v. U.S. EPA*, 904 F.2d 1276, 1289 (9th Cir. 1990).

pollutants associated with a discharge." WAC 173-201A-020. The Washington Supreme Court has further clarified that the "reasonableness" prong of AKART involves both technological and economic feasibility. *Puget Soundkeeper Alliance v. Ecology*, 102 Wn. App. 783, 792-793, 9 P.3d 892, 897 (2000).

15.

In evaluating MEP and AKART for the Phase I Permit, we start with the context that this is a "programmatic" permit that regulates the discharge from MS4 systems on a jurisdiction-wide basis, through the municipalities' implementation of their Stormwater Management Programs. In several instances the permit requires that through these Stormwater Management Programs, municipalities enact ordinances or orders, or adopt other enforceable documents, to control pollution in stormwater. *See, e.g.*, Condition S5.C.1. The nature and scope of the LID provisions in the Permit, and what can be required through the permit, must therefore be evaluated within the broader context of the SWMP requirements and the programmatic nature of this permit.

16.

The permit's reliance on a flow control standard as the primary method to control stormwater runoff from MS4s fails to reduce pollutants to the federal MEP standard, and without greater reliance on LID, does not represent AKART under state law. The permit's reliance on terms that simply require "removal of obstacles" and actions to "allow" use of LID is insufficient to meet these same federal and state pollution control standards. The testimony presented by PSA, the Utilities, and Ecology's technical experts leads to the indisputable conclusion that application of LID techniques, at the parcel and subdivision level, is a currently known and existing methodology that is reasonable both technologically and economically to control discharges entering into MS4s covered by the Phase I Permit. The great weight of testimony before the Board, from various experts and Ecology witnesses, was that in order to reduce pollution in urban stormwater to the maximum extent practicable, and to apply AKART, it is necessary to aggressively employ LID practices *in combination with* conventional stormwater management methods. Thus, we conclude that under state law, the permit must require greater application of LID techniques, where feasible, in combination with the flow control standard, to meet the AKART standard. The permit must also require the application of LID, where feasible, and conventional engineered stormwater management techniques to remove pollutants from stormwater to the maximum extent practicable in order to comply with federal law. Our recognition that use of LID is to be employed where feasible recognizes that, like all stormwater management tools, it too is subject to limitations in its practical application by site or other constraints. *See* Findings of Fact 49-51. We do not change the applicable legal standard by use of this term. Accordingly, the permit must be remanded for modification in light of this conclusion.

17.

Although we conclude that the permit must require municipalities to employ broader use of LID at the parcel and subdivision level, we stop short of concluding that the permit must, at this time, require use of LID at a basin and watershed level. Based on the evidence before the Board, we cannot conclude that the current iteration of the permit must require implementation of LID on a basin or watershed scale in order to meet federal and state water quality standards. Little evidence was presented as to the elements and cost of basin or watershed planning that would be necessary to implement LID at this level. Ecology testified that the current Phase I and Phase II permits result in a patchwork of regulation of municipal stormwater, and jurisdictions are at greatly varying degrees of readiness to manage stormwater on basin or watershed levels. The Phase II permittees themselves are at greatly varying degrees of readiness and capacity to undertake LID on a basin and watershed level, and would need to work with Phase I and other jurisdictions to do so. Given these several factors, the Board concludes that a permit condition requiring municipalities to implement LID at a basin or watershed level is not, at this time, reasonable or practicable. This is not to say that no steps can or should be taken at this time. Ecology has identified the particular importance of basin planning in areas which are relatively undeveloped where new development is occurring. The Board concludes that city and county permittees should identify such areas where potential basin planning would assist in reducing the harmful impacts of stormwater discharges upon aquatic resources. This will assist Ecology in readying for the next round of permits when such a requirement may be necessary to meet the state AKART standard and, under federal law, to reduce pollutants in municipal stormwater to MEP. As we discuss in further conclusions, we do not find the Growth Management Act to be an impediment to Ecology requiring greater use of LID than represented by the current permit, including at the basin and watershed planning level. Because the CWA and state water quality laws anticipate that there will be increasingly stringent requirements imposed on those that discharge pollutants to the state's waters, including municipalities, efforts to further basin and watershed planning efforts in order to incorporate the known and available LID techniques should begin in anticipation of the next permit cycle.

18.

No party challenges Ecology's authority to require LID techniques if they are necessary to meet the AKART or MEP standards. The Board affirmed this point in its summary judgment order. Order on Dispositive Motions: (Phase I Municipal Stormwater Permit) (April 8, 2008). The Board further stated:

> As pointed out by PSA, it is impossible to untangle stormwater management from land use. Even the commonly accepted water quality technique of requiring a stormwater retention pond at a site takes up significant area in a development, potentially reducing the number of buildable sites and constituting a land use restriction. The challenge, as recognized by both Ecology and PSA, is to most effectively harmonize Ecology's authority over site design and land use standards under the water pollution laws with other state laws that are specifically aimed at addressing land use on a broader scale.

Id. While Ecology does not dispute that it has the authority to require the use of LID techniques, it was constrained in the full exercise of this authority because of concerns about intruding too far into local government land use planning efforts under the Growth Management Act. Ecology's position is somewhat puzzling, as it has, through various requirements of its Stormwater Management Manual, and the permit itself, already required a number of LID techniques, and has required local government to remove obstacles to use of the same.[25] The

[25] We also note that, in another context, Ecology has recently adopted rules for the implementation of the Shoreline Management Act which outline a comprehensive process for preparing or amending shoreline master programs that requires, among other things, local governments to incorporate the most current, accurate, and complete scientific and technical information available that is applicable to the issues of concern; prepare a characterization of shoreline ecological functions, including hydrologic functions; identify water quality and quantity issues relevant to master

Board concludes that contrary to the concerns raised by Ecology during permit development, that the GMA is not a barrier to greater use of LID but rather complements the efforts of Ecology to move forward with requiring the use of LID techniques under the Phase I Permit.

19.

The Legislature enacted the Growth Management Act (GMA), Ch. 36.70A RCW in 1990 and 1991, largely "in response to public concerns about rapid population growth and increasing development pressures in the state, especially in the Puget Sound region." *Quadrant Corp. v. State Growth Management Hearings Bd.*, 154 Wn.2d 224, 231-232, 110 P.3d 1132, 1136 (2005) (citations deleted). The GMA includes a broad statement of goals to guide local governments in their development and adoption of comprehensive plans including a goal to "Protect the environment and enhance the state's high quality of life, including air and water quality. . ." RCW 36.70A.020(10).

20.

The GMA mandates that local governments adopt comprehensive plans which include, among other elements, a land use element addressing, "drainage, flooding, and stormwater run-off in the area and nearby jurisdictions" and providing "guidance for corrective action to mitigate or cleanse those discharges that pollute waters of the state, including Puget Sound or waters entering Puget Sound." RCW 36.70A.070(1); *Swinomish Indian Tribal Community v. Skagit*

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program provisions; identify important ecological functions that have been degraded through loss of vegetation; and identify measures to ensure that new development meets vegetation conservation objectives. WAC 173-26-201.

Co., 138 Wn. App. 771, 774, 158 P.3d 1179 (2007) (concluding that the GMA mandates that local governments adopt comprehensive plans to protect surface and ground water resources.)

21.

The state WPCA predated the GMA, with the specific purpose of protecting the waters of the state. RCW 90.48.010. The Legislature tasked Ecology with the job of implementing the WPCA. RCW 90.48.030, .035. Clearly, there is an area of interface and overlap between the GMA and the WPCA.

22.

The Washington Courts have stated that statutes are to be read together harmoniously whenever possible. "The construction of two statutes shall be made with the assumption that the Legislature does not intend to create an inconsistency." *Peninsula Neighborhood Ass'n v. Dep't of Transportation*, 142 Wn.2d 328, 342, 12 P.3d 134 (2000). Further, as the Washington Supreme Court recently stated: "We do not favor repeal by implication, and where potentially conflicting acts can be harmonized, we construe each to maintain the integrity of the other". *Anderson v. State, Dept. of Corrections,* 159 Wash.2d 849, 859, 154 P.3d 220, 225 (2007)(citing *Misterek v. Washington Mineral Products, Inc.*, 85 Wn.2d 166, 168, 531 P.2d 805 (1975)). *See also Kariah Enterprises, LLC v. Ecology*, PCHB No. 05-021, Corrected Order Granting Partial Summary Judgment (Jan. 6, 2005).

23.

The Board has addressed the interface between the GMA and the WPCA in the *Kariah* decision, cited above. In that case, the appellant challenged Ecology's denial of a CWA Section

401 Water Quality Certification for a proposed residential development. The Appellant argued that the Legislature, through GMA, had delegated Ecology's authority over wetlands under the WPCA to local governments. The Board rejected this argument, concluding that neither chapter 90.48 RCW nor 36.70A RCW contained any express provisions delegating Ecology's authority over protecting water quality in wetlands to cities and counties. The Board went on to conclude that the WPCA and the GMA should be harmonized, and that:

> The legislative policy articulated in RCW 36.70A.010 indicates the GMA was directed at addressing uncoordinated and unplanned growth, not at shifting the responsibility to regulate wetlands from the state government to local governments.

Kariah, CL 33.

24.

Similarly, in a Shoreline Hearings Board decision addressing the interaction between the Shoreline Management Act (SMA) and the GMA, the Board concluded that Ecology's newly adopted shoreline rules did not improperly usurp the authority of local governments planning under the GMA, despite venturing into land use controls. *Association of Washington Businesses v. Ecology*, SHB No. 00-037, Order granting and denying appeal (2001)(Issue 9).[26]

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[26] Although this decision was split on several issues, the holding on the GMA issue was unanimous. We note that even prior to the GMA, the Shoreline Management Act (SMA), Ch. 90.58 RCW, was enacted by initiative of the people in 1971 after recognizing the "ever increasing pressures of additional uses … being placed on the shorelines necessitate[e] increased coordination in the management and development of the shorelines of the state." RCW 90.58.020. The SMA includes a broad policy to protect the waters of the state and gives preference to uses that protect water quality and the natural environment. *Id*. The SMA establishes a balance of authority between local and state government, where cities and counties have the primary responsibility for initiating the planning required by the Act and administering the regulatory program, and Ecology is tasked with providing assistance to local governments in the development of their shoreline master programs and "insuring compliance with the policy and provisions of [the Act]." RCW 90.58.050.

25.

The Legislature has not expressed any intent, either through the GMA, SMA, or amendments to the WPCA, to redirect Ecology's role in water quality protection to the local governments. The Department of Community, Trade and Economic Development (CTED), the agency charged with implementing and interpreting the GMA, has considered the interaction between the GMA and pre-existing laws not specifically addressed in the GMA. In WAC 365-195-700, CTED's GMA regulations state:

> For local jurisdictions subject to its terms, the Growth Management Act mandates the development of comprehensive plans and development regulations that meet statutory goals and requirements. <u>These plans and regulations will take their place among existing laws relating to resource management, environmental protection, regulation of land use, utilities and public facilities. Many of these existing laws were neither repealed nor amended by the act.</u>
>
> <u>This circumstance places responsibilities both on local growth management planners and on administrators of preexisting programs to work toward producing a single harmonious body of law.</u>
>
> WAC 365-195-700 (emphasis added).[27]
>
> CTED's regulations further explain that:
>
> Overall, the broad sweep of policy contained in the act implies a requirement that all programs at the state level accommodate the outcomes of the growth management process wherever possible. State agencies are rarely concerned solely with the rote application of fixed standards. The exercise of statutory powers, whether in permit functions, grant funding, property acquisition or otherwise, routinely involves such agencies in discretionary decision-making. The discretion they exercise should now take into account the new reality of legislatively mandated local growth management

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[27] Ecology's SMA rules recognize a similar responsibility to harmonize overlapping bodies of law and regulation, which now provide: "It is the responsibility of the local government to assure consistency between the master program and other elements of the comprehensive plan and development regulations." WAC 173-26-191(e).

programs.

WAC 365-195-765(4).

26.

The Phase I permittees are all cities and counties required to plan under the GMA. RCW 36.70A.040. Their planning must address protection of surface and ground water. RCW 36.70A.070(1). CTED has identified the Ecology Stormwater Management Manual as best available science in regard to stormwater management under the GMA. Ecology, as a state agency, must also work toward implementation of the GMA. We conclude that there is no conflict between GMA and the WPCA, nor the roles of local governments and Ecology under these statutes. These roles support and complement each other and can be harmonized to allow water quality efforts to be considered and integrated into the growth management process outlined in the GMA.

27.

The Board concludes Ecology may, within the bounds of the GMA, require use of LID as a water quality management tool. The Board further concludes that the Phase I Permit must be modified to require use of LID where feasible, as it is necessary to meet the MEP and AKART standards of federal and state law, respectively. RCW 36.70A.070(1) already provides the mandate for local governments planning under the GMA to address drainage, flooding, and stormwater runoff in order to mitigate or cleanse discharges of water pollution. The Permit, including the Manual, merely sets forth the methods to accomplish this requirement.

D. Existing Development (Issue F.2)

28.

PSA and the Utilities contend that the permit provisions addressing existing development are inadequate to meet the MEP and AKART standards. Their primary complaint is that both the structural and source control provisions applicable to existing development require only that programs "reduce" impacts from discharges (S5.C.6) or that the permittees "reduce" pollutants in runoff (S5.C.7). They contend that these sections do not set any minimum expectation for the level of effort required and allow the permittees to make deminimus reductions in polluting discharges, and thus constitute impermissible self regulation. *PSA v. Ecology*, PCHB Nos. 02-162, -163, and -164, Order Granting Partial Summary Judgment (June 6, 2003)(CL XVI)(citing *Environmental Defense Center v. Environmental Protection Agency*, at U.S. App. 497, at 57-62 (9th Cir., Jan. 14, 2003)).

29.

The Board agrees the structural stormwater control program, as drafted, amounts to impermissible self-regulation. First, the permit fails to require a minimum level of effort for the permittees in the selection and prioritization of structural stormwater projects, and provides no review and approval role for Ecology. Second, the permit fails to comply with the applicable EPA rule and therefore amounts to impermissible self regulation on this basis as well. 40 C.F.R 122.26(d)(2)(iv) requires that "Proposed management programs shall describe priorities for implementing controls." Condition S5.C.6 merely requires the permittees to develop a program within 12 months and provide Ecology a "list of planned individual projects that are scheduled for implementation" during the term of the permit. S5.C.6.b.i. While initial project selection is presumably subject to the MEP and AKART standard of the permit, Ecology plays no role in ensuring these standards are met, even through simple review of the selected projects. The permit does not contain any requirement that permittees describe their project priorities or require that Ecology review the permittees' structural stormwater control program. Ecology is not expected to approve the municipalities' prioritization of projects in relation to the pollution reduction requirements of the permit. While Ecology testified that the permit "implied" there needs to be a prioritization of planned structural stormwater control projects, and a schedule reviewed by Ecology *(Moore testimony)*, the permit does not expressly state this requirement and the fact sheet explicitly states that "review and approval by Ecology is not a permit requirement." *Ex. Muni 0002, p. 35*. Thus, the structural stormwater control program is left entirely to the discretion of the municipalities, not only with respect to which projects they initially select, but also in the timing and manner in which they implement the selected projects. Prioritization of projects is particularly important given that Conditions S5 and S6 are based upon actions taken by the permittees and not outcomes, and this structural stormwater control provision is to "address impacts that are not adequately controlled by the other required actions of the SWMP." Prioritization helps to ensure that the sites where the permittees choose to "act" are meaningful in providing environmental protection. It can also assist to engage the public as a partner in reducing pollutants in discharges and the overall volume of discharges. A community, for example, could request a permittee to focus a project in an area which discharges near shellfish beds. While the Board recognizes that local funding will influence the selection of planned projects and that municipalities must therefore retain local control in the selection process, we conclude that the permit must require permittees to describe the prioritization of their selected projects in order to comply with federal rules, demonstrate compliance with the MEP and AKART standards, and facilitate oversight by Ecology to ensure the legal standards of the permit are applied on a programmatic level. *See Save Lake Sammamish v. Ecology*, PCHB Nos. 95-78 & -121, Order Granting Summary Judgment (Dec. 12, 1995).

30.

In contrast to the structural stormwater control program provisions, the source control program for existing development requires a more rigorous program to reduce pollutants in runoff from areas that discharge to MS4s owned or operated by the permittee, and does not suffer from the same flaws as the structural stormwater control program. The permit requires that Ecology must review and approve the source control program. S5.C.7.b.i. Therefore, the Board concludes that the source control program as drafted meets the MEP and AKART standard.

E. Water quality violations (Issues F.1.a., F.2.a,, and F.4)

PSA and PSE argue, through several different issues, that the permit fails to prevent discharges that violate water quality. *See* F.1.a (permit fails to require LID techniques which results in discharges that violate water quality); F.2.a (permit allows discharges from existing development that violate water quality); F.4 (Permit as a whole allows discharges that violate water quality standards; Prohibition on violations of water quality standards contained in Special Condition S4 conflicts with other provisions of the permit). The Board concludes that the permit, with the amendments directed by the Board to meet AKART and MEP, and with the amendments directed by the Board to the S4.F compliance process,[28] is adequately conditioned to comply with state law.

F. Timelines for Compliance (Issue F.5)

31.

The CWA sets out a number of deadlines related to NPDES permits for industrial and large municipal dischargers, including a deadline for EPA to establish regulations setting forth permit application requirements, a deadline for filing permit applications, and a deadline for EPA's approval or denial of the permits. 33 U.S.C. § 1342 (p)(4)(A). The final sentence in 33 U.S.C. § 1342 (p)(4)(A) states: "Any such permit shall provide for compliance as expeditiously as practicable, but in no event later than 3 years after the date of issuance of such permit." PSA contends that the Phase I Permit violates this provision.

32.

The Board has addressed this specific sentence before, in a case involving a challenge to a renewal of the Industrial Stormwater General NPDES Permit. *PSA v. Ecology*, PCHB Nos. 02-162, -163, -164, Order Granting Partial Summary Judgment (June 6, 2003). In that case, involving industrial stormwater discharges, the Board concluded that the reference to "compliance" in the sentence referred to compliance with the permit requirement contained in 33 U.S.C. § 1342 (p)(3)(A)(the provision pertaining to industrial stormwater discharges). *PSA* at CL XXI. Applying that same analysis to this case, involving municipal stormwater discharges,

[28] These modifications are ordered in the Board's Findings, Conclusions and Order on S4, issued on August 7, 2008.

the reference to “compliance” is to 33 U.S.C. § 1342 (p)(3)(B)(the provision establishing the MEP standard for municipal stormwater discharges). Therefore, the question becomes whether the permit allows any actions to occur later than three years after the date of issuance of the permit that are necessary to reduce discharges of pollutants to the maximum extent practicable.

33.

Several of the conditions of the Phase I Permit allow actions required by the permit to occur more than three years after the date of issuance of the permit. PSA and the Utilities contend that this establishes that the permit violates 33 U.S.C. § 1342 (p)(4)(A). However, this fact alone does not establish a violation of 33 U.S.C. § 1342 (p)(4). PSA and the Utilities, as the parties with the burden of proof, must bring forth evidence establishing that earlier compliance with one of the permit provisions currently allowing implementation outside of the three year statutory window is necessary to meet the MEP standard. Ecology has developed a programmatic permit with multiple components to be implemented throughout the permit cycle which, collectively, represent MEP and AKART. To read the statute as suggested by PSA and the Utilities would inappropriately limit Ecology’s ability to include within the permit additional conditions or requirements that may not be practicable within three years but which are reasonable within a longer time frame. The Board concludes that PSA and the Utilities have failed to meet their burden on this issue. The record does not contain sufficient evidence on any specific permit condition to convince the Board that the permit violates 33 U.S.C. § 1342 (p)(4)(A).

34.

Any Finding of Fact deemed to be a Conclusion of Law is hereby adopted as such.

Having so found and concluded, the Board enters the following

ORDER

Having concluded that portions of the Phase I Permit are invalid, the Board remands the Phase I Permit to Ecology pursuant to WAC 371-08-540, for modifications consistent with this opinion.

1. Ecology shall modify Special Condition S6.E.7 as follows:

> 7. Source Control in existing Developed Areas
>
> The SWMP shall include the development and implementation of one or more Stormwater Pollution Prevention Plans (SWPPPs). A SWPPP is a documented plan to identify and implement measures to prevent and control the contamination of discharges of stormwater to surface or ground water. SWPPP(s) shall be prepared and implemented for all Port-owned lands, **except environmental mitigation sites owned by the Port of Tacoma,** that are not covered by either a General Permit or an individual NPDES permit issued by Ecology that covers stormwater discharges.
>
> (modified language is in bold and underlined)

2. With respect to the use of LID, in addition to the specific modifications identified in No. 1 above, Ecology shall also modify the permit consistent with this opinion as follows :

   a. Modify Permit Condition S5.C.5.b to read as follows:

   > iii. The program must ((~~allow~~)) **require** non-structural preventive actions and source reduction approaches ((~~such as~~))**, including** Low Impact Development Techniques (LID), to minimize the creation of impervious surfaces, and measures to minimize the disturbance of soils and vegetation **where feasible**.

b. Require permittees to identify barriers to implementation of LID and, in each annual report, identify actions taken to remove barriers identified.

c. Require permittees to adopt enforceable ordinances that require use of LID techniques where feasible in conjunction with conventional stormwater management methods.

d. Require permittees to address in their annual report to Ecology under the Phase I Permit, information on the extent to which basin planning is being conducted in their jurisdiction, either voluntarily, or pursuant to GMA or any other requirement.

e. Require permittees to identify, prior to the next permit cycle or renewal, areas for potential basin or watershed planning that can incorporate development strategies as a water quality management tool to protect aquatic resources.

3. Ecology shall modify Special Condition S5.C.6.b.ii, related to structural Stormwater control programs minimum performance measures, to require that permittees describe the prioritization of their selected projects as required by federal rules, in order to facilitate oversight by Ecology to ensure that the MEP and AKART standards are met on a programmatic level.

SO ORDERED this 7th day of August, 2008.

POLLUTION CONTROL HEARINGS BOARD
Kathleen D. Mix, Chair
William H. Lynch, Member
Andrea McNamara Doyle, Member

Kay M. Brown, Presiding
Administrative Appeals Judge

State and Local Policies Encouraging or Requiring Low Impact Development in California

January 2008

Prepared for the
Ocean Protection Council of California

Prepared by TETRA TECH

State and Local Policies Encouraging or Requiring Low Impact Development in California

Final Report

Prepared for:

Ocean Protection Council

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January 2008

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Executive Summary

Stormwater pollution occurs when rain falls onto developed areas. Under natural conditions, much of the rainwater soaks into the soil, returning to streams, lakes, and other waterbodies through the ground. Surface runoff is usually limited and is slowed by dense vegetation. With development, specifically with the creation of impervious surface such as streets, driveways, sidewalks, and roofs, rain is prevented from infiltrating into the ground, causing it to flow over the surface in much larger quantities. Along the way this runoff mobilizes pollutants and transports them to waterbodies where they eventually flow to the Pacific Ocean.

In California, 691 waterbodies are considered impaired because water quality is too poor to support designated uses.[1] Of these impaired waterbodies, 110 are bays and harbors, 39 are estuaries, and 4 are tidal wetlands, indicating that pollution is affecting California's coastal resources. Urban runoff-related pollutants, such as pathogens, nutrients, metals (e.g., mercury, copper, lead), sediment, and toxic chemicals, are among the top causes of impairment statewide. Many California communities have issued a standing warning to avoid swimming, surfing, or other contact recreation at beaches for 72 hours after rainstorms due to high bacterial counts and increased concentrations of other potentially harmful pollutants being discharged from stormwater outfalls. Beach closures and swimming restrictions are commonly attributed to urban runoff, in some cases even during dry weather. Urban runoff can cause physical damage by accelerating stream channel erosion, modifying instream aquatic habitat, and altering riparian zones. Flood damage can also be more frequent and severe when runoff is not properly mitigated.

The effects of urban runoff have been exacerbated by stormwater management techniques popularized after World War II, in which drainage systems were designed to rapidly convey vast amounts of stormwater through gutters and pipes with no attenuation or pollutant removal. These high-volume, high-velocity flows have eroded stream channels, destroyed habitat, and caused flooding and property damage.

In the past decade a stormwater management technique called Low Impact Development (LID) has been gaining ground as the preferred method for mitigating stormwater impacts. The technique minimizes hardscape and uses the pervious surfaces on a development site, such as landscaped areas, to infiltrate and/or temporarily store runoff, allowing the site to more closely mimic a "natural" state with respect to hydrology. LID site design incorporates such diverse practices as bioswales, filter strips, flow-through planter boxes, porous pavement, cisterns, rain barrels, green roofs, and other micro-scale best management practices, allowing a great deal of flexibility in design. Widespread application of LID practices is expected to help restore the natural water balance when used in redevelopment and infill applications, which is particularly important in urbanized areas to help reverse the ill effects of past development. LID is also expected to maintain the hydrologic balance and reduce pollutants in newly developing areas, helping to ensure protection of high-quality water resources.

Regulations are in place in California and nationwide to prevent and/or mitigate the effects of stormwater pollution. The California State Water Resources Control Board and Regional Water Quality Control Boards have set requirements for municipalities and construction sites to control stormwater under the National Pollutant Discharge Elimination System regulations. Municipal stormwater permits developed by the Regional Water Quality Control Boards in Southern California and the San Francisco Bay area have begun to incorporate explicit LID requirements. These requirements are not standardized and only apply locally, however, limiting their impact statewide. The draft Construction General Permit includes incentives to incorporate LID techniques in stormwater plans statewide and will apply to most new and redevelopment. However, comprehensive state legislation could be adopted to "set the bar" for LID

[1] EPA. 2008. *2006 Section 303(d) List Fact Sheet for California*. http://iaspub.epa.gov/waters/state_rept.control?p_state=CA

incentives and requirements to ensure that all of the State's water resources are protected. Recommended language should be based on existing models within California and in other areas, integrating the "best of the best" while balancing the needs of large, urban communities with those of smaller, suburban or rural communities.

Beyond statewide legislation, other opportunities exist to integrate LID into related programs and initiatives. Stormwater concerns dovetail nicely with smart growth, watershed protection, water conservation, and green building initiatives, for example. Dialog and partnerships among State and local agencies, environmental groups, trade associations, water agencies, academia, and citizen groups will be essential for LID to become "business as usual" in California, with benefits not only to water quality but also for community livability and sustainability.

This report includes background information on stormwater pollution and impervious surface effects (Section 1). Section 2 presents an overview of LID principles and practice along with highlights of agencies and organizations that have incorporated LID. Section 3 categorizes a variety of options for state, regional, and local LID requirements, while Section 4 summarizes existing stormwater regulations in California and elsewhere and integrates these examples into recommendations for statewide LID legislation if the state were interested in adopting such requirements. Section 5 discusses ways in which LID can be incorporated into local codes, ordinances, and standards, along with programmatic steps communities can take to improve LID program administration. Key elements of progressive stormwater codes and ordinances are included as models for other communities. Finally, a procedure and criteria are presented that would assist a State agency in evaluating applications if grant funding is made available for local LID planning and implementation projects.

This report is intended to describe ways in which LID practice can be enhanced in California on state, regional, and local levels. It is meant to complement the policy analysis and recommendations outlined in the December 2007 report from the California State Water Resources Control Board Stormwater Program and The Water Board Academy, *A Review of Low Impact Development Policies: Removing Institutional Barriers to Adoption*. Other recent reports provide a different perspective on LID, such as two 2007 reports evaluating costs and benefits of LID practices: *The Economics of Low Impact Development: A Literature Review* by ECONorthwest[2] and the U.S. Environmental Protection Agency's *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*.[3] Technical guidance for LID is continually being developed on the local and regional levels, and many of these guidance manuals provide valuable, location-specific guidelines for LID applicability along with detailed design, installation, and maintenance specifications.

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[2] ECONorthwest. 2007. *The Economics of Low Impact Development: A Literature Review*. http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf.

[3] EPA. 2007. *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*. http://www.epa.gov/owow/nps/lid/costs07/documents/reducingstormwatercosts.pdf.

1 Introduction

1.1 Overview of Impervious Surfaces

The term impervious surface refers to land cover, both natural and human-made, that cannot be penetrated by water. Consequently, precipitation that falls on impervious surfaces does not infiltrate into the soil. Instead, it runs off to a pervious area where all or a portion infiltrates into the soil, or it continues to travel down-slope on impervious surfaces, including saturated soils, until it is eventually conveyed to a ditch, a storm drain network, or a receiving waterbody. Most of the impervious cover in an urban watershed or subwatershed is from rooftops, roads, sidewalks, driveways, parking lots, and recreational facilities (e.g., tennis courts, swimming pools, etc.).

Impervious surface is typically measured as total impervious area or effective impervious area. Total impervious area includes all impervious cover in the watershed and is typically represented as a percent of the entire watershed area. Effective impervious area is the portion of impervious cover that is directly connected to stormwater conveyance systems or receiving waterbodies. Effective impervious area tends to be a better proxy for hydrologic and pollutant impacts from development because flows from these areas are not infiltrated, evaporated, or otherwise treated before being discharged to waterbodies. In many cases, a large portion of total impervious area can be "disconnected" by diverting flows to pervious surfaces such as landscaped areas. For example, gutter downspouts on residential homes can be disconnected to direct flows over the lawn or into infiltration basins.

Both the amount of impervious area and the relationship between total and effective impervious areas vary according to land use.[4] For example, work in the Puget Sound area revealed that total impervious area in low-density residential sites averaged approximately 10 percent, with an effective impervious area of only 4 percent. In commercial and industrial areas, however, total impervious area averaged about 90 percent. Almost all of the total impervious area is also effective impervious area because of the lack of pervious areas to break up direct connections.

1.2 Effects of Increased Imperviousness

Watershed imperviousness plays an important role in determining the conditions in waterbodies because it leads to more runoff. Increased runoff carries more pollutants to receiving waters and transports them faster than they would normally travel with the help of streets, driveways, parking lots, rooftops, sidewalks, curbs, gutters, and storm drain pipes. Increased runoff also has physical effects on streams and rivers—the larger, faster flows are more erosive and can alter the size, shape, and habitat quality of channels. Higher runoff volumes also exacerbate flooding and property damage.

Impervious cover is an inescapable attribute of development and a permanent part of the urban/suburban landscape. As might be expected, there is a linear relationship between impervious surface in a given area and the amount of runoff generated. What is unexpected is what this means in terms of both the volume of water generated and the rate at which it exits the surface. Depending on the degree of impervious cover, the annual volume of storm water runoff can increase to anywhere from 2 to 16 times the predevelopment amount.[5] Impervious surface coverage as low as 10 percent can destabilize a stream channel, raise water

[4] Caraco, D., R. Claytor, P. Hinkle, H.Y. Kwon, T. Schueler, C. Swann, S. Vysotsky, and J. Zielinski. 1998. *Rapid Watershed Planning Handbook*. Center for Watershed Protection, Ellicott City, MD.

[5] Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3): 100–111.

temperature, and reduce water quality and biodiversity.[6] One study found that connected imperviousness levels between 8 and 12 percent represented a threshold region where minor changes in urbanization could result in major changes in stream condition.[7] Table 1 provides a detailed summary of the effects of urbanization and increased imperviousness on streams.

Table 1. Urbanization Effects on Streams. [8]

Effect	Description
Bankfull and subbankfull floods increase in magnitude and frequency	The peak discharge associated with the bankfull flow (the 1.5- to 2-year return storm) increases sharply in magnitude in urban streams. Channels experience more bankfull and subbankfull flood events each year and are exposed to critical erosive velocities for longer intervals.
Dimensions of the stream channel are no longer in equilibrium with its hydrologic regime	The hydrologic regime that defined the geometry of the predevelopment stream channel irreversibly changes, and the stream experiences higher flow rates on a more frequent basis. The higher-flow events of the urban stream are capable of moving more sediment than before.
Channels enlarge	The customary response of an urban stream is to increase its cross-sectional area to accommodate the higher flows. This is done by streambed downcutting, channel widening, or a combination of both. Urban stream channels often enlarge their cross-sectional area by a factor of 2 to 5 depending on the degree of impervious cover in the upland watershed and the age of development.
Stream channels are highly modified by human activity	Urban stream channels are extensively modified in an effort to protect adjacent property from streambank erosion or flooding. Headwater streams are frequently enclosed within storm drains, while other streams are channelized, lined, and/or “armored” by heavy stone. Another modification unique to many urban streams is the installation of sanitary sewers underneath or parallel to the stream channel.
Upstream channel erosion contributes greater sediment load to the stream	The prodigious rate of channel erosion coupled with sediment erosion from active construction sites increases sediment discharge to urban streams. Researchers have documented that channel erosion constitutes as much as 75 percent of the total sediment budget of urban streams. Urban streams also tend to have a higher sediment discharge than non-urban streams, at least during the initial period of active channel enlargement.
Dry weather flow in the stream declines	Because impervious cover prevents rainfall from infiltrating the soil, less flow is available to recharge ground water. Consequently, during extended periods without rainfall, baseflow levels are often reduced.
Wetted perimeter of the stream declines	The wetted perimeter of a stream is the proportion of the total cross-sectional area of the channel that is covered by flowing water during dry weather, and it is an important indicator of habitat degradation in urban streams. Given that urban streams develop a larger channel cross-section at the same time that their base flow rates decline, it follows that the wetted perimeter will become smaller. Thus, for many urban streams, this results in a very shallow, low-flow channel that “wanders” across a very wide streambed, often changing its lateral position in response to storms.

[6] Schueler, T. 1995. *Site Planning for Urban Stream Protection*. Metropolitan Washington Council of Governments, Washington, DC.

[7] Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales. *Environmental Management* 28(2): 255–266.

[8] U.S. Environmental Protection Agency. 2005. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*. Office of Water, Washington, DC.

Table 1. Urbanization Effects on Streams. [8]

Effect	Description
Instream habitat structure degrades	Urban streams are routinely scored as having poor instream habitat quality, regardless of the specific metric or method employed. Habitat degradation is often exemplified by loss of pool and riffle structure, embedding of streambed sediments, shallow depths of flow, eroding and unstable banks, and frequent streambed turnover.
Large woody debris is reduced	Large woody debris is an important structural component of many low-order stream systems because it creates complex habitat structure and generally makes the stream carry more water. In urban streams, the quantity of large woody debris found in stream channels declines sharply because of the loss of riparian forest cover, storm washout, and channel maintenance practices.
Stream crossings and potential fish barriers increase	Many forms of urban development are linear in nature (e.g., roads, sewers, and pipelines) and cross stream channels. The number of stream crossings increases in direct proportion to impervious cover, and many crossings can become partial or total barriers to upstream fish migration, particularly if the streambed erodes below the fixed elevation of a culvert or pipeline.
Riparian forests become fragmented, narrower, and less diverse	The important role that riparian forests play in stream ecology is often diminished in urban watersheds as tree cover is often partially or totally removed along the stream as a consequence of development. Even when stream buffers are preserved, encroachment often reduces their effective width and native species are supplanted by exotic trees, vines, and ground covers.
Water quality declines	The water quality of urban streams during storms is consistently poor. Urban storm water runoff contains moderate to high concentrations of sediment, carbon, nutrients, trace metals, hydrocarbons, chlorides, and bacteria. Although considerable debate exists as to whether storm water pollutant concentrations are actually toxic to aquatic organisms, researchers agree that pollutants deposited in the streambed exert an undesirable impact on the stream community.
Summer stream temperatures increase	The impervious surfaces, ponds, and poor riparian cover in urban watersheds can increase stream temperatures by several degrees. Because temperature plays a central role in the rate and timing of instream biotic and abiotic reactions, such increases have an adverse impact on streams. In some regions, summer stream warming can irreversibly shift a cold-water stream to a cool-water or even warm-water stream, resulting in deleterious effects on salmonids and other temperature-sensitive organisms.
Reduced aquatic diversity	Urban streams are typified by fair to poor fish and macroinvertebrate diversity, even at relatively low levels of watershed impervious cover or population density. Declines in sensitive species have been observed at levels of impervious cover as low as 4 percent. Impervious cover in highly urbanized areas comprising greater than 25 percent of a watershed may even preclude the Clean Water Act goal of “fishable” waters. The ability to restore predevelopment fish assemblages or aquatic diversity is constrained by a host of factors, including irreversible changes in carbon supply, temperature, hydrology, lack of instream habitat structure, and barriers that limit natural recolonization.

Figure 1 shows the relationship between impervious cover and aquatic insect diversity; Figure 2 shows the relationship between imperviousness and fish diversity.

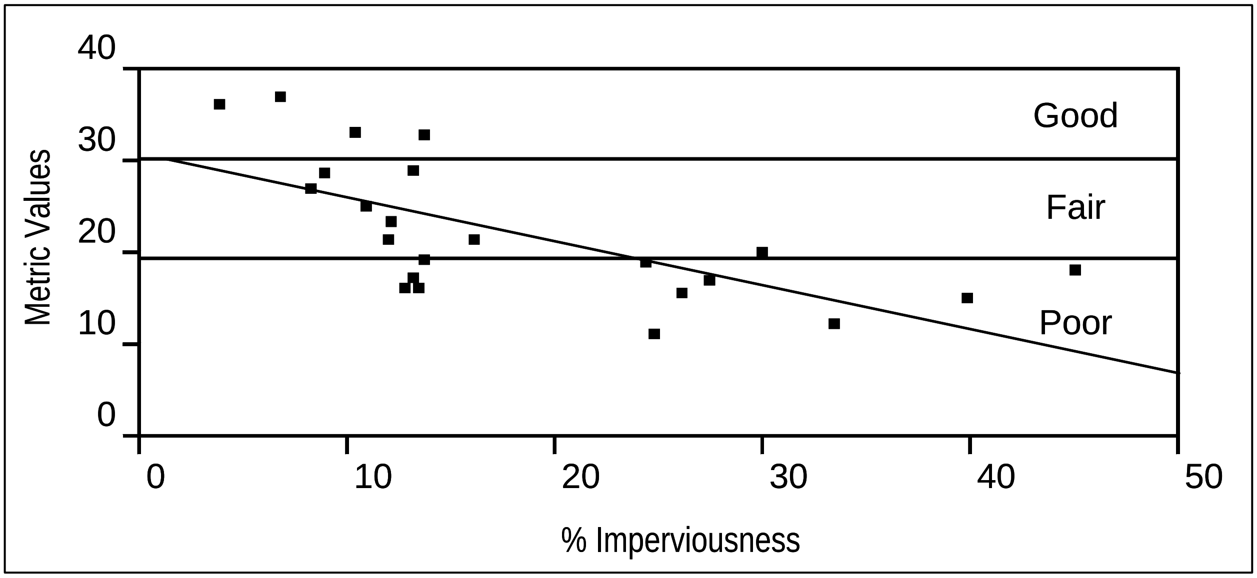

Figure 1. Relationship between impervious cover and aquatic insect diversity in Anacostia River subwatersheds (Schueler and Galli, 1992, as cited in Schueler, 1995).

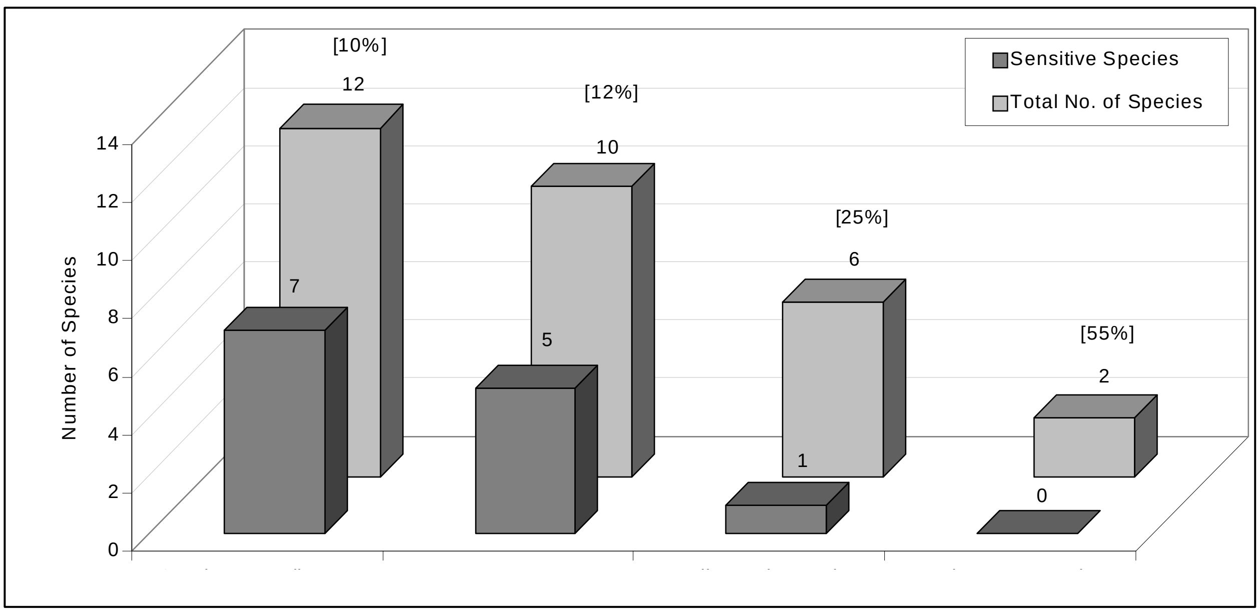

Figure 2. Fish diversity in four subwatersheds of different impervious cover in the Maryland Piedmont (Schueler and Galli, 1992, as cited in Schueler, 1995).

2 Low Impact Development

2.1 What is Low Impact Development?

According to the Low Impact Development Center, Low Impact Development, or LID, is a stormwater management strategy concerned with maintaining, mimicking or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives. LID addresses stormwater through small, cost-effective site design and landscape features that are distributed throughout the site. In shorthand, LID is often referred to as a requirement that the post-development stormwater runoff profile equal the pre-development conditions, both in terms of volume and rate.

Best management practices associated with LID typically come in the form of "green" or non-structural practices. Some conventional practices are often used, such as dry detention basins and swales. Modified landscaping is increasingly popular since cities often already have landscaping codes in place.[9] The modifications include use of engineered soils for water handling purposes, tree canopy requirements, use of native landscaping, and the use of cisterns and other runoff storage devices. In residential settings, rain gardens, coving, and storage devices such as rain barrels and cisterns are being promoted or required. While conventional house designs often directed downspouts to paved driveways, new designs for both pervious driveway surfaces and diverted flow into natural areas are likely to become standard practice.

While initial LID practices were mainly written for new residential subdivisions, a new generation of practices (and combination of practices) has emerged for commercial applications and urban settings that cannot rely on large parcels for infiltration. As such, green roofs, permeable paving, improved parking lots, and landscaping are gaining attention. In some cases, a combination of "green" techniques and structural practices (e.g., vaults) will be needed to meet performance goals.

While many communities are adopting informal guidelines on LID, regulatory recognition of LID is increasing at the State and local levels. Established LID programs exist at the State level in Maryland, Washington, and Massachusetts. Some States have adopted LID requirements for sensitive areas, for example the Pinelands region of New Jersey. Among cities, Portland, Oregon, and Chicago, Illinois, are leaders.

LID programs vary around the country, with differing performance standards, definitions, and regulatory structures. In most cases, the program first establishes the baseline natural hydrologic regime, and sets development performance based on meeting targets for runoff volume, runoff rates, and pollutant loads.

With LID, it is important to strike a balance that recognizes the impact that development has on ecology and hydrology. Establishing the baseline, pre-development condition may seem simple, but it would be unrealistic to expect that true pre-development conditions can be achieved fully. The baseline might be set higher where waterbodies are impaired, for example, requiring development to mimic the hydrology of a forest, even if the predevelopment condition provides lower ecological services. On the other end of the spectrum, some locales set the pre-development condition based on the status of the site immediate to construction. Thus, redevelopment of a 100 percent impervious site under this type of regulation need only meet minimal (or no) on-site stormwater requirements. Realistic requirements should be written to strike a balance: achieve improvement over existing conditions but take into account economic development goals and site constraints.

[9] Note that California has State standards for commercial landscaping; this code is currently being amended under 2006 legislation for water conservation.

For regulatory structures, LID can be introduced in several ways:

- A new, stand-alone code
- Integrated codes (that is, integrated into existing zoning and building codes)
- Subdivision regulations, sub-area plans, or specific plans
- Guidelines
- Alternative compliance programs

Like other planning programs, LID is constantly evolving. Research and policy options for LID at a larger scale are now underway. In fact, one of the weaknesses of early LID efforts was its confinement to individual sites and projects. Green highways and green infrastructure are commanding a great deal of attention. LID at the district scale is also likely to gain profile for development designs where individual lots are not likely to meet strict performance measures. Finally, policy options for retrofitting existing development with LID techniques will gain attention, in particular for built out watersheds draining to impaired waterways.

2.2 LID on Multiple Scales: Considering Smart Growth

The intersection of development and watershed planning tends to settle upon one concept: impervious surface. As discussed in section 1, the importance of imperviousness cannot be under-stated and is well known as an indicator of watershed health. Limiting the effects of impervious surface is becoming more common in local zoning codes in the form of impervious surface caps, requirements to disconnect impervious surfaces, and infiltration requirements. Because they are contained in zoning codes, the policies tend to apply to individual sites. Thus, limiting effective impervious surface coverage on individual sites has emerged as the preferred regulatory instrument for limiting the effects of impervious surfaces.

While this approach works in some development contexts, there can be applications that limit the full potential of LID. For new development, it is possible for individual sites to meet LID specifications, even as they add to wider disturbance arising from cumulative and induced development impacts. These often-overlooked impacts arise not because of LID, but because of the underlying pattern of dispersed development. Second, site-level application of LID can pose a challenge in districts that coordinate a higher intensity of development on a compact footprint because space for infiltration may be limited, for example transit area planning, redevelopment of older downtowns, and master-planned town centers.

Early smart growth projects were isolated and did not make full use of on-site and/or distributed stormwater management. Although new designs call for narrow roads, the curbs, gutters and conveyance systems rely on conventional, untreated drainage. For developed areas, improving impaired waterways will be met through retrofits of existing development, not new development. Even though urban redevelopment projects have an implicit watershed benefit by reusing impervious surface, each project will need to contribute to stormwater management and improvement. This is often missing from urban public works planning, in part because the development operating system was built on conventional curb-and-gutter drainage.

These points illustrate the importance of scale when assessing and evaluating low impact and smart growth policies. Those scales include the watershed (or region), the subwatershed (or district), and the site, simultaneously. Successfully coordinating watershed management and reducing the impacts of development typically occur within a comprehensive plan.

2.3 LID ON THE GROUND IN CALIFORNIA

There are a number of California organizations who have made great strides in researching, implementing, and developing guidance for LID. The following are highlights from the California Department of Transportation (Caltrans) and three regional, umbrella stormwater organizations: the Santa Clara Valley Urban Runoff Pollution Prevention Program, the Contra Costa Clean Water Program, and the Alameda Countywide Clean Water Program.

2.3.1 Caltrans

Caltrans has several programs underway to address the installation and retrofit of State roads and highways, though the work can apply to non-State roads as well. Because roads traditionally represent a high degree of connected impervious cover, special attention should be devoted to retrofitting streets with LID. The following summary introduces several Caltrans programs underway that incorporate LID activity.

Best Management Practice Retrofit Pilot Program (2004, 316 pages) – This pilot program was initiated to assess the potential for large-scale retrofit of Caltrans roads with stormwater BMPs. Thirty-two pilot sites in the Los Angeles and San Diego regions were outfitted with a variety of structural and non-structural BMPs. The program produced information on the effectiveness of BMPs in pollutant removal efficiencies, as well as the technical feasibility of the BMPs as retrofits in highway and support facility settings. LID techniques, such as swales, biofiltration, and infiltration, were tested both alone and as part of a "treatment train," where several BMPs were installed in a series. http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/new_technology/CTSW-RT-01-050.pdf

Storm Water Quality Handbook: Project Planning and Design Guide (2007, 354 pages) – This recently revised Handbook incorporates several "green" features, including reference to the 2004 BMP Retrofit study listed above. The foremost consideration in stormwater design is preservation of the maximum amount of vegetative condition no matter the context. The Handbook also notes up front that the requirements are minimal; any roadway within an MS4 would be subject to additional post-construction (or permanent) stormwater management practices. An important feature of the Handbook is the presentation of Accepted Water Quality Treatment BMPs and specifications for their construction, operation, and maintenance. Many techniques used in prominent "green streets" retrofits are included (for example infiltration devices and bioswales). http://www.dot.ca.gov/hq/oppd/stormwtr/Final-PPDG_Master_Document-6-04-07.pdf

2.3.2 Stormwater Management Programs

The issuance of municipal stormwater permits has created a new generation of programs dedicated to not only permit compliance, but also to integration of stormwater runoff into other watershed management and regional planning efforts. In some organizations, stormwater management is housed in traditional flood control programs, while in other programs, new, stand-alone programs were formed to address NPDES requirements. The proliferation of smaller programs has led to larger umbrella organizations like the Bay Area Stormwater Management Agencies Association (BASMAA), which serves as a regional liaison among local and regional governments and the Regional Water Quality Control Boards. Three notable local programs are the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), the Contra Costa Clean Water program, and the Alameda Countywide Clean Water Program (ACCWP).

In 2001, the San Francisco Bay Regional Water Quality Control Board reissued the NPDES permit for MS4s and included a measure called "C.3." As noted previously in this report, this measure, which was landmark, extended stormwater practices to new development and redevelopment projects. Both

SCVURPPP and the Contra Costa programs developed comprehensive program materials to address the new requirements. Details are presented below.

Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)

SCVURPPP is a program addressing water quality in thirteen cities and towns in the Santa Clara Valley. These cities and towns are responsible for implementing a municipal stormwater permit issued by the San Francisco Bay Regional Water Quality Control Board. According to the program's Website (http://www.scvurppp-w2k.com/default.htm), the five goals of the Program include:

- Permit Compliance
- Establishing Determinants of Success
- Adjusting Activities to Change
- Achieving Acceptance of Urban Runoff Management Activities
- Integrating Urban Runoff Program Elements into Other Programs

To meet these goals, the Program offers a number of services, including workshops, fact sheets, guidance manuals, interpretation of permit requirements, model language, targeted reports, and presentations. For LID, the following products are particularly helpful:

- Stormwater Pollution Control Requirements: What Developers, Builders and Project Applicants Need to Know (Fact Sheet) http://www.scvurppp-w2k.com/pdfs/0506/C3%20flyer%20update%20120505.pdf
- Understanding Hurdles To Using Better Site Designs for Water Quality Protection (PowerPoint presentation: http://www.scvurppp-w2k.com/project_reports_fy0304/Hurdles.pdf)
- Addressing Fire Department and Public Safety Concerns http://www.scvurppp-w2k.com/project_reports_fy0304/potential_hurdles_fire_dept_100803.pdf
- Developments Protecting Water Quality: A Guidebook of Site Design Examples http://www.scvurppp-w2k.com/permit_c3_docs/SCVURPPP_Site_Design_Manual.pdf
- Applicability of New C.3 Provisions – Development Flow Chart http://www.scvurppp-w2k.com/project_reports_fy0304/Stormwater_Requirements_Checklist.pdf
- Site Design Guidance for Review of Local Codes and Standards http://www.scvurppp-w2k.com/pdfs/dvlpmnt_plcs/report/III_Conc_Conflicts_and_Rcmdns.PDF

Contra Costa Clean Water Program (CCCWP)

The Contra Costa Clean Water Program (www.cccleanwater.org) was formed by representatives of Contra Costa County, nineteen of its incorporated cities, and the Contra Costa County Flood Control and Water Conservation District. The CCCWP strives to eliminate stormwater pollution through public education, inspection and enforcement activities as well as outreach to industrial dischargers, residents and businesses. The CCCWP members are responsible for implementing the requirements of a municipal stormwater permit issued by the San Francisco Bay Regional Water Quality Control Board.

CCCWP has emerged as a leader in intergration of LID into the land development process. For LID, the following products are particularly helpful:

- Stormwater Control Plans and the Development Review Process (PowerPoint Presentation: http://www.cccleanwater.org/Publications/Oct06Workshop/SWControlPlans&DevReviewProcess.ppt)
- Contra Costa Approach (I): Experience So Far Using LID to Implement Stormwater Treatment Requirements (PowerPoint Presentation: http://www.cccleanwater.org/Publications/StormCon-5-06/5-ContraCostaApproach-I-Dalziel-Cloak.ppt)

- Sizing Integrated Management Practices Sizing Calculator – this model supports site designers in choosing and sizing LID techniques http://www.cccleanwater.org/new-developmentc3/stormwater-c3-guidebook/, See Appendix I

Alameda Countywide Clean Water Program (ACCWP)

Like other stormwater programs, the Alameda Countywide Clean Water Program (ACCWP, http://www.cleanwaterprogram.org/indexFlash.htm) has been active in developing information on meeting the C.3 provisions for new development and redevelopment. For LID, ACCWP has addressed one of the thornier issues related to both structural and non-structural BMPs—maintenance. The following templates have been developed and are applicable to any stormwater program.

- How to Use the Templates http://www.cleanwaterprogram.org/uploads/6.0%20Template%20Intro%20FINAL.pdf
- Vegetated Swale Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.1%20Veg%20Swale%20template%20FINAL.doc
- Vegetated Buffer Strip Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.2%20Buffer%20Strip%20template%20FINAL.doc
- Tree Well Filter Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.3%20Tree%20well%20filter%20template%20FINAL.doc
- Media Filter Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.4%20media%20filter%20template%20FINAL.doc
- Flow-Through Planter Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.5%20flo-thru%20plntr%20template%20FINAL.doc
- Bioretention Area Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.6%20Bioretention%20Area%20template%20FINAL.doc
- Infiltration Trench Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.7%20Infiltration%20Trench%20template%20FINAL.doc
- Extended Detention Basin Maintenance Plan Template http://www.cleanwaterprogram.org/uploads/6.8%20Detention%20Plan%20template%20FINAL.doc

Emeryville is a member of ACCWP and is recognized nationally as a leader in ultra-urban LID. In 2003, the City obtained a grant to develop "Guidelines for Dense, Green Development" (http://www.ci.emeryville.ca.us/planning/pdf/stormwater_guidelines.pdf). Emeryville faces a built environment that appears to preclude many LID techniques, including clay soils, legacy contaminants, and few green spaces. However, the City used the research behind the guidelines, the planning process, a BMP sizing spreadsheet, and code changes to institute reform. Note that the City did not only focus on new development and redevelopment, but also looked to the city's infrastructure for opportunities.

2.4 REGULATIONS GOVERNING NEW AND REDEVELOPMENT IN CALIFORNIA

2.4.1 Background

California has been delegated the authority to develop and administer Clean Water Act programs. Because the State's landscape varies dramatically, the responsibility has been divided among nine regional water quality control boards (RWQCBs). The State Water Resources Control Board (SWRCB) is the agency that oversees the nine regional boards. Under the SWRCB, each RWQCB acts as a semi-autonomous water quality agency. Under the State Porter-Cologne Water Quality Act (Porter-Cologne), each RWQCB is required to develop its own Basin Plan that contains water quality objectives and criteria for the region. The RWQCBs must use their judgment to determine water quality objectives that provide for "reasonable protection of beneficial uses and the prevention of nuisance." Within their Basin Plans, the RWQCBs must also specify plans for meeting the objectives, which include actions to be taken, a timeline for proposed actions, and a plan for evaluating success with achieving the objectives.

The State Water Quality Control Board and the nine RWQCBs have begun work on a number of LID initiatives[10] including:

- Requiring use of LID through site-specific and general permits
- Advocacy and outreach to local governments through the Water Board's Training Academy and regional workshops
- Research on incorporating LID language into Standard Urban Storm Water Mitigation Plan (SUSMP) requirements
- Funding of LID-related projects through consolidated grants program
- Funding through CWA 319 funds to support research on the applicability of the Impervious Surface Analysis Tool (ISAT) for land use planners and for the California Water and Land Use partnership (CaWaLUP) through the Center for Water and Land Use at U.C. Davis Extension

2.4.2 California Regulations

The integration of LID into local development codes will not occur in a regulatory vacuum. As localities draft land development codes, there are many, often competing, objectives involved with each and every parcel. Stakeholders interested in economic development, traffic, neighborhood preservation, housing, and equity, are among many players who shape decisions both at the larger policy level and during individual approval processes. As such, new requirements for stormwater management will enter an already complex regulatory environment, and California is no exception. In fact, there are several legal and policy issues unique to California that must be considered if LID is to be successfully integrated into State and local land development codes.

Stormwater Construction General Permit

The Construction General Permit is issued by the State Water Resources Control Board (SWRCB) and regulates stormwater discharges from construction activities (new development and redevelopment) at sites that disturb one or more acres. All construction projects in the state meeting the size criterion must submit a notice of intent to the RWQCB to obtain coverage under the permit. NOI submission requires development of a stormwater pollution prevention plan (SWPPP) that specifies how stormwater and

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[10] SWRCB. 2003. *Low Impact Development - Sustainable Storm Water Management*. http://www.waterboards.ca.gov/lid/index.html. Accessed October 18, 2007.

pollutants will be managed during and after construction. A revised Construction General Permit has been proposed but is not yet approved. The following are features of the draft permit:

The permit seeks to limit hydromodification impacts that can adversely affect downstream channels and habitat. Specifically, for all projects disturbing one acre or more, the permit requires that the post-development volume of runoff from impervious surfaces approximates the pre-project runoff volume. Projects that disturb more than two acres have additional requirements to (1) preserve post-construction drainage divides and (2) maintain or extend pre-project time of concentration. Projects that disturb more than 50 acres must (1) preserve pre-construction drainage patterns by distributing their non-structural and structural controls within all drainage areas serving first order streams or larger and (2) maintain or extend pre-project time of concentration.

Applicants for coverage under the permit are required to submit a map and worksheets that demonstrate compliance with the above requirements. Detailed instructions are provided for calculating the volume of runoff that needs to be managed (or more sophisticated watershed models can be used).

LID is specifically incorporated into the draft permit in that it offers volume credits for the following types of nonstructural practices:

- Tree canopy cover
- Downspout disconnections
- Impervious area disconnection
- Vegetated swales
- Permeable pavers

The Construction General Permit is an important tool for stormwater management and LID promotion because it covers the entire state, whereas municipal stormwater regulations only apply to municipalities with populations greater than 10,000, small communities located within major metropolitan areas, and towns and cities specifically identified by the State based on projected growth rate or special water quality concerns.

Municipal Stormwater Permits

The Regional Water Quality Control Boards have issued permits to large, medium, and small municipalities throughout California to develop and implement multi-faceted stormwater management programs. Many of these programs, particularly those in large metropolitan areas, have been in place since the early 1990s. One of the main components of stormwater management programs is to regulate stormwater impacts from new development. Municipalities accomplish this by setting minimum runoff control and treatment requirements and reviewing and approving development plans that specify appropriate stormwater best management practices (BMPs).

On October 5, 2000, the SWRCB adopted Order WQ 2000-11, a precedential decision concerning the use of Standard Urban Storm Water Mitigation Plans (SUSMP) [11] in MS4 permits for new development and significant redevelopment projects. The SWRCB found that the SUSMP standards, which essentially require that urban runoff generated by 85 percent of storm events from specific development categories be infiltrated or treated, reflected the MEP standard. The SUSMP requirements were initially adopted by the Los Angeles RWQCB to require treatment controls for new and significant redevelopment projects. Because of the precedent set by Order WQ 2000-11, the RWQCBs' MS4 permits must be consistent with applicable portions of the State Board's decision and include SUSMP requirements. A statewide policy

[11] The term SUSMP is used by the Los Angeles and San Diego Regional Water Boards, but other Boards have adopted different terms for the new development requirements (such as Water Quality Management Plans, Development Standards, or Stormwater Quality Urban Implementation Plans).

memorandum (dated December 26, 2000) interprets the Order to provide broad discretion to RWQCBs and identifies potential future areas for inclusion in SUSMPs and the types of evidence and findings necessary. Such areas include ministerial projects, projects in environmentally sensitive areas, and water quality design criteria for retail gasoline outlets. Because each RWQCB has discretion to interpret and modify the requirements in the State Board order, each permit can have slightly different SUSMP requirements.

A number of RWQCBs have explicitly required the preferential use of LID to manage stormwater. The following are examples of LID provisions from recent permits or draft permits:

Los Angeles Municipal Stormwater Permit

The Los Angeles Municipal Stormwater Permit (Order 01-182, NPDES Permit # CAS004001) specifies that development projects are required to

- Maximize the percentage of pervious surfaces to allow percolation of stormwater into the ground
- Minimize the quantity of stormwater directed to impervious surfaces and the MS4
- Minimize pollution emanating from parking lots through the use of appropriate Treatment Control BMPs and good housekeeping practices
- Properly design and maintain Treatment Control BMPs in a manner that does not promote the breeding of vectors
- Provide for appropriate permanent measures to reduce stormwater pollutant loads in stormwater from the development site

The permit requires control of the post-development peak stormwater runoff discharge rates, velocities, and duration (peak flow control) in natural drainage systems that mimic pre-development hydrology to prevent accelerated stream erosion and to protect stream habitat.

Under SUSMP provisions, single-family hillside homes are required to:

- Conserve natural areas
- Protect slopes and channels
- Provide storm drain system stenciling and signage
- Divert roof runoff to vegetated areas before discharge unless the diversion would result in slope instability
- Direct surface flow to vegetated areas before discharge unless the diversion would result in slope instability

SUSMP requirements apply to sites that discharge to an Environmentally Sensitive Area (ESA), create 2,500 square feet or more of impervious surface area, and discharge stormwater that is likely to impact a sensitive biological species or habitat.

The permit allows municipalities to establish alternative compliance programs that offer participation in regional or sub-regional stormwater mitigation projects for development sites that receive a waiver for impracticability in meeting the performance requirements.

San Diego Municipal Stormwater Permit

The San Diego Municipal Stormwater Permit (Order No. R9-2007-0001, NPDES No. CAS0108758) specifies that municipalities develop requirements for all development projects that include LID BMPs where feasible that "maximize infiltration, provide retention, slow runoff, minimize impervious footprint, direct runoff from impervious areas into landscaping, and construct impervious surfaces to minimum widths necessary." There is also a requirement to establish or maintain buffer zones for natural waterbodies, where feasible. Where buffer zones are infeasible, project proponents are required to implement other buffers such as trees, access restrictions, etc., where feasible.

The permit further specifies LID BMP requirements to collectively minimize directly connected impervious areas and promote infiltration at Priority Development Projects[12] as follows:

- For Priority Development Projects with landscaped or other pervious areas, drain a portion of impervious areas (rooftops, parking lots, sidewalks, walkways, patios, etc) into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious areas shall correspond with the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.
- For Priority Development Projects with landscaped or other pervious areas, properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.
- For Priority Development Projects with low traffic areas and appropriate soil conditions, construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.

The permit specifies other LID BMPs to be implemented at all Priority Development Projects where applicable and feasible:

- Conserve natural areas, including existing trees, other vegetation, and soils
- Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised
- Minimize the impervious footprint of the project
- Minimize soil compaction
- Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions, etc.)

Municipalities must update SUSMP BMP requirements to add LID and source control BMPs (including siting, design, and maintenance criteria) and to define minimum requirements to maximize the use of LID practices and principles.

Restrictions are set forth for infiltration of runoff from areas that generate high levels of pollutants to protect groundwater. Specifically, this entails pretreatment (e.g., sedimentation, filtration) for infiltration BMPs, diversion of polluted dry weather flows, a minimum distance from seasonally high groundwater table, a minimum horizontal distance from wells, and restrictions on land uses that can drain to infiltration

[12] Priority Development Projects include housing subdivisions of 10 or more dwelling units, commercial developments and developments of heavy industry greater than one acre, automotive repair shops, restaurants, all hillside development greater than 5,000 square feet, ESAs, parking lots 5,000 square feet or larger or with 15 or more parking spaces and potentially exposed to urban runoff, streets, roads, highways, freeways, and retail gasoline outlets. Priority Development Projects also include those redevelopment projects that create, add, or replace at least 5,000 square feet of impervious surfaces on an already developed site that falls under the project categories or locations listed previously. Within three years of adoption, Priority Development Projects will also include all other pollutant generating projects that result in the disturbance of one acre or more of land.

BMPs (e.g., industrial or light industrial activity, high vehicular traffic areas, automotive repair shops, car washes, fleet storage areas, nurseries).

Redevelopment projects that create, add or replace at least 5,000 square feet of impervious surfaces on an already developed site that falls under the Priority Development Project categories are subject to tiered requirements as follows:

- If redevelopment results in an increase of less than fifty percent of the impervious surfaces of a previously existing development, and the existing development was not subject to SUSMP requirements, the numeric sizing criteria applies only to the addition and not to the entire redevelopment site.
- Where redevelopment results in an increase of more than fifty percent of the impervious surfaces of a previously existing development, the numeric sizing criteria applies to the entire development.

Waivers of numeric sizing criteria can be granted when all available BMPs have been considered and rejected as infeasible. Alternative compliance for waiver recipients can be allowed by contributing the cost savings to a storm water mitigation fund that can be used on projects to improve urban runoff quality within the watershed of the waived project.

Draft Ventura Stormwater Permit

The Draft Ventura Stormwater Permit sets overall goals for stormwater management at regulated development sites[13] as follows:

- Minimize the percentage of impervious surfaces on land developments to support the percolation and infiltration of storm water into the ground.
- Minimize pollutant loadings from impervious surfaces such as roof-tops, parking lots, and roadways through the use of properly designed, technically appropriate BMPs (including Source Control BMPs such as good housekeeping practices), Low Impact Development Strategies, and Treatment Control BMPs.

All regulated projects are required to integrate LID principles into project design. LID strategies are required to be the first BMPs considered for a development site, followed by integrated water resources management strategies and multi-benefit landscape features, all of which contribute to the overall goals of LID. The least preferred BMP type is modular/proprietary treatment control BMPs.

The draft permit requires that all new and redevelopment projects reduce "the percentage of Effective Impervious Area (EIA) to less than 5 percent of total project area." Impervious surfaces may be rendered "ineffective" if the storm water runoff is

- Drained into a vegetated cell, over a vegetated surface, or through a vegetated swale, having soil characteristics either as native material or amended medium using approved soil engineering techniques; or

[13] Projects required to meet new development standards include all development projects equal to 1 acre or greater of disturbed area; industrial parks, commercial strip malls, retail gasoline outlets, restaurants, streets, roads, highways, freeway construction, and automotive service facilities with 5,000 square feet or more of surface area; parking lots with 5,000 square feet or more of surface area or with 25 or more parking spaces; redevelopment that results in the creation or addition or replacement of 5,000 square feet or more of impervious surface area on an already developed site on development categories listed previously; projects located in or directly adjacent to, or discharging directly to an Environmentally Sensitive Area (ESA), where the development will discharge storm water runoff that is likely to impact a sensitive biological species or habitat or will create 2,500 square feet or more of impervious surface area; and single-family hillside homes.

- Collected and stored for beneficial use such as irrigation, or other reuse purpose; or
- Discharged into an infiltration trench.

Redevelopment requirements are based on the extent to which redevelopment activities[14] alter the site, as follows:

- Where redevelopment results in an alteration to more than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, the entire project must be mitigated.
- Where redevelopment results in an alteration to less than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, only the alteration must be mitigated, and not the entire development.

Local jurisdictions can develop Redevelopment Project Area Master Plans (RPAMPs) for redevelopment projects within redevelopment project areas[15] to set unique requirements to balance water quality protection with the needs for adequate housing, population growth, public transportation and management, land recycling, and urban revitalization. Goals for hydromodification control are to prevent accelerated downstream erosion and to protect stream habitat in natural drainage systems. The permit specifies that a project's pre-development storm water runoff flow rates and durations be maintained based on a stream's Erosion Potential. Controls may include on-site, regional, or subregional hydromodification control BMPs, LID strategies, or stream restoration measures, with preference given to LID strategies and hydromodification control BMPs. A hydromodification control study is underway to determine an appropriate hydromodification management plan for the region. Until that plan is complete, projects under 50 acres are required to match within 1 percent the 2-year, 24-hour pre-development hydrograph and projects larger than 50 acres are required to implement a Hydromodification Analysis Study.

Local jurisdictions can establish a regional or sub-regional storm water mitigation program to substitute in part or wholly for on-site post-construction requirements. Conditions for the mitigation program are that the projects result in equivalent or improved storm water quality, protect stream habitat, are fiscally sustainable and have secure funding, promote cooperative problem solving by diverse interests, and be completed in four years or less including the construction and start-up of treatment facilities. Local jurisdictions can also set up mitigation funding to fund regional or subregional solutions to stormwater pollution where a waiver for impracticability is granted, funds become available, off-site mitigation is required because of loss of environmental habitat, or where an existing water resources management plan exists that has an equivalent or improved strategy for stormwater pollution mitigation.

Local jurisdictions are required to provide outreach to stakeholders and develop a LID technical guidance section for the regional stormwater guidance manual, which includes objectives and specifications for integration of LID strategies, including LID credits.

Draft San Francisco Bay Area Municipal Regional Permit

Provision C.3 of the Draft Municipal Regional Permit for the San Francisco Bay Region (RWQCB 2) requires that all new development and redevelopment projects encourage the inclusion of the following

[14] Routine maintenance activities, emergency redevelopment activities required to protect public health and safety, and existing single-family structures that do not create, add, or replace 10,000 square feet of impervious area are exempted from redevelopment requirements.

[15] Redevelopment project areas include city center areas, historic district areas, brownfield areas, infill development areas, and urban transit villages.

LID-related measures: minimizing land disturbance and impervious surfaces (especially parking lots); clustering of structures and pavement; disconnecting roof downspouts; use of micro-detention, including distributed landscape detention; preservation of open space; protection and/or restoration of riparian areas and wetlands as project amenities.

New development and redevelopment projects that create and/or replace 10,000 square feet or more of impervious surface are considered "regulated projects" and are subject to post-construction stormwater management requirements. This includes commercial, industrial, residential developments as well as road and paved trail projects, with some exclusions. Starting July 1, 2010, the 10,000 square foot threshold will lowered to 5,000 square feet.

For redevelopment projects where more than 50 percent of the impervious surface of a previously existing development is altered, the entire project, consisting of all existing, new, and/or replaced impervious surfaces, must be included in the treatment system design. Where less than 50 percent of the impervious surface is altered, only the new and/or replaced impervious surface of the project must be included in the treatment system design.

Projects that meet EPA's Brownfield Sites definition, low-income and senior citizen housing developments, and Transit-Oriented Development projects that minimize the new or replaced impervious surface onsite can provide alternative compliance by installing, operating and maintaining equivalent offsite treatment at an off-site project in the same watershed or contributing equivalent funds to a regional project, to be completed within 3 years after the end of construction.

Regulated projects are required to implement the following LID measures:

- Install landscaping that minimizes irrigation and runoff, promotes surface infiltration, and minimizes the use of pesticides and fertilizers.
- Conserve natural areas, to the extent feasible, including existing trees, other vegetation, and soils.
- Minimize the impervious footprint.
- Minimize disturbances to natural drainages.
- For regulated projects with landscaped or other pervious areas, drain a portion of impervious areas into pervious areas before discharging to the storm drain and properly design and construct pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope and other pertinent factors.
- For regulated projects with low traffic areas and appropriate soil conditions, construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.

Regulated projects are required to select stormwater treatment systems in the following order of preference:

- Stormwater treatment systems that reduce runoff, store stormwater for beneficial reuse, and enhance infiltration to the extent that is practical and safe.
- Multi-benefit natural feature stormwater treatment systems, such as landscape-based bioretention systems, vegetated swales, tree wells, planter boxes, and green roofs.
- Prefabricated and/or proprietary stormwater treatment systems.

The permit stipulates that stormwater discharges from hydromodification projects, which create and/or replace one acre or more of impervious surface, "shall not cause an increase in the erosion potential of the receiving stream over the pre-project (existing) condition. Increases in runoff flow and volume shall be managed so that post-project runoff shall not exceed estimated pre-project rates and durations, where such increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts on beneficial uses due to increased erosive force." Hydromodification controls include onsite, regional, and instream controls and measures.

Single-family home projects that create and/or replace 5,000 square feet or more of impervious surface are required to implement one or more of the following LID-related BMPs:

- Diverting roof runoff to vegetated areas before discharge to storm drain.
- Directing paved surface runoff flow to vegetated areas before discharge to storm drain.
- Installing driveways, patios and walkways with pervious material such as pervious concrete or pavers.

The permit requires that groundwater be protected through site evaluation and source control measures when infiltration practices are used. Infiltration devices are prohibited unless pretreatment is used in industrial and light industrial applications, areas subject to high vehicular traffic, automotive repair shops; car washes, fleet storage areas, nurseries, and other land uses that pose a high threat to water quality.

The permit requires regulated municipal permittees to update their General Plans to integrate water quality and watershed protection with water supply, flood control, habitat protection groundwater recharge, and other sustainable development principles and policies.

City of Salinas MS4 Permit

The City of Salinas MS4 Permit (Order R3-2004-0135, NPDES Permit # CA0049981) was issued by the Central Coast RWQCB in 2004. The permit includes provisions that, though not called low impact development, are intended to achieve results similar to low impact development requirements. Relevant provisions include a requirement to incorporate water quality and watershed protection principles into planning procedures and policies. The permit defines such procedures/policies as the General Plan or equivalent plans. The identified goal is "to direct land use decisions and require implementation of consistent water quality protection measures for all development projects."

The permit specifies that watershed protection principles and policies consider:

- Minimizing the amount of impervious surfaces and directly connected impervious surfaces in areas of new development and redevelopment
- Using on-site infiltration of runoff in areas with appropriate soils where there is no threat to groundwater quality
- Preserving and creating/restoring riparian corridors, wetlands, buffer zones, and other areas that provide important water quality benefits
- Limiting disturbance of natural waterbodies and natural drainage systems
- Requiring developers to prepare and submit studies analyzing pre- and post-project pollutant loads and flows resulting from projected future development
- Requiring incorporation of structural and non-structural BMPs to mitigate the projected increases in pollutant loads in runoff

The permit also specifies that restrictions be in place for infiltration BMPs to ensure that groundwater quality standards are not violated.

Waivers can be granted on a project-by-project basis for infeasibility. As specified by the order, Salinas "may propose a waiver program that would require any developers receiving waivers to transfer the savings in cost, as determined by the Permittee, to a storm water mitigation fund" subject to RWQCB approval. Funds are to be used for urban runoff quality improvement projects in the same watershed as the waived project. Waivers can only be granted “when all appropriate structural treatment BMPs have been considered and rejected as infeasible.”

The permit also requires Salinas to provide a description of necessary modifications to existing codes and ordinances and an implementation schedule for these modifications.

General Plans

General Plans (required under Government Code section 65300 *et seq*) were first introduced in the 1920’s to plan and coordinate development. Like other areas of the country, the General Plan orchestrates local government Departments, their budgets and community goals, and is implemented by the zoning code and subdivision regulations. In California, State law mandates several required elements: Land Use, Circulation, Housing, Conservation (including Air and Water Quality), Open Space, Noise and Safety. Cities may also include other elements, such as Economic Development. In addition to required elements, the State required study, identification and presentation of detailed information, for example, the allowable uses within zoning codes and land subject to flooding. In 1971, a consistency requirement strengthened the elements within General Plans; development and zoning amendment need to be consistent with the General Plan. Thus, legal decisions affecting growth and development often hinge on the content and exact wording contained within General Plans.

Cities often adopt “Specific Plans” within the General Plan, which act like a special zoning code for a specific area, such as a Downtown Plan or a Master Planned Community.

All General Plans must comply with State law, and be updated as State laws are updated or revised. Finally, General Plans must go through a rigorous review under the California Environmental Quality Act.

Specific Area Plans

California, like other areas around the country, is addressing the shortcomings of conventional zoning and the associated environmental impacts. Successfully addressing impacts tends to occur not from adjusting parameters within codes, but with wholesale change to the alignment of public and private space within districts, such as downtowns, Master Plans, and corridors. Specific area plans are essentially “overlay” zones that orchestrate the relationships among sites, infrastructure, open space, drainage, and uses. Specific area plans have been increasingly used to introduce use mix (and hence reduce trip-making), encourage walkability, redevelop older towns and cities, and develop master-planned communities.

California Environmental Quality Act

California Environmental Quality Act (CEQA) analysis is a major part of the development landscape in California. The purpose of CEQA is to fully vet environmental impacts related to land development decisions and determine whether environmentally preferred options exist. CEQA is perhaps best presented as a step-wise process:

> **Step 1: The Application of CEQA** – CEQA applies to “projects,” which are defined as actions approved at the discretion of a local government (such as issuing a permit). In some instances the discretionary action can involve very small projects, and in others, large ministerial projects need to no CEQA review at all. There is a list of exemptions, such as demolition permits, small infill sites, and affordable housing projects in urban areas. In addition, there are categorical exemptions, such as projects less than 10,000 square feet, and projects of three homes or fewer.
>
> **Step 2: The Initial Study** – If CEQA applies, an initial study is undertaken to determine whether there will be “significant environmental effects. This is among the most litigated parts of the process and is loosely defined. For stormwater, note that thresholds and checklists have been turned down in

Courts for determining significance, even as checklists and thresholds gain in popularity for stormwater management programs.

Step 2a: Mitigated Negative Declaration – If the environmental impacts are easily identified and mitigated, a developer is often asked to mitigate those impacts up front, in essence reducing the impacts below the “significance” threshold that triggers further CEQA review. LID requirements may come into play for this step in CEQA.

Step 3: The Environmental Impact Report (EIR) – If the Initial Study shows the potential for significant impacts, an EIR must be prepared. EIRs are at the “public information” core of CEQA and can be far-ranging in detail and scope. Because EIRs can take months to prepare and significant up-front cost, there is some evidence that the process drives smaller projects and players out of contention. In presenting impacts to the public, the EIR must present the following:

- Significant environmental effects
- Unavoidable environmental effects
- Significant irreversible environmental change
- Alternatives to the project (for example, an alternative design or a “no build: alternative)
- Cumulative Impacts arising in combination with other projects
- Growth-inducing impacts
- Mitigation measures that will be adopted

Step 4: Local Government Action – Even with significant impacts a local government may approve a projects. However, the government may also deny the project, approve one of the alternatives, or specify mitigation measures.

At the State level, the Office of Planning and Research issues CEQA guidelines, which, despite the name, are mandatory. They spell out rules on process and content. For stormwater, the new NPDES regulations, as well as emerging research on LID and BMPs, will likely enter into State language on data collection and analysis, in particular for General Plans.

CEQA is also recognized for what it does not do. Regional (or watershed) cooperation is not among the outcomes sought. Alternatives analyses are typically not informative, and there is little direction (other than often contradictory Court decisions) that helps streamline CEQA. Moreover, the data most related to watershed-wide impacts (analysis of cumulative and growth-inducing impacts) are the weakest elements within CEQA review.

Subdivision Map Act

The original intent of the Subdivision Map Act was to denote clear title to plots of land. Over the years, the Act was used by land speculators who would produce older maps to claim rights to subdivision as land development rules tightened. However, the strongest attribute of the Act is the establishment of fees and exactions. The ability to impose impact fees, require dedication of land, and provision of infrastructure have their roots in the Act; LID requirements may need to be framed within this exaction process.

Exactions in California have been at the center of legal activity for decades, and will shape effective LID requirements, in particular the dedication of land for infiltration or stormwater management. In a nutshell, the cases have been:

Erlich v. Culver City – This case tried to resolve a myriad of loosely related decisions on impact fees. In the end, tests were established for different project types. A “reasonable relationship” test must be met when exactions are required of all developers as a matter of broad policy. The stricter rough proportionality/essential nexus test is to be used with single developers.

Nollan v. California Coastal Commission – This Supreme Court case established the "direct nexus" test between a project and the exaction required. (The same year, AB 1600 was passed, which requires local governments to identify how fees and exactions are to be used). "Nexus studies" are now a routine part of the development approval process; for supra-site level LID, measuring the wider stormwater impacts and how they are addressed beyond site level impacts will likely loom large.

Dolan v. Tigard – This Supreme Court Case decision builds on the Nollan case, and specifies that not only does a local government need to show a nexus, but also the final exaction must have a "rough proportionality" to the project. This will likely come into play with CEQA analyses that show induced growth, and LID assignments that might be required outside the boundaries of the project (the logic will follow the process of determining developer exactions for an off-site Highway interchange *and* the roads within the boundaries of a project).

The end result of all these cases strengthens the role of the General Plan. Thus, if the State requires LID via General Plans, the reasonable relationship test must be met. However, cities and Counties that do not include LID in General Plans may need to perform a higher level of analysis to link exactions and project review.

The use of maps in planning and zoning is widespread but has legal bearing in decisions on subdividing land. Developers often produce a "tentative map" to show lots, improvements, and response to initial feedback from regulators Local governments at this stage have leverage over site design, land conservation, and other matters. Developers will often seek a "vested tentative map," which grants entitlements for a period of time. Once approvals are accepted, the developer produces a final map. Note that localities can deny maps based on incompatibility with the General Plan, physical unsuitability of the site, or environmental damage.

Affordable Housing

Affordable housing in California is not only the grist of national headlines but is now firmly established in State law. Cities are required to develop density bonus programs for affordable housing and provision of second units. The nexus between affordable housing and environmental protection is also well recognized. California's 2003 "Environmental Goals and Policy Report[16]" clearly links low density housing, sprawl, and environmental degradation. The city of San Jose has established policies that essentially recognize certain affordable housing projects as stormwater BMPs. The logic behind this is that if affordable housing is not provided on a small footprint near jobs and services, the demand will exert itself elsewhere in the watershed, most likely on a much larger footprint and on land providing watershed services.

This linkage is likely to emerge in LID policymaking in several ways. First, laws allowing second units on a property will run squarely into strict on-site LID requirements, especially if local rules cap impervious coverage in areas with traditionally small home sites. Opponents of the new stormwater rules are already raising affordable housing shortages as the primary consequence of potential policies. However, a second linkage will emerge as variations of the San Jose policy. If affordable and workforce housing are primary drivers of imperviousness, then "housing as a low impact strategy" will emerge as a powerful practice. The key will be quantifying the relationship. Finally, in largely built-out areas, particularly in coastal California, where improving stormwater will primarily arise from retrofit, any successful LID policy may need to pull together other programs to help underwrite on-site BMPs, in particular for areas struggling to attract redevelopment interest under current rules.

[16] California Office of Planning and Research. 2003. *Governor's Environmental Goals and Policy Report*. http://opr.ca.gov/planning/publications/EGPR--11-10-03.pdf. Updated November 10, 2003. Accessed October 18, 2007.

Roadways

According to the Center for Watershed Protection, “habitat for cars” comprises more than half of all impervious surface coverage. Overly wide road standards (sometimes referred to as “geometric standards) are a culprit. In California, road standards tend to follow the Institute for Transportation Engineers guidebooks and standards established by local Fire Protection Districts.

Advocates for smart growth, climate change, and watershed health agree that road standards need to change for a reduced impact. Work over the past decade has revealed the impetus for over-engineered roadways: (1) national standards provide local governments with a tested and low-risk model, (2) emergency responders direct standards to maximize access for equipment and maneuverability, (3) a sprawling pattern dictates the hierarchical systems of increasingly wide roadways to funnel traffic (as opposed to a grid, which disperses traffic), even though developers provide local roads, and (4) seismic requirements for highly engineered roadbeds and shoulders.

The October 2007 California fires and earthquakes highlighted the role of roads and access; thus discussions on lower-impact roads in rural areas might not gain traction. This may, however, strengthen the argument for lesser road impact in areas inside the urban/wild interface. The U.S. Environmental Protection Agency’s Smart Growth program recently awarded the Congress for New Urbanism a grant to address road widths and design nationwide because mandating new road geometry in legislation is not likely to succeed given the competing safety, community, and environmental goals. This will dovetail with previous work by the Sacramento-based Local Government Commission and the Sustainable Streets effort within the University of California-Irvine (UC Irvine). In addition, Caltrans is developing a “smart mobility” scorecard that will be used in future funding decisions, and researchers at UC Davis are working on a green streets initiative and, in cooperation with Caltrans, incorporation of trees into highway systems that can aid in stormwater mitigation.

Initial research from UC Irvine shows that the environmental street design discussion is bifurcated into two areas: (1) sustainable streets with an emphasis on stormwater, or (2) mobility and design. There is a need to shepherd the two into one effort to achieve both objectives.

3 Types of LID Requirements

There are a number of ways in which LID criteria can be incorporated into statewide, regional, or local stormwater requirements. Table 2 lists the different approaches and briefly describes advantages and disadvantages of each.

Table 2. Types of LID Criteria

Type	Advantages	Disadvantages
Uniform Performance Standards		
Uniform performance standards	Ease of administration	Insensitive to site constraints, unique conditions, and development context
Uniform performance standards with list of accepted BMPs	• Ease of administration • Certainty for planners/ developers	BMP lists may be outdated, in particular for emerging LID BMPs
Uniform performance standards with list of accepted BMPs and predetermined list of exemptions	• Ease of administration • Certainty for planners/ developers • Exemptions can be tailored	• BMP lists may be outdated • Exemption list may no include full range of constraints • Exemption process can be resource intensive • Potential for exemptions to become rule if not carefully crafted
Tiered Performance Standards		
Tiered criteria based on subwatersheds	• Criteria can be established based on pollutants/ development context of subwatershed • Can address flooding within the subwatershed	• Subwatershed mapping needs to be developed and supported by strong data collection program. • Subwatersheds may lie across several jurisdictions, which would require cooperation or uniform rules
Tiered criteria based on predetermined geographical areas	Criteria can be established within established geographical or jurisdictional boundaries	Rules established for a jurisdiction may not capture entire subwatershed
Tiered criteria based on development parameters: infill, new development, and redevelopment	Criteria can be targeted based on watershed function lost or designed to match BMPs to development contexts	May be seen as relaxing rules for one type of development
Tiered criteria based on economic development parameters	• Can be used to attract development to distressed areas (in particular where watershed benefits would be achieved via redevelopment) • Ease of administration where economic development areas are supported by existing programs • Can be used to attract investment for repairing infrastructure.	Some economic development districts lie in areas in most need of higher performance standards for volume or pollutant removal

Table 2. Types of LID Criteria

Type	Advantages	Disadvantages
With Supporting Credit System		
Hydrology criteria supported by credit manual	Credits can be advantageous for practices that are not easily measured or for which performance has not been established. Credits typically easier to administer than exemptions since they are front-loaded into the process.	Relief provided by credits may not be justified by analysis, paperwork or application fee. Credits may not apply to all development contexts and may result in uneven regulatory playing field. Small stormwater programs may not have resources to develop credit manual.
With Alternative Compliance Process		
Limited alternative compliance options with prescribed triggers and process for developing a "Finding of Impracticability"	• Alternative compliance is advantageous where there are numerous site constraints or varying landscape considerations • Alternative compliance programs can be used to fund district or regional BMPs • Alternative compliance programs can be written to support preferred practices where on-site BMPs are not practical	• The list of triggers may not encompass entire range of conditions or constraints • The process for "Finding of Impracticability" may be burdensome for smaller developers/sites • Widespread use can lead to lesser application of BMPs on individual sites
Case-by-case	Case-by-case application may be needed where a "Finding of Impracticability" or need is not apparent or where there are a number of constraints	Evaluation process is resource-intensive
With Exemptions		
Exemption process spelled out in regulations or technical manual	• Exemptions allow flexibility in *de minimis* situations • Exemption process can ease administration and add certainty	Widespread use of exemptions can erode the effectiveness of the BMP program
Case-by-case	Case-by-case assessment allows for closer examination of site conditions and considerations	Evaluation process is resource-intensive
Tied to Other Water Performance Standards and Programs (e.g., TMDLs, Anti-Degradation)		
LID criteria with reference to methodology for determining BMP performance required	Integrating Clean Water Act programs can make use of existing data and improve efficiency of administration	CWA programs have differing legal processes that may be challenged with integrated program requirements
LID criteria with monitoring and triggers	Monitoring results can tailor BMP response to specific pollutant reduction or elimination needs	• Monitoring results subject to challenge, which may extend process • May not be sensitive to upstream/downstream considerations (i.e. downstream permittees carry BMP responsibility for upstream loadings) • Response may need larger action than additional triggers for on-site BMPs

Table 2. Types of LID Criteria

Type	Advantages	Disadvantages
LID Criteria included in Technical Manual	• Only bare-boned ordinance, with reference to technical manual, needed • Technical manual can be a better vehicle for presenting information on size, type, and installation of BMPs that respond to wider variety of environmental pressures (such as habitat or land conservation) • Eliminates multiple manuals for different programs • Technical manuals can be written for a specific plan (e.g. downtown) to coordinate and integrate land development and BMP designs	More than one manual may be needed when there is a wide variety of environmental or development circumstances
LID criteria included in technical manual with levels of service (LOS)	• Setting LOS can help establish benchmarks within the program manual itself and assist in measuring results and reporting • LOS can either be environmental LOS or programmatic LOS (or both)	Benchmarks may be viewed as non-compliance triggers
Other		
Tied to other environmental performance standards and programs (e.g. greenhouse gas, energy, anti-sprawl)	• Best practices for other environmental programs offer watershed benefits (e.g., reduction of auto use) • Can help attract grant dollars for multi-objective programs	Ties to other mandates may be challenged as over-reaching in terms of achieving CWA compliance
Developed via inter-jurisdictional programs	• Can help avoid shifting development to areas with lesser standards and criteria • Coordination can allow better leveraging of resources • Many California jurisdictions have already formed regional alliances, thus models exist	• Smaller jurisdictions may be reluctant, in particular where larger jurisdictions have adopted stringent rules • May require development of unified land development regulations, which is time consuming • Administration requires frequent collaboration, which can be time-intensive

4 Options for State LID Statute Requirements

California has yet to implement a statewide policy governing LID or smart growth, though both regulatory and non-regulatory approaches can be used to promote LID implementation. (Non-regulatory approaches that build on existing initiatives are described in Appendix A.) In major metropolitan areas of the state, LID and smart growth policies are being incorporated into municipal stormwater permits; however, these requirements are not being applied to rapidly growing exurban areas. The Construction General Permit, currently undergoing revision, will apply to construction activities disturbing greater than one acre in all areas of the state and is expected to include a more progressive LID approach to stormwater management. Because California already has mechanisms in place or soon to be in place that require or encourage the use of LID, proposed state statute requirements should draw from these precedent approaches. A major benefit of a state statute for LID would be to provide consistency for how LID is addressed in stormwater Phase I communities, Phase II communities, and those areas not regulated under the municipal stormwater program.

Low impact development techniques and natural drainage are a logical first step for the design of any area planning. Care must be taken, however, in crafting regulatory language related to LID. Where regulations and performance standards are written exclusively for individual sites, the ability to credit the collective natural system can be lost, giving developers little incentive to use natural systems for multiple sites. Even where the regulations note that natural drainage should be given preference, the performance standards for individual parcels form the legal baseline. Likewise, the most effective water quality and runoff management program may be a shared system, not the additive effects of plot-level BMPs. Watershed planners and localities need to be given this option.

Any state statute requiring LID needs to be crafted with extensive stakeholder input, particularly from the Regional Water Quality Control Boards and regulated stormwater municipalities who have already done extensive work incorporating LID into permits and programs. The State should make every effort to avoid undermining progressive requirements already in place in some areas (particularly southern California and the Bay area) by setting performance standards that are less stringent than current requirements. On the other hand, the requirements should not be so stringent that smaller municipalities that have less experience with LID and stormwater management will have trouble implementing them. New legislation should balance water quality needs with existing and future capacity to implement LID requirements.

The following is a set of key concepts, including regulated projects, requirements, credits, waivers, and alternative compliance mechanisms, that a state statute on LID could address. It is important to note that this text is not intended to be statute language, per se, but it could serve as a foundation for a set of legal requirements that define minimum, progressive standards while allowing flexibility at regional and local levels to account for existing regulatory mechanisms and differing environmental conditions and management objectives. These recommendations are based on precedents from within California (described in Section 2.4) and from other states (a compendium of LID requirements from other states can be found in Appendix B).

4.1 Recommended Low Impact Development Requirements for California

A state statute on LID will likely need to address the following key concepts:

- **General Plans** – provide language on low impact development into the Land Use and Conservation Elements of General Plans
- **Specific Plans** – inserts language on establishing tiered design review for specific plans requiring an assessment and use, to the extent practicable, of natural drainage systems

- **Regulated projects** – defines the threshold for projects that need to address the LID requirements, including schools, universities, and other public facilities (i.e., no exemptions for non-traditional MS4s)
- **Requirements** – describes the requirements for LID statewide (will likely be further specified in NPDES permits or local regulations)
- **Stormwater credits** – provides the authority to issue credits that encourage better stormwater practices
- **Waivers** – provides the authority to waive requirements when certain conditions are met
- **Alternative compliance** – provides authority for innovative practices, in lieu of payments or mitigation
- **Definitions** – defines key terms

The key concepts above are further discussed below in the format of a hypothetical state statute. Each element is intended to encourage, facilitate, or require implementation of LID and is based on precedents from within California and from other states. Additional areas that might be included in an LID statute are penalties for noncompliance, enforcement, and regional variations.

4.1.1 General Plans

Local jurisdictions shall incorporate low impact development and natural drainage techniques into the Land Use and Land Conservation Elements of General Plans.

4.1.2 Specific Plans

Local jurisdictions shall amend procedures regulating the development of specific planning to include opportunities to incorporate and preserve natural drainage into the overall design of specific areas. This shall also apply to Master Plans.

4.1.3 Regulated Projects

Regulated development projects include (1) new development creating at least 5,000 square feet of total impervious surface area and (2) redevelopment that results in the creation, addition, or replacement of 5,000 square feet or more of impervious surface area on an already developed site, not including road resurfacing or repair projects.

Local jurisdictions shall have the authority to set a lower threshold of total impervious surface area to be more inclusive of sites that discharge to environmentally sensitive areas or impaired waterbodies, hillside sites, sites with a high likelihood of pollution generation, sites with highly erodible soils, or other areas requiring special protection from stormwater impacts.

4.1.4 Requirements

Regulated development projects shall be required to implement site design, source control, and stormwater treatment measures to control post-development stormwater volume and peak flows (stormwater discharge rate, velocity, and duration) to mimic pre-development hydrology, prevent accelerated stream erosion, protect stream habitat, and provide for the reuse of stormwater.

Source controls and low impact development techniques shall be the primary methods for managing post-construction stormwater on a development site. Additional stormwater detention, retention, and treatment practices shall be implemented as needed to manage excess stormwater to meet water quality and hydrologic goals.

Regulated development projects shall reduce the percentage of effective impervious area to less than five percent of total project area by draining stormwater into landscaped, pervious areas. The pervious areas shall be designed and constructed to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slopes, and other pertinent factors.

For redevelopment projects where the redevelopment results in an alteration to 50 percent or more of impervious surfaces of a previously existing development, the entire project, consisting of all existing, new, and/or replaced impervious surfaces, shall be required to meet these performance requirements.

For redevelopment projects where the redevelopment results in an alteration to less than 50 percent of impervious surfaces of a previously existing development, only the new and/or replaced impervious surface of the project shall be required to meet these performance requirements.

Note: an alternate requirement would be to require that redevelopment projects reduce impervious surface by 20 percent or provide water quality treatment of 20 percent of the site's imperviousness, or achieve a combination of both imperviousness reduction and water quality treatment equal to 20 percent.

4.1.5 Stormwater Credits

Local jurisdictions shall have the authority to reduce the required capture volume of stormwater retention practices by offering credits for low impact development techniques implemented on a development site that reduce total and effective impervious surface area and intercept, capture, infiltrate, evaporate, or reuse stormwater. Local jurisdictions that choose to employ a stormwater credit system shall develop and submit to the Regional Water Quality Control Board for approval a methodology for applying credits to stormwater management sizing calculations. The methodology shall include a procedure for verifying that low impact development techniques were implemented as described in the site design.

4.1.6 Waivers

Local jurisdictions shall have the authority to grant a waiver of the performance requirements on a project-by-project basis if a development site owner demonstrates that all available best management practices have been considered and rejected as infeasible due to site constraints. Local jurisdictions shall notify the Regional Water Quality Control Board within 60 days of granting a waiver for infeasibility. The notification shall include the evidence of infeasibility and the nature of the alternative compliance payment or activity to be implemented.

Alternative and Innovative Compliance

Local jurisdictions shall have the authority to establish joint low impact development and stormwater planning practices that can be shown to deliver superior protection to the applicable stormwater performance standards.

Payment in Lieu

Local jurisdictions shall have the authority to establish a regional or subregional stormwater management fund to pay for watershed projects that have stormwater benefits (e.g., regional stormwater management systems; riparian, wetland, or coastal restoration projects). Development site owners that have been granted waivers for infeasibility may be offered the option of a payment to this fund in lieu of meeting the performance requirements. The amount of this payment shall be determined by the local jurisdiction and shall be based on the estimated water quality and hydrologic impacts of stormwater discharges from the development site.

Mitigation Projects

Local jurisdictions shall have the authority to establish an alternative compliance program that offers development site owners who have received a waiver for infeasibility the option to participate in regional or sub-regional stormwater mitigation projects. Mitigation projects shall impact the same receiving water as the development site wherever possible and offer an equivalent level of environmental benefits.

4.2 DEFINITIONS

Best Management Practices – Methods, measures, or practices designed and selected to reduce or eliminate the discharge of pollutants to surface waters from point and nonpoint source discharges including storm water. BMPs include structural and nonstructural controls, and operation and maintenance procedures, which can be applied before, during, or after pollution-producing activities.

Effective Impervious Surface Area – The area of hardened surfaces that do not infiltrate stormwater and drain directly to a storm drain system, open channel, or natural stream.

Low Impact Development – A stormwater management strategy concerned with maintaining, mimicking or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives. It involves implementing small-scale, site design and landscape features that are distributed throughout a development site and result in the infiltration and treatment of runoff from impervious surfaces.

Regulated Development Projects – New development creating at least 5,000 square feet of total impervious surface area and (2) redevelopment that results in the creation, addition, or replacement of 5,000 square feet or more of impervious surface area on an already developed site, not including road resurfacing or repair projects.

Specific Area Plan – A specific area plan is a relatively detailed plan for the development of a particular part of a city (both new development and redevelopment), which may include a master environmental impact review.

Total Impervious Surface Area – The total area of hardened surfaces that do not infiltrate stormwater, including paved streets, sidewalks, parking lots, buildings, and roofed areas.

5 LID in Local Codes and Ordinances

5.1 Options for Incorporating LID

Many land use and development decisions take place at the local level, so managing the impacts of impervious cover first requires an understanding of the local codes and standards that direct the size and placement of hardscape. Land development codes tend to operate at both the site level and at the larger city or county scale. The larger scale codes can be found in subdivision regulations, geometric dimensions for streets, and general plans. In California, master plans and specific plans coordinate the “footprint” of both the public realm (streets, parks) and individual lots even when the entire site is carried out as one project.

At the site scale, zoning ordinances, landscape codes, and building codes direct a building’s bulk dimensions, parking, placement, and landscaping. Parking codes merit special attention because parking looms as one of the larger features in the built environment. Parking may be included within individual zoning codes, within specific or master plans, or in a city-wide code.

Municipalities have a number of options for integrating LID and smart growth into codes and the development approval process. For example, they can choose to implement a voluntary or regulatory approach, or they can choose a hybrid program that incorporates both voluntary and required elements. Table 3 describes options for integrating LID into existing land development ordinances, including some advantages and disadvantages of each approach.

Table 3. Approaches for Integrating LID Into Local Codes and Ordinances

Approach	Advantages	Disadvantages
Voluntary Measures – The least rigid process for implementation is to establish voluntary guidelines.	Since some LID measures reduce costs, or have benefits that exceed conventional practices, developers and homeowners may gravitate to LID. Voluntary measures also have the benefits of allowing flexibility and creativity since prescribed practices are not in place. Because the practices are voluntary, developers do not have to worry about sanctions for improperly installed or maintained BMPs.	As implied by the name, adoption is voluntary, and may require extensive outreach and education of the benefits.
Incentives-Based Approach – Communities may adopt voluntary or regulatory LID practices that are accompanied by an incentives program.	Incentives can help introduce new practices, or help bridge costs where LID installations are higher (as compared to conventional practices). Incentives can also be offered to induce developer interest in neighborhoods targeted for redevelopment.	Departments would have to establish new funding streams, which can be a challenge.
LID Ordinance – Communities may adopt stand-alone LID ordinances.	Stand-alone ordinances are easy to draft and enact.	A separate code may be confusing because it may not consider (or even conflict with) similar regulations on stormwater performance criteria or landscaping codes. Developers and site designers must refer to multiple codes. If changes to the code are needed, improvements must go through the sometimes lengthy process of code change.

Table 3. Approaches for Integrating LID Into Local Codes and Ordinances

Approach	Advantages	Disadvantages
Stormwater Management Ordinance – May require or encourage LID as part of a stormwater management ordinance.	Phase II communities are adopting post-construction ordinances to fulfill MS4 permits. LID can be incorporated into these ordinances without having to create a separate ordinance. Stormwater management performance standards can be key to the implementation of LID.	Communities will still need to review and revise development codes to eliminate or minimize barriers to LID.
LID Ordinance with Reference to Design Manual – Many communities oversee site and district design through design manuals.	Design manuals can go into more detail on LID selection and sizing. Design manuals can also integrate several development objectives at once, for example, combining LID with transportation-oriented development, use mix and/or redevelopment. Established design guidelines may be readily adapted to integrate natural drainage and LID. Perhaps the biggest benefit is that any fine-tuning of a design guideline does not need to go through that same process as code change.	Guidelines can be resource and time intensive. Cities with a variety of landscapes, development formats, and terrain will likely need to develop several guidelines.
Rezoning to Match General Plan Updates or NPDES MS4 Permit Requirements – Some cities use the General Plan process to introduce new zoning and land development regulations.	Applying new zoning codes clearly denotes site design and construction parameters. Emerging NPDES permits with on-site or LID requirements require a coordinated change in General Plans and ordinances.	The rezoning kicks in only where a property is developed or redeveloped (as opposed to a building rehabilitation). New zoning code requirements on LID could result in many non-conforming properties. If new LID requirements are viewed as a downzoning, cities and counties will be faced with addressing these concerns.
Building Code Changes – Building code changes can also be modified to integrate LID practices.	This is an option in cities or counties without zoning. In addition, building code changes may be more easily passed than a zoning code overhaul. Where the minimum land disturbance triggers are not met with NPDES permitting, building code changes can be changes to trigger LID with building rehabilitation. Even where rezoning occurs, building code changes may be necessary for green roof and onsite storage (e.g., cisterns and vaults).	Building code changes may not cover site design. In addition, LID at the district scale would not be thoroughly addressed if only building codes are amended.
Overlay Zoning – Overlay zoning is an increasingly popular method of introducing new requirements. While some overlay codes supersede the underlying zoning, in many cases, the overlay zoning is an option.	Overlay zoning can be matched to Master Planned development and Specific Plans to overcome the disadvantages of older, conventional zoning codes. For LID, an overlay zone can match BMPs to specific stressors, TMDLs or restoration needs.	Where the overlay is an option, cities or counties may need to offer incentives to increase the chances that the overlay will be adopted.

Table 3. Approaches for Integrating LID Into Local Codes and Ordinances

Approach	Advantages	Disadvantages
Alternative Compliance – Alternative compliance (including "fee in-lieu-of" programs and waivers) are a universal feature of any land development code.	Alternative compliance recognizes the wide variety of environmental or development conditions. While infiltration is a key feature of LID, many areas are unsuitable for infiltration practices (e.g., where the water table is high or where legacy contaminants pose a risk). "Fee in-lieu-of programs" can be designed to address the highest priority stormwater or flooding problems first.	Widespread waivers of alternative compliance can undermine the original environmental program. Cities must be able to quantify the fee associated with in-lieu-of programs. Some programs are seen as a developer giveaway.
Credit System – Credits for LID are increasingly popular, especially for stormwater and drainage requirements.	Credits are often used to promote environmentally preferable practices. They can also be used where the water resource benefits are difficult to fully quantify (e.g., preventative BMPs and smart growth practices). Where financial incentives are unavailable, credits can be used since they often lower costs. Cities and counties can use credit systems to attract development to certain areas (depending on how the credit system is structured).	Credits tend to put pressure on quantification to ensure fairness and environmental compliance. Thus, the advantage of crediting practices that are difficult to quantify is reduced. Credit systems can be resource intensive and are difficult to rescind once practices become commonplace. Where localities set strict initial performance standards, a credit system can be viewed as "going backwards" since the performance standard is viewed as the starting point for all projects.

While it may seem that instituting LID performance standards into zoning codes is straightforward, reducing and eliminating excess impervious cover is typically a multi-stage effort. This is because established zoning and land development codes have been built over time with input from a variety of parties with an interest in zoning parameters. Municipalities undertaking code and ordinance changes to incorporate LID should tailor their approach to the local context, taking into consideration existing development patterns, watershed conditions, stakeholder input, and other factors that will affect the opportunities for BMP implementation. Table 4 describes changes to codes that are appropriate for different types of development in urban, suburban or edge, and rural settings.

Table 4. Code Changes for Different Development Types and Settings

Development Type	Urban Codes	Edge Codes	Rural Codes
New Development	In highly developed urban areas, new development is likely to install impervious cover in the last absorptive places, though lot sizes are likely to be small. Codes should look at the stormwater functions lost and whether there are "hotspot" issues related to legacy contaminants. In urban areas, combinations of structural techniques (vaults) and small scale distributed landscaping are emerging practices to balance stormwater handling and water conservation. Code amendments will need to balance structural/non-structural techniques. Green roof technology improvements are responding to the range of environmental conditions. In Southern California, there is fear that green roofs would require irrigation most of the year. Moreover increased roof weight can trigger additional seismic requirements.	On the edge, new development is likely to consist of Master Planned Communities that are urban in nature (i.e., high levels of trip-making, demand for mix of uses, school travel). Reducing the impacts of impervious surface will come from both community design and onsite practices. Where urban boundaries are not in place, there may be opportunities to tie open space proffers to stormwater management. For new development in edge and rural areas, street designs should be carefully addressed. Where the format is mainly urban, narrow connected streets will better support activities. Where the format is more rural in nature, fewer engineered factors (i.e., no sidewalks) will form design. Note that "Campus Zoning" is replacing office park zoning. While the new designs emphasize green features onsite, the transportation remains auto-dominant.	Many rural areas of California lie outside of NPDES regulations. Some new low impact designs reduce developer costs (less street infrastructure). This can assist in provision of affordable housing, but also may attract development from regulated areas. Currently, 10 to 20 acre ranchettes are emerging as a popular housing type. The environmental impacts are not well-defined, however there are rural design/code options to lessen those impacts (e.g., shared facilities for stables, RV parking on a smaller footprint). New development in rural areas is likely to undergo increased CEQA scrutiny, in particular for induced growth, cumulative impacts and transportation-related climate change.
Redevelopment	Redevelopment projects in urban areas are likely to be part of a specific plan. Reducing the impacts of replaced imperviousness thus will rely on coordination of hardscape and open spaces. There may be socioeconomic factors in addressing redevelopment via NPDES. The additional requirements may further depress development interest in certain neighborhoods, thus cities may need to combine stormwater control with economic incentives.	Redevelopment at the urban edge may consist of a mix of new development and redevelopment. Thus, reducing the effects of imperviousness may involve reviews of specific plans, corridor redevelopment planning, use of remaining natural drainage and onsite measures. Parking codes are likely to dominate discussions where auto-dominant landscapes are being retrofitted with pedestrian features.	Rural "smart growth" designs often focus on historic downtown areas, crossroads and corridors. Code changes will need to recognize the watershed benefits of compact design.

Table 4. Code Changes for Different Development Types and Settings

Development Type	Urban Codes	Edge Codes	Rural Codes
Infill	Like new development, infill may involve a net increase in impervious surface. In urban areas, the increasing size of infill housing and its character are the subject of code changes; the stormwater regulations may also fit in these discussions and might be used as a tool to negotiate better housing and landscape design. New stormwater regulations are likely to put pressure on the construction of second units, in particular in areas with smaller lot sizes.	Infill projects need to be assessed for proximity to existing centers to determine community design features. Like urban areas, the character of infill housing in older neighborhoods is entering code change discussions. Form-based codes were authorized in State law, and are being adopted. Their role in stormwater management is to lessen the impact of vacant properties (since reuse is made easier with flexible form). Likewise FBCs are typically part of a coordinated district, which necessarily includes shared drainage.	Rural infill may be most common in rural industrial centers where transportation and water infrastructure were constructed to support past/current industrial uses. These areas may be candidates for small industry seeking attractive sites with green amenities.
Retrofits	In urban areas, the most important stormwater improvements, especially coastal cities, may arise from retrofitting properties and infrastructure with LID techniques in areas important for volume control and treatment. However, since NPDES permits only apply to new development and redevelopment, cities may want to use alternative compliance or "in-lieu-of fees" to address retrofit directly. In addition, cities will need to address retrofits through non-NPDES programs. Note that code changes were required to encourage use of solar devices. Local governments may need to add similar language to balance onsite practices in built out areas with property protection from runoff.	Retrofits on the urban edge are likely to focus on residential areas (since they comprise the largest area of developed land). Thus, both NPDES and non-NPDES programs will be needed. Like other retrofit programs, "punching holes" in existing impervious areas can direct improvements. There is also more opportunity for riparian buffers in areas that are less than built out.	The issue of retrofits for rural areas is small, though there may be increased opportunities for transfer of development rights for water harvesting or watershed water balance (for example where increased densification is balanced by an "offset"). However, in agricultural areas, the combined mandates for low impact development and water conservation will drive demand for different stock for commercial landscaping in urban and edge areas.

5.2 LID Elements of Codes and Ordinances

As described in Section 5.1, municipalities can employ a variety of approaches for integrating LID into codes and ordinances. A review of codes and ordinances that encourage or require LID from progressive stormwater programs around the country (summarized in Appendix C) shows that there are a number of common elements to the codes and ordinances. Based on these findings, the following are initial steps that communities can take to incorporate LID into their local codes and ordinances:

- Adopt goals and objectives for stormwater management.
- Conduct technical analyses to evaluate and determine appropriate performance standards that help you meet goals and objectives.
- Finalize performance standards.
- Conduct a review of existing ordinances and manuals to identify (1) the need for additional ordinances and (2) needed revisions to existing ordinances to create requirements or incentives for LID and remove barriers to LID. This includes review of existing stormwater, sedimentation and erosion control, subdivision, zoning, and/or unified development ordinances. (A checklist is presented in Appendix D that outlines key features of ordinances and common elements where LID can be incorporated or where barriers may exist.)
- Conduct roundtable discussion of needed ordinance revisions. This discussion should include sectors of the development community, bankers, DOT officials, environmentalists, and local government departments, etc.
- Based on recommendations from the roundtable discussions, draft new ordinance (e.g., stormwater management ordinance) and proposed text revisions for existing ordinances.
- Hold public meetings and public hearings.
- Adopt ordinances.

5.3 Overcoming Process Barriers to Code Reform

In addressing aspects of codes and development regulations that may pose a barrier to LID, it is important to recognize that the code parameters were put in place to address a particular policy or development matter. Established codes and standards can be difficult to change for a variety of reasons:

- *Fair application of development rules.* One broad standard may be viewed as serving any project that meets size or use standards.
- *Ease of administration*. One enforced standard is easier to implement than several codes.
- *Investment in the status quo*. Stakeholders adjust operations to existing zoning and anticipate financial loss or risk in any change.
- *Legal support*. By using a recognized national code, cities and counties may feel “covered” when safety or other concerns are brought forward with development projects.
- *Margin of safety*. The over-design of infrastructure and development is often attributed to risk reduction for extreme weather or emergency response events.
- *Resource constraints*. Amending standards or offering a choice of codes and standards requires human and financial resources. During project or site review, there are resource implications for training staff or altering engineering models.

- *Lack of outreach and education*. Even as models for better development emerge, there can be a lag time in obtaining buy-in from developers, the public and local Departments.
- *The desire for uniformity and predictability among development projects*. The desire for uniformity is evident in both the public and private sectors. Developers and their financial backers often associate a uniform development style with reduced risk. For cities and the larger public, a move away from conventional development can also be viewed as a risk to the tax base and property values.

5.4 Program-Building Steps

Before the effective date of ordinance revisions, a new local program needs to be established to implement the LID provisions. In fact, depending on the degree of local support, work should begin on building program elements during the period of public discussion if the effective date of the ordinance revisions is to be soon after their adoption. Otherwise, the effective date of the ordinance revisions should be delayed by 6 months to one year to allow for capacity building.

The local government is encouraged to have implemented the following steps prior to the effective date of the ordinance revisions:

1. Develop stormwater design manual or revise existing manual to incorporate LID techniques.
2. Develop tools or standardized methods for evaluating compliance with the Performance Standards. These are to be used by project applicants and staff.
3. Develop Standard Operating Procedures for
    - Development review
    - Inspections (including inspections check list; inspections/maintenance documentation procedures; database to manage inspection/maintenance history)
    - Enforcement
4. Conduct analysis of new staffing requirements. Hire staff as needed.
5. Train new and/or existing staff on use of the Design Manual; evaluation methods; standard operating procedures.
6. Conduct workshops for the development community on new requirements. This should ease the transition and minimize mistakes in early submittals.
7. Develop program evaluation framework, including benchmarks to ensure that goals are being met.
8. Be patient and creative. Work with the applicant to find solutions. Remember there is a transition phase when staff and project applicants are learning and helping work out the “kinks” in the manual, evaluation methods, and Standard Operating Procedures. Treating the program as a partnership will increase the likelihood of long-term support and success.

Appendix A: Options for Enhancing LID in California Policies

The following is a list of policies and programs in California through which LID can be promoted or enhanced. The list includes a description of the policy or program, including how it is related to LID, and action items that might be considered to remove barriers to LID implementation and better integrate LID into planning and development policies and practices. This list is intended to be fairly comprehensive, and as a result some of the options may be determined to be infeasible in California for a variety of reasons. This list is not static, as new policies and programs arise regularly. Discussions with other LID stakeholders will likely generate additional policies/programs and action items that should be added to this list.

CONTENTS

A. STATE ENVIRONMENTAL POLICIES

Like many states, California has delegated oversight of infrastructure and the built environment to many entities. As such, many policies can work at cross-purposes and funding priorities may be misaligned. To ensure adequate coordination and mutual support for LID and other environmental goals, State policies should be reviewed and aligned.

Issues

A1. ***Blanket application of a "Meadow" Performance Standard for LID may result in degradation***
Many LID equations set a baseline, pre-development condition against which stormwater management performance can be gauged. A common requirement is that the hydrology of a development site mimics that of a meadow. The "meadow" equation has the effect of treating conversion of a meadow and conversion of an abandoned parking lot as equal in terms of runoff. While this might be desirable in some situations, there could be degradation in other cases, for example if the pre-development condition is a forest, which has greater stormwater attenuation than a meadow. This approach to LID performance also fails to recognize receiving water condition. It may be necessary to institute a two-tiered approach where the first line of questions examines loss of ecosystem services. Thus, conversion of a meadow or forest would require a higher level of treatment and control than conversion of an impacted site.

A2. ***Many State agencies have recently updated codes and standards to include "green practices," though LID is not well represented***
Many improved guidance documents, manuals and directives were recently released (in 2006 and 2007), representing enormous efforts to integrate environmental planning, site design, and operations. Erosion controls for the construction phase of development seem to be the top stormwater priority, as exemplified in the new scorecard for High Performing Schools and the General Services manual.

A3. ***General Plans do not explicitly address LID***
General Plans guide land use and future development and can affect the amount and placement of impervious surfaces in watersheds. General Plans that do not integrate stormwater concerns with other pressing environmental issues such as water supply, total maximum daily loads (TMDLs), water conservation and

infrastructure might allow or encourage development patterns that adversely impact waterbodies. Explicitly incorporating LID goals into General Plans will help to ensure that watershed impacts will be considered on a regional planning scale.

A4. ***Communities require education on LID approaches***
Many local governments have not been educated on the benefits of LID and how to incorporate LID approaches into stormwater management plans, codes, or ordinances.

A5. ***LID not integrated into State Environmental Goals and Policy Report***
Every four years the Governor is required by State law to update the State Environmental Goals and Policy Report. The report was last updated in 2004. The top three priorities in the Report are summarized as follows: (1) to promote infill development and equity, (2) to protect environmental and agricultural resources, (3) to encourage efficient development patterns. Using LID approaches, these three priorities can be addressed to meet State environmental goals.

A6. ***LID projects using CWA §319 funds require a 40 percent non-federal match***
This federal program is among the most popular sources of money for model or pilot projects to mitigate runoff. However, the program requires a 40 percent non-federal match. Over $5 million has been available for projects, which must be implementation projects of between $250,000 and $1 million.

A7. ***Proposition 218 limits stormwater utility formation***
Stormwater utilities are widespread and growing as a way to manage stormwater and drainage. In California, stormwater utility formation is limited due to Proposition 218. Legislation has been introduced to place stormwater funding outside of Proposition 218. In many areas of the country, utilities (actually credits from utility fees) have been an effective means for fostering LID based on monetary incentives (especially for larger businesses and lots).

A8. ***LID is not incorporated into Clean Water Revolving Loan Funds***
The State Water Resources Control Board (SWRCB) sets priorities for the use of funds under the Clean Water State Revolving Loan Fund through annual “Intended Use Plans,” in general directing money to the most pressing health and environmental problems first.

Opportunities and Action Items

Legislative

A9. Establish through legislation a statewide requirement that new State-owned buildings and those undergoing renovation to buildings/grounds meet the standard that post-development stormwater peak flow rate and volume from the site match the pre-development stormwater peak flow rate and volume. Note that this is a stringent requirement that may be controversial because this standard may not be feasible where soils are contaminated, in ultra-urban areas, or where the groundwater table is high. An alternative compliance option should be offered to allow developers to provide equivalent watershed benefits where site limitations prevent achievement of the performance standard onsite.

A10. For General Plans, require a new “Water Element” to combine water supply, stormwater, TMDLs, watershed planning, water conservation, LID, water infrastructure, and floodplain management. If legislation to require a Water Element is too aggressive, provide policy support for communities that choose to adopt a water element, including LID. The Local Government Commission’s handbook on the Ahwahnee Water Principles (http://www.lgc.org/ahwahnee/principles.html) includes model policy language and information on the initial content for a Water Element.

Aspirational

A11. Develop a prototype two-tiered approach to stormwater that tiers post-construction best management practice (BMP) requirements based on the loss of ecosystem services.

A12. Sponsor a review of California State programs based on barriers or support for joint LID/planning, policy, funding and regulation. Provide suggestions to overcome barriers and highlight best practices. The review may cross-reference the top priorities and include LID.

A13. Sponsor or co-sponsor a regional Low Impact Development Conference to aid in education and training. OPC, in coordination with the State and Regional Water Boards, could develop workshops and training seminars to educate planning authorities and communities on how to incorporate LID approaches into growth strategies; how to design, implement, and evaluate LID approaches; and how to ensure long-term maintenance of LID practices.

A14. Sponsor a mock or pilot CEQA analysis of build-out for a region comparing an LID scenario with current zoning to provide a "ready alternatives analysis" based on LID.

A15. Contact the State's Office of Planning and Research to begin work on integrating low impact designs and development into the State Environmental Goals and Policy Report. This would strengthen the priority to "protect environmental and agricultural resources," which is now geared towards preserving farmland and open space, and should be a complement to the priorities of promoting infill and encouraging efficient land use.

Funding

A16. Support efforts to exempt stormwater funding from Proposition 218 limitations.

A17. Provide part of the 40 percent match for section 319 funding for LID pilot projects, LID planning or other activities covered under Clean Water Act §319.

A18. Work with the SWRCB to assess where changes to the "Intended Use Plans" for the Clean Water State Revolving Loan Fund might be combined with LID to improve water quality. The SWRCB notes in their 2007 Annual Report, Section II, that only 6 percent of funds were delivered to nonpoint source programs, though they will pursue increasing this amount because nonpoint source projects are critical to water quality. In addition, the SWRCB may be open to a "fix it first" alignment of funds for certain water funding programs.

A19. Assist municipalities in seeking grants from the Proposition 84 Storm Water Grant Program that provide matching grants to local public agencies for the reduction and prevention of storm water contamination of rivers, lakes, and streams.

A20. Work with the SWRCB to see where LID can be inserted into Supplemental Environmental Projects, which are financial contributions made as part of an enforcement action under the Clean Water Act. These projects must address the harm reported in the violation. Thus, an enforcement action for lack of sediment control at a construction site might include a LID retrofit for a public park experiencing erosion problems.

B. Building and Zoning Standards

Building codes and standards are used to prescribe an expected level of health, safety and structural safeguards. These codes are commonly adopted by reference or integrated into local zoning codes. While these codes are vital for numerous reasons, inflexible "one-size-fits-all" codes tend to dictate a development format that cumulatively does not meet new or emerging challenges, in particular environmental challenges. For example, within building codes, traditional drainage parameters are written to move water away from building foundations and into streets through as direct a route as possible. Cities in California are in the process of revising their building codes to adopt new standards based on updates to the California Building Code, as well as other codes such as plumbing, electrical and fire.

Issues

B1. ***Provisions of the California Building Code preclude LID implementation***
The California Building Code includes many site, building and foundation codes, some of which may limit the use of infiltration BMPs. For example, limitations associated with expansive soils, seismic requirements and foundation integrity could all limit onsite infiltration, in particular on small sites where area for infiltration is limited. The new codes include language that allows localities to designate alternative drainage requirements, though this language is vague and does not specifically promote LID.

B2. ***Building footprint limits can drive imperviousness on a larger scale***
Maximum building footprint limitations place an upper bound on the building footprint size (e.g., a footprint can be no more than 30 percent of site coverage). While this is often a strategy for LID because it ostensibly reduces the impervious area attributed to a building, lower caps can drive inefficient land development at a larger scale by spreading out building imperviousness. In addition, parking often ends up occupying the space not used for the building.

B3. ***Building height limits and minimum frontage requirements can spread development outward***
Where development demand is high, building height restrictions tend to spread development outward. Where setbacks are small, this can lead to "horizontal density," which leaves little room to manage stormwater and forces an overall larger degree of low-density, highly impervious development. Minimum frontages (e.g., 100 feet) mandate a large parcel footprint for even smaller establishments.

B4. ***Rigid setbacks can limit LID application***
A setback is the minimum distance a building's side may be constructed from the front right-of-way and adjoining properties. Small setbacks have advantages (they support compact formats) and disadvantages (they leave little room for landscaping and aesthetics). Large setbacks of 30 feet or more add to driveway, walkway and other impervious infrastructure lengths. On the other hand, the larger the setback, the greater the opportunity for infiltration. Setbacks also tend to be rigid, preventing site designers from optimizing infiltration depending on individual site characteristics.

B5. ***New guidance for State buildings includes little direction on post-construction stormwater control***
The California Department of General Services updated its Best Practice Manual for State Buildings (http://www.documents.dgs.ca.gov/green/BPM-bbmbt.pdf) in 2006. The new manual includes information on managing construction site runoff but offers little information on managing post-construction stormwater onsite and provides no information on performance standards.

Opportunities and Action Items

Legislative

B6. Require all State buildings (new and substantial remodeling) to institute LID requirements for buildings, grounds and parking. Work with stakeholders to determine the development and redevelopment thresholds for LID requirements and retrofits.

Aspirational

B7. Sponsor an examination of the California Building Code to see which provisions might impede infiltration and LID, or which provisions require clarification on the use of LID. Use the review to suggest changes to the Building Code to meet multiple goals and provide assistance to local governments that have adopted the California Building Code by reference or are in the process of adopting the updated codes.

B8. Support a program for municipal building and zoning code audits to support environmental improvement (i.e., the audits would address not only stormwater via LID, but watershed, transportation, and heat island issues through more efficient forms of development and redevelopment).

Funding

B9. Provide incentives (i.e., funding for LID and stormwater-related implementation projects) and guidance to communities who agree to audit and modify local codes and standards to allow or promote LID.

C. Streets, Roads, and Highways

The design of highways, streets and roads has a high degree of impact on watersheds. The location of new roads, the geometric standards that govern road construction, the width of rights-of-way, and the connections among sites to the larger stormwater conveyance system are all factors that affect the degree of stormwater impacts from development. In addition, roads, even small roads with minimal shoulders, fracture important drainage networks and alter local hydrology.

One emerging issue is construction and improvement of roads in rural areas at the urban-wildland interface. On the one hand, improved roads assist in firefighting response, which is a pressing issue in developed areas adjacent to forests and scrubland. However, improved roads in rural areas can send signals that the areas are prepared to handle more development, which can contribute to sprawl and increased regional imperviousness.

Issues

C1. *Overly wide street widths*
Street width in California is written into the State Streets and Highway Code, Section 1805 (http://www.legaltips.org/california/california_streets_and_highways_code/). The code requires that the width of all city and county streets and county highways (other than bridges, alleys, lanes and trails) shall be at least 40 feet wide. A county board of supervisors may elect smaller streets only by a unanimous vote of its members; within cities the requirement is a 4/5 vote. Also, emergency responders tend to request overly large street widths for maneuvering large equipment and vehicles. Engineering guides used throughout California establish minimum street and right-of-way widths, which can also include bike lanes, sidewalks, medians and planters. Efforts to reengineer streets, including reduced widths, are underway, mainly through Specific Area Plans.

C2. *Overly wide sidewalks and sidewalks on both sides of the street*
While walkability is a popular amenity and even integral to transportation, wide sidewalk requirements on both sides of the street add impervious cover. In addition, the Americans with Disabilities Act requirements direct sidewalk placement and widths, which are needed for accessibility.

C3. *Inefficient street layouts*
Most states, including California, have built highway systems based on a hierarchical model. This model funnels traffic from residential projects to local streets, to arterials and then to freeways. The system tends to arise where development is unconnected and scattered throughout a watershed. This adds to imperviousness and congestion, reduces options for alternative routes, and limits non-auto modes of travel.

Title 14 of California's Public Resource Code includes minimum road standards for wildland areas. Many county manuals mandate certain concrete, asphalt and substrate materials, in part to bear the weight of larger vehicles (often up to 40,000 pounds). Many cities and counties adopt standards developed by Fire Protection Districts (for example Ventura County's access standards, http://fire.countyofventura.org/departmentservices/fireprevention/standards/index.asp). These rules require certain paving materials and can prohibit the use of pervious pavers and alternative materials for access ways, parking lots, shoulders and turnarounds. Even where codes only apply to certain fire-prone areas, the standards are sometimes adopted for the entire county or city.

C4. *Funding for streets and highways from the California State Controller does not encourage LID*
In 2004, the California State Controller's Office issued Guidelines Relating to Gas Tax Expenditures For Cities and Counties (http://www.sco.ca.gov/aud/gastax/gastax2004.pdf) to describe how funds collected for vehicles and gas, the major source of transportation infrastructure funding for localities, may be used. This authoritative document was developed to assist cities in determining how gas taxes may be used for street and highway improvement. While LID techniques appear to be included in the narrative, the definitive list of techniques that may be used, even for environmental mitigation and retrofits, is dominated by engineering approaches.

Opportunities and Action Items

Legislative

C5. Require that LID be incorporated into any new Caltrans road project, where feasible. Work with Caltrans planners to identify appropriate BMPs and performance standards for different types of road projects.

C6. Require LID retrofitting with any State-sponsored repair or maintenance project. This may include new materials for shoulders, the use of paving alternatives or improvements to stormwater management. Work with stakeholders and Caltrans to determine repair/maintenance project thresholds for the use of LID retrofits.

C7. Remove the 40-foot minimum street width from the Street and Highway Code for city and county streets.

Aspirational

C8. Work with Caltrans planners on the following programs that can include an LID or "green streets" component:

- Add an LID component or develop an LID matrix for "Corridor System Management Planning" projects intended to retrofit major corridors (http://www.dot.ca.gov/dist3/departments/planning/corridorplanning.html)
- Incorporate LID goals and objectives into the "Regional Blueprint Project" and the "Blueprint Learning Network" (http://www.dot.ca.gov/hq/tpp/offices/orip/bln.html).

C9. The Congress for the New Urbanism recently was awarded a grant to work with emergency responders nationwide on the issues of street widths, design and access. The State could support work on the paving materials and street design aspects of the project, since these should be part of the larger discussion. The State may also want to explore discussions on vehicle and apparatus design, since road designs are driven by the need to support vehicle size and weight. In California, the Local Government Commission has developed State-specific materials and training.

C10. Develop a High Performing Infrastructure report that integrates all utilities and infrastructure located in public rights-of way, including natural drainage (similar to that developed by New York City, http://www.designtrust.org/publications/publication_03hpig.html).

C11. Contact the California State Controller's Office to update and clarify language related to use of gas tax funding for environmental improvements and LID. Note that the Controller's Office has also issued Guidelines on use of Traffic Congestion Relief Funds (http://www.sco.ca.gov/aud/traffic/ab2928.pdf), which states that:

> Funds may also be used for the cost of work that is associated with and incidental to a street or road maintenance or reconstruction project within the street or road right-of-way, provided the work is necessary and/or required to bring the street or road to current design standards.

Further language refers to "associated curb and gutter work," though the overall wording tends to imply engineering approaches. The State can approach the Controller to see if specific guidance on "green streets" can be developed.

Funding

C12. Caltrans is developing a "smart mobility" scorecard to institute a new prioritization system for allocating funds. This scorecard will be used to underwrite investments in street systems that better support existing developments and pedestrian and bike infrastructure and improvements. This same type of scorecard might be used in distribution of stormwater infrastructure and nonpoint source funding.

D. Parking Lots

The impact of parking cover tends to fall into two categories: (1) decisions on overall parking supply and (2) the design of individual spaces and lots. In general parking is oversupplied due to the use of high minimum standards, requirements from financial lenders, and the lack of incentives to share parking among individual land uses. In general, workable reductions in the footprint of parking require a multi-disciplinary, planning approach.

Issues

D1. ***Parking lot landscaping requirements preclude infiltration***
Many parking lot codes require a continuous elevated curb around landscaped areas, which eliminates the ability to direct runoff into natural areas.

D2. ***Parking lot surface requirements limit porous pavement application***
Some parking codes limit the material selection to asphalt and concrete, prohibiting the use of permeable pavements.

D3. ***Overly large parking space dimensions***
Many codes require minimum space dimensions, as well as dimensions for drive aisles. In some cases, residential codes require a minimum number of spaces for recreational vehicles in addition to automobiles. Overly generous stall dimensions can increase parking lot imperviousness by 15 percent.

D4. ***Minimum required number of parking stalls leads to too many spaces***
Parking allotments often overstate actual demand and a minimum standard allows for more parking at the developer's discretion. The Institute for Transportation Engineers' "Parking Generation" establishes minimum number of parking stalls rather than maximum. Financial institutions tend to require extra parking as a margin of safety for overflow, even though extra spaces tend to be factored into the minimums. All of these factors contribute to increased parking lot impervious surface.

D5. ***Shared/joint parking and loading prohibited or not incentivized***
Many local codes either prohibit joint/shared parking, or give little incentive to do so. As such, the system errs on the side of oversupply for each project that is built or redeveloped, resulting in additional impervious surface.

D6. ***Zoning code limitations on charging for parking***
Many California cities prohibit charging for parking for any spaces that are required by code. This eliminates a market-based tool for to manage parking demand.

D7. ***Parking costs are "bundled" into rents***
Parking costs are "bundled" into rents, which (1) charges parking costs to renters who do not own cars and (2) conceals the true cost of parking. One strategy being used across the country is the unbundling of parking and rent costs, which provides more transparency on the costs of parking and can reduce parking demand. Lower demand means smaller lots.

Opportunities and Action Items

Legislative

D8. For parking lots serving State buildings, require that any maintenance or resurfacing project affecting more than 20 percent of the lot include LID retrofits that address runoff for the entire lot (or some negotiated percentage of the lot based on site constraints).

D9. Require that all sections within municipal zoning codes related to parking present both a minimum and maximum parking space allotment. Alternatively, require all State buildings to adhere to both minimum and maximum parking numbers.

D10. Draft enabling legislation allowing cities and counties to treat any surface parking over and above the minimum prescribed amount differently in stormwater management calculations. For example, developments with excess parking space would be required to manage 150 percent of the stormwater volume or provide an equivalent degree of off-site management/retrofit.

D11. Prohibit the practice of limiting parking charges for any parking required under code.

D12. Craft legislation requiring the unbundling of parking costs for residential sites that are within one mile of heavy rail or fixed guideway transit stations, one half mile of bus transfer stations and one quarter mile of bus stops. Proximity to public transit offers residents alternatives to driving/parking, allowing them to choose not to pay for parking once costs become transparent.

Aspirational

D13. Provide a model parking sharing arrangement to foster joint and shared parking.

Funding

D14. Provide funding for communities to conduct parking demand studies.

D15. Fund pilot projects testing innovative parking lot designs and the use of innovative materials.

E. Landscaping

The landscaped areas of development and redevelopment sites offer opportunities for stormwater management, even on small parcels in ultra-urban areas. However, cities often develop guidance documents and zoning code language that result in undesired environmental practices (e.g., the use of fertilizer- and water-dependent plants, limitations on efficiently using open space for infiltration, and engineering requirements that inhibit runoff capture and treatment).

Issues

E1. ***Landscaping codes and ordinances can conflict with LID***
Most California localities include landscaping ordinances within their zoning codes. LID in urban areas generally applies to commercial landscaping, including multi-family residential projects and landscaping within parking lots. Some landscaping codes reduce areas for stormwater infiltration by not specifying appropriate infiltrative soils. Others encourage raised landscaping by requiring planting areas be protected by curb or wheel stops, which eliminates the ability to treat runoff in landscaped beds. In addition, some codes limit the use of non-plant materials, such as gravel, to 10 percent of the area. This limits the ability to use rocks and gravel for energy dissipation, which is essential for hydromodification control. The lack of understanding how LID approaches can be incorporated into landscaped areas often result in a greater amount of land area dedicated for traditional stormwater controls and conveyance.

E2. ***Water conservation is not explicitly linked to LID and stormwater management***
In 2006 new legislation took effect under the Water Conservation in Landscaping Code (http://www.cuwcc.org/ab2717_landscape_task_force.lasso). Language on stormwater infiltration and reuse is in the legislation, though it is not strong. As new stormwater permits are issued, a bond will need to be forged among LID, permit performance standards, and the landscaping rules. Note that much of the language on water conservation in landscaping pivots on water budgets and irrigation. The use of LID will affect these budgets, though little research has been done to determine how stormwater infiltration will ultimately be factored into these budgets.

E3. ***Many exemplary landscaping codes include requirements for maintenance***
Maintenance of stormwater BMPs, including LID techniques, is often overlooked, resulting in reduced performance in handling volume and removing pollutants. Audits of the Phase I program by EPA showed that lack of maintenance was the top weakness of the stormwater program. As such, zoning codes that include maintenance (including inspection and enforcement) can be modified and used to sustain the benefits of LID.

Opportunities and Action Items

Legislative

E4. Require greater minimum area dedicated to landscaping in development and redevelopment codes. Require that a Landscape Plan include a site evaluation of existing conditions (soil hydrology, vegetation) to consider in designs before grading or other impacts to the site have taken place. Provide model ordinance for these changes.

Aspirational

E5. Contact the California Urban Water Conservation Council (http://www.cuwcc.org/home.html) on integrating LID into new guidance and model codes. The language on infiltration exists and provides an "in" for LID, but it is not strong. The potential exists for codes to be written without factoring in water budget changes that arise from capturing water onsite. Some work is underway: the Urban Water Conservation Council must develop a model code by January 1, 2009, with local ordinance adoption within one year.

E6. Develop a cross-program education and communications strategy for LID, including options for urban areas, master planned areas, new development, redevelopment and infill.

E7. Provide technical assistance (e.g., guidance, trainings) for incorporating LID into local codes and for design, installation, and long-term maintenance of landscape-based BMPs, including pesticide, fertilizer, and herbicide use.

E8. Work with the California Nursery Growers Association on ramping up plant selection and practices to meet both LID and upcoming water conservation standards. http://www.nurserygrowers.org/index.html.

F. Open Space

California has many programs devoted to preservation of open space, forests, park land, and desert land. Last year, legislation limiting development in floodplains increased protection of streamside open space. Urban open space, parkland and forestry are important but often overlooked opportunities to manage runoff. To make the most efficient use of open space for stormwater management, areas that have natural drainage properties amenable to LID should be dedicated for this use. Minimum open space requirements that do not take into consideration these site properties may not provide adequate stormwater management benefits.

Issues

F1. *Minimum open space requirements might drive inefficient land use*
California requires minimum open space for multi-family residential projects. While open space is an important component for urban areas, large minimums may be driving inefficient land use without providing meaningful natural or recreational spaces. The open space requirements for multi-family residential projects are often in addition to other requirements such as parking, setbacks, internal circulation, sidewalks, club houses and other amenities. In addition, many local codes disallow land devoted to onsite stormwater management to count towards the minimum open space provisions. However, reducing open space is likely to be controversial because most assessments of the value of open space do not consider any countervailing effects on efficient use of land.

F2. *Inconsistent and inadequate buffer widths*
Aquatic buffers serve as natural boundaries between local waterways and existing development. They help protect water quality by filtering pollutants, sediment, and nutrients from runoff. Other benefits of buffers include flood control, stream bank stabilization, stream temperature control, and room for lateral movement of the stream channel. Good aquatic buffer ordinances specify the size and management of the stream buffer and are a specific planning tool to protect stream quality and aquatic habitat. Buffers can be multifunctional, serving as areas for sheet flow and infiltration to reduce stormwater pollutants and volume, improve baseflow conditions and increase groundwater recharge.

F3. ***The Williamson Act can be used to prioritize preservation of infiltration areas***
The California Land Conservation Act of 1965 (Williamson Act) enables local governments to enter into contracts with private landowners for the purpose of restricting specific parcels of land to agricultural or related open space use. Landowners receive property tax assessments based upon farming and open space uses as opposed to developed market value. Local governments receive an annual subvention of forgone property tax revenues from the State via the Open Space Subvention Act of 1971.

Opportunities and Action Items

Legislative

F4. Create a Williamson Act/Open Space Subvention Act of 1971 counterpart for infiltration and aquifer recharge. Base the program on areas best suited for infiltration. Alternatively, allow localities to include infiltration as "production" under the Williamson Act in areas delineated for aquifer protection.

F5. Require that open space designations be reviewed during local plan review to assure that the area is used in the most efficient manner for present and future needs, including stormwater management and groundwater recharge. The State can provide model ordinance language to require open space designation review.

Aspirational

F6. Provide examples of supplying land-efficient open space from other parts of the country, in particular for dense urban districts. Alternatively, develop and promote examples of open space landscaping that supports both stormwater handling and active/passive recreation (e.g., using soccer fields as infiltration basins, developing water gardens with aesthetic and stormwater treatment functions).

F7. Encourage local governments to adopt ordinances that apply minimum buffer widths and maintenance requirements to all lots that are contiguous with or directly adjoin an intermittent or perennial stream or river, particularly those identified in and consistent with impairments or threatened/sensitive species.

G. Schools

School building and renovation offer LID opportunities. The decision of whether to redevelop an existing school or build anew at another location has broad watershed implications. First, older schools tend to be located on smaller sites. Secondly, the increasing costs of land and construction exert financial pressure to build on cheaper, more distant, and undeveloped land. A variety of factors then feed into the ultimate footprint of the school, including parking, pick-up, fields, classroom size and the like. California has been a national leader in school siting reform, including a push to use schools as centers of community and voter approval of funding to provide green retrofits.

Schools provide an ideal opportunity to demonstrate LID approaches to the public because they serve as polling places and meeting locations in addition to educational facilities. Operation and maintenance can generally be assured at schools. Placement of stormwater management features on school grounds can provide opportunities for LID outreach and education to children and adults. There are still areas of improvement needed, in particular as it relates to the overall stormwater and carbon footprints of new schools.

Issues

G1. ***"Schools as Centers of Community" policies can be used to promote LID***
California has instituted "Schools as Centers of Community" policies over the past decade to efficiently supply services, parks and facilities. School parking lots, fields, land and landscaping may provide capacity to address local flooding, provide land or storage for stormwater and otherwise address stormwater hotspots.

G2. ***School Facility Hardship Grant Program might discourage LID and/or redevelopment***
California's School Facility Hardship Grant Program, which provides grants to correct safety problems, discourages school districts from considering renovation options for historic schools by limiting funding if renovation costs exceed 50 percent of the cost of new construction. This can limit renovation of already

developed properties, which might include incorporation of LID into landscaped areas. This policy may encourage school construction on undeveloped lands, which increases impervious area (newer schools typically have a larger footprint), requires additional infrastructure and can increase brownfield or vacant land(if the old school property is not redeveloped.

Opportunities and Action Items

Legislative

G3. Require LID for new school construction. Where feasible, require use of school property for collective drainage and infiltration. For new and existing schools, require water harvesting equal to a locally preferred design storm (for example the design storm used for transportation projects). Where possible encourage school construction or reconstruction on infill or redeveloped lands and discourage construction on undeveloped lands. The State can provide incentives (i.e., funding for LID and stormwater-related implementation projects) and guidance to communities who agree to modify local codes and standards to promote infill and redevelopment.

Note that the California Department of General Services and California High Performing Schools initiative recently launched its $100 million High Performing Schools Program, funded by Proposition 1D in 2002. The criteria for selection and level of funding is based on a scorecard (http://www.chps.net/manual/documents/CHPS-NewConstruction_Scorecard_060821.xls), which only has a non-required stormwater item for "minimizing runoff," although other factors might reduce runoff, such as a factor to "minimize parking."

Aspirational

G4. Under recent legislative changes, school districts may develop Master Environmental Impact Reports (EIRs). The State can work with the Department of Education's facilities group to integrate LID into all master EIRs for educational facilities.

G5. Encourage passage of State legislation to require new school construction to meet LEED Silver standards.

Funding

G6. Sponsor water infrastructure upgrades to include LID in existing schools. By underwriting new infrastructure for historic schools, energy and water costs can decrease and in some cases they can address deferred maintenance that might otherwise feed into the renovation cost calculation and tip the decision to new construction. One group that has been effective at this is TreePeople in Los Angeles.

H. District Planning, Redevelopment, and Infill

Increasingly, cities and counties are turning to district planning for efficient delivery of services, coordinated infrastructure, and economic development. Although most LID codes and examples have been applied to individual sites, one key to effective implementation is how the larger area performs for watershed health and restoration. This involves how streets are designed; what the use mix is; how accessible common trips are to jobs, home and school; the extent to which site elements are shared; the footprint of development; and how open space is used (or set aside).

In California, there has been an upsurge in district planning. New models of district planning have been launched and fine-tuned in California, including form-based codes, new urbanism, transit-oriented development, and a new Leadership in Energy and Environmental Design (LEED) pilot for neighborhood development (LEED-ND). For redevelopment, main streets, infill and highway corridors have been the focus of activity. For new development, traditional neighborhood design, master-planned communities, conservation or cluster subdivisions, mixed-use projects (sometimes called "lifestyle centers"), and planned unit development projects, are common formats.

The regulatory structure for district planning typically rests on specific area planning. These plans often occupy a separate section within zoning codes and have detailed maps and infrastructure plans. Financing for districts is complex. For redevelopment, redevelopment agencies usually oversee special financing through tax-increment financing. Impact fees can pay for new development, though "community financing districts," or Mello-Roos districts (see http://www.mello-roos.com/pdf/mrpdf.pdf), are increasingly used to pay for construction, operation and maintenance. Note that Mello-Roos districts can also be formed for redevelopment districts, though the more common application is for new development.

Issues

H1. *LID requirements are often written to apply to individual projects, which results in uneven application*
LID is often defined as a site-level approach, and as such, many LID regulations set one uniform performance standard across all "projects" that are part of a "common development plan." Developers of large greenfields projects have leeway in arranging lots and open space to meet the performance standard. For example, if a new development must be limited to no more than 10 percent impervious cover, individual home sites need not meet this requirement as long as the overall development plan has less than 10 percent cover. However, for redevelopment, most projects are individual sites with little or no space or flexibility for BMP design. This creates a situation where a large greenfield project allows flexibility as a common development plan, but redevelopment must meet the entire performance standard within the site boundaries.

H2. *Research on district-level LID is limited*
Most research on LID efficacy has been conducted on individual sites. The most robust data for a subdivision, from the Jordan Cove National Nonpoint Source Monitoring Program project in Connecticut (http://www.jordancove.uconn.edu/), was only recently released.

H3. *LID often designates hydrology as the indicator of environmental impacts*
By their regulatory nature, stormwater rules have the farthest reach into zoning codes. These rules tend to emphasize stormwater peak flow attenuation and volume capture, causing hydrologic performance to outweigh other important environmental issues that are considered in non-regulatory planning documents, such as infill and redevelopment priorities and regional growth patterns that can affect watershed health.

H4. *Suburban-style LID requirements can run counter to the planning, transportation and climate emphasis on compact design*
Meeting strict stormwater performance standards in urban areas can be much more difficult than in open areas with room for swales, infiltration and detention. While LID techniques can decrease costs for greenfields applications, they can pose higher costs for urban developers, since underground vaults are often needed to augment urban green building, streetscape and landscape BMPs to meet performance standards.

H5. *Barriers to redevelopment*
Many barriers stand in the way of redevelopment projects compared to new development in greenfield areas. Developers who undertake redevelopment face different (and almost always more) barriers to redevelop a parcel than those who build new projects in greenfields. Barriers include small, odd-shaped lots, multiple ownership, localized economic blight, outdated infrastructure, increased number of required permits and opposition from existing residents and businesses.

H6. *Redevelopment sites may not offer the same level of receiving water and flood mitigation benefits*
Redevelopment sites differ based on a number of factors that affect LID applicability and efficacy, such as the condition of infrastructure, pollutants of concern, economic development prospects, restoration potential and degree of impervious cover. Most LID requirements apply a blanket threshold and performance level based one or more gross categories (e.g., "new development" or "significant redevelopment"). This blanket approach does not account for constraints at individual redevelopment sites that might limit LID implementation. Strict performance rules might preclude redevelopment of an infill property, despite significant community benefits and the regional benefit of concentrating imperviousness in the urban center and reducing sprawl. Also, some receiving waters in heavily urbanized areas are so impaired that only through redevelopment will there be opportunities to install onsite practices and provide restoration opportunities.

H7. *There is growing belief that subwatershed planning is the best structure for matching BMPs to runoff stressors*
The easiest method for developing regulations is through uniform performance standards that apply equally to all sites within a jurisdiction. However, this may not adequately match BMPs to the development context, economic factors, and specific stormwater problems, especially related to redevelopment and retrofits.

Moreover, the Basin Plans developed by Regional Water Quality Control Boards often do not align with land development plans, Integrated Regional Watershed Management Plans, and NPDES stormwater requirements.

H8. ***General Permits discourage infill***
Construction Activities Stormwater General Permit (or local grading permits) are often inflexible in their stormwater management requirements and as a result discourage infill and redevelopment that could incorporate LID. Many stormwater codes do not encourage infiltration practices because of the perceived potential contamination issues. Also, some developers perceive that LID practices require a much greater area and that they dramatically reduce the buildable area. These misperceptions, along with a lack of recognition that integrated management practices can be shoehorned into required landscaping (i.e., stormwater planters), leads developers to dismiss the LID approach.

Opportunities and Action Items

Legislation

H9. Create legislation directing the SWRCB to more fully develop "Redevelopment Project Area Master Plans" as described in the draft Ventura County Municipal Stormwater Permit.

H10. Introduce legislative language to classify certain affordable housing/infill projects as post-construction BMPs based on their location and configuration in the watershed (according to General Plans and local housing plans). This program might be based on the spreadsheet model such as that developed by Grand Rapids, Michigan, or others, which estimate the impervious cover prevented by directing housing construction to infill areas identified for growth.

H11. Sponsor legislation to require consideration of natural drainage as an initial step within Subdivision Map Act, as well as rules on Master Plans and Specific Area Plans.

Aspirational

H12. Sponsor an analysis of pilot neighborhoods in the LEED-ND program to see if they meet stringent stormwater requirements (for volume, treatment and flow control). Similarly, conduct a survey of LEED-certified buildings to see how they perform relative to stormwater performance standards in permits. Note that this may be somewhat risky if the first generation of buildings fail to meet recent performance standards. For a list of projects in LEED-ND, see http://www.usgbc.org/ShowFile.aspx?DocumentID=2960.

H13. Sponsor a pilot analysis of the stormwater, climate, and other environmental impacts of vacant property (i.e., the runoff volume created and miles traveled past "dead" sites). Develop strategies to encourage redevelopment and improvement of these sites (requiring LID where feasible). Alternatively or in addition, lobby for the establishment of a program, such as a neighborhood improvement initiative, to convert these sites to parks/open spaces that act as "urban sponges" that capture and infiltrate stormwater from adjacent properties.

H14. Sponsor a pilot study to align major water planning documents (e.g., Basin Plan, Integrated Regional Watershed Management Plan) with regional and local requirements (e.g., stormwater permit requirements and local zoning codes) with respect to LID goals and requirements.

H15. Sponsor a study of "community facilities districts" or Mello-Roos, to see how LID would be treated (or constrained) for new development, infill and redevelopment. Investigate the legal structure and issues related to construction, operation and long-term maintenance under such districts. Because the maximum term and maximum bond amount must be specified up front, this research could provide guidance on assessing this cost. Finally, the study should include an analysis of costs for LID versus traditional conveyance systems as they relate to overall costs for the district.

H16. Create a tool similar to "redevelopment ready" districts that pools existing and planned stormwater improvements for multiple redevelopment sites and considers shared drainage and LID for a pre-permitted district. This will help "level the regulatory playing field" between greenfield and infill development sites by allowing more flexibility for placement of stormwater features in the redevelopment district.

Funding

H17. Fund a project to better describe LID techniques based on development settings in California similar to the effort underway within the Congress for New Urbanism based on the "transect." The transect establishes seven transect zones based on intensity of development and urban form. This approach was used to develop new street standards and could serve as a model for stormwater management as well.

H18. Provide funding for localities that are taking a subwatershed approach to matching BMP selection, development context and pollutants of concern.

H19. Provide matching funds for BMPs installed in mixed-use housing projects. Such a program would need to prioritize funding based on multi-objective planning needs, location in a watershed or alignment with redevelopment/housing program needs.

H20. Provide funding to retrofit or supply LID for small-scale, stand-alone businesses or business districts in economically challenged neighborhoods.

Appendix B: LID Policies Outside of California

The following is a brief summary of stormwater- and LID-related policies from other states that have relatively innovative requirements. It also includes a new requirement for federal buildings and a summary of the LEED-ND standards.

CONTENTS

CONNECTICUT

Policy Structure	The Connecticut Clean Water Act (CCWA) of 1967 (P.A. 67-57) launched Connecticut's modern water pollution control program. This statute (Chapter 446k of the Connecticut General Statutes (CGS)) forms the authority for Connecticut's Department of Environmental Protection to regulate discharges to surface waters under both the CCWA and the federal NPDES Program.
Impervious Surface	Stormwater management requirements are triggered for projects one acre or larger or industrial development creating 10,000 square feet or more of impervious cover. Residential projects with fewer than 5 dwelling units are required to manage stormwater only if final impervious cover will exceed 30%. Impervious cover should be measured from the site plan and includes all impermeable surfaces that are directly connected to the stormwater treatment practice such as paved and gravel roads, rooftops, driveways, parking lots, sidewalks, pools, patios and decks.
Infiltration	Developers are required to maintain predevelopment groundwater recharge volume to the MEP through the use of infiltration measures. The groundwater recharge volume (GRV) is the post-development design recharge volume (i.e., on a storm event basis) required to minimize the loss of annual pre-development groundwater recharge. The GRV is determined as a function of annual pre-development recharge for site-specific soils or surficial materials, average annual rainfall volume, and amount of impervious cover on a site.
Innovative Measures	Typical of other states
LID Requirements	No requirements, but the 2004 Connecticut Stormwater Quality Manual contains summary descriptions of small-scale LID practices. The design sections of this Manual contain more detailed guidance for similar, larger-scale stormwater treatment practices such as bioretention, infiltration, and filtration system.
LID Incentives	N/A
Redevelopment	N/A
Links to Language	Statute: http://www.cga.ct.gov/2005/pub/Chap446k.htm Connecticut Stormwater Quality Manual: http://www.ct.gov/dep/cwp/view.asp?a=2721&q=325704

DELAWARE

Policy Structure	The Delaware Sediment and Stormwater Regulations set forth requirements for post-construction stormwater management.
Impervious Surface	N/A
Infiltration	The regulations include guidelines and technical standards for the use of infiltration practices but do not require a particular level of infiltration.
Innovative Measures	The Delaware Sediment and Stormwater Regulations state that the state's overall goal is to utilize stormwater management as a means to minimize water quantity and water quality impacts and to mimic pre-development hydrology to the MEP in regards to the rate, volume, and duration of flow. Projects in certain watersheds (Mill Creek, Little Mill Creek, Red Clay Creek, White Clay Creek, Persimmon Creek, and Shellpot Creek) need to control runoff volume to mimic pre-development land use conditions using recharge, infiltration, and reuse where site conditions allow.
LID Requirements	The state's preferred option for water quality protection is the use of "Green Technology BMPs." Other practices can only be considered after the preferred practices have been eliminated for engineering or hardship reasons as approved by the plan approval agency.
LID Incentives	N/A
Redevelopment	N/A
Links to Language	Delaware Sediment and Stormwater Regulations: http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Stormwater/Regs/SSRegs_4-05.pdf Green Technology Guidance: http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/DURMM_TechnicalManual_01-04.pdf

DISTRICT OF COLUMBIA

Policy Structure	The District of Columbia is working with EPA to revise its NPDES permit to add innovative LID features. These were outlined in a letter to EPA dated November 27, 2009. Permit language had not been finalized at the time of this report's publication.
Impervious Surface	N/A
Infiltration	The regulations include guidelines and technical standards for the use of infiltration practices but do not require a particular level of infiltration.
Innovative Measures	Initiatives include • A tree-planting goal of planting and maintaining 13,500 trees in the manner recommended by the Green Build-Out Model. Current tree planting rate is more than 4,000 trees per year. • Development of a master LID implementation list and construction of 17 LID projects by August 2009. • Conversion of paved or hardened areas throughout the District, such as traffic street medians and large sidewalk areas into green space in the form of pocket parks or green streets. • LID incentives will be extended to include rain barrels and downspout disconnections. • Installation of approximately 50 rain gardens and 125 rain barrels and disconnection of 200 downspouts. Review of District properties for feasibility of green roof retrofits. Commitment to include green roofs on new buildings and major renovations where feasible.

DISTRICT OF COLUMBIA

LID Requirements	N/A
LID Incentives	The District plans to develop legislation to establish tax credits or other incentives programs for installation of green roofs on non-governmental buildings.
Redevelopment	N/A
Links to Language	Letter of agreement sent from the District to EPA outlining new LID measures (and other changes to their NPDES permit requirements): http://www.epa.gov/reg3wapd/npdes/dcms4.htm

MARYLAND

Policy Structure	The state recently adopted the Stormwater Management Act of 2007 that requires that Environmentally Sensitive Design (ESD), which is similar to LID, be implemented to the MEP. The Act also specifies the practices considered to be ESD. Previously, ESD had been encouraged through stormwater credits (see LID incentives). The purpose and scope of the previous (adopted in 1983) stormwater regulations (Code of Maryland Regulations 26.17.02,) states that "the primary goal of the State and local stormwater management programs is to maintain after development, as nearly as possible, the predevelopment runoff characteristics." Under the state stormwater regulations, all counties are required to adopt stormwater ordinances. The stormwater regulations specify minimum requirements for the county stormwater ordinances. The stormwater design manual interprets the stormwater regulations and provides guidelines and credits towards compliance.
Impervious Surface	From 2000 SW Design Manual page 1.13: Performance Standard 1: Site designs shall minimize the generation of stormwater and maximize pervious areas for stormwater treatment.
Infiltration	Recharge volume required as part of BMP design. The goal of this requirement is to maintain existing or predevelopment recharge rates.
Innovative Measures	Typical of other states
LID Requirements	The 2007 Act is likely to result in LID-related requirements.
LID Incentives	From page 5.17 of 2000 Stormwater Design Manual: Developments less than 15% impervious can be exempt from structural practices if they employ environmentally sensitive development techniques, which have LID elements including disconnection of rooftop runoff, use of grass swales, and dedication of natural areas. The manual provides other credits under the broader umbrella of Innovative Site Planning.
Redevelopment	From Code 26.17.02.05: Reduce existing imperviousness by 20%, or provide water quality treatment for 20% of site's imperviousness, or use a combination of imperviousness reduction and water quality treatment equal to 20%, or implement a locally approved practical alternative (e.g., fees, off-site implementation, watershed or stream restoration or retrofitting).
Links to Language	Stormwater Management Act of 2007: http://mlis.state.md.us/2007RS/chapters_noln/Ch_121_sb0784T.pdf

MASSACHUSETTS

Policy Structure	EPA is responsible for issuing stormwater general permits for construction sites disturbing more than one acre under the NPDES General Permit for Stormwater Discharges from Construction Activities. Although EPA is issuing authority, the MADEP reviews the conditions of each permit, certifies the program unconditionally, or with specific conditions according to requirements of Section 401 of the Federal CWA. In addition to the EPA NPDES requirements, the MADEP has state standards for stormwater discharges which are enforced through different MADEP regulations, including, but not limited to, the Mass. Wetlands Protection Act regulations (310 CMR 10.00), Mass. 401 Water Quality Certification regulations (314 CMR 9.00), and Mass. Surface Water Quality Discharge Standards (314 CMR 3.00 and 4.00).
Impervious Surface	N/A
Infiltration	From the Stormwater Management Policy Handbook: "Recharge must be provided to offset the recharge lost due to site development to the maximum extent practicable and determined using the existing (pre-development) soil conditions [according to hydrologic soil group]."
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A
Redevelopment	From the Stormwater Management Policy Handbook: Redevelopment of previously developed sites must meet the Stormwater Management Standards to the maximum extent practicable. However, if it is not practicable to meet all the Standards, new (retrofitted or expanded) stormwater management systems must be designed to improve existing conditions. Definition -- Redevelopment projects include: Maintenance and improvement of existing roadways, including widening less than a single lane, adding shoulders, and correcting substandard intersections and drainage, and repaving; and Development, rehabilitation, expansion, and phased projects on previously developed sites, provided the redevelopment results in no net increase in impervious area.
Links to Language	SW Management Handbooks and other documents: http://www.mass.gov/dep/water/laws/policies.htm#storm

NEW JERSEY

Policy Structure	Stormwater management requirements are specified in the New Jersey Administrative Code (NJAC), Title 7, Chapter 8 Stormwater Management. Major developments (defined as disturbing one or more acres of land or increasing impervious surface by one-quarter acre or more) are required to comply with the stormwater management rules. When municipalities, counties, or regional governments develop stormwater management plans, they must use the stormwater rules as minimum standards.
Impervious Surface	*7:8-5.3 Nonstructural stormwater management strategies* requires that standards be met using nonstructural practices to the MEP, including minimizing and disconnecting impervious surface.
Infiltration	The state requires that developers demonstrate through hydrologic and hydraulic analysis that (1) the site and its stormwater management measures maintain 100 percent of the average annual preconstruction groundwater recharge volume for the site, or (2) that the increase of stormwater runoff volume from pre-construction to post-construction for the 2-year storm is infiltrated. This groundwater recharge requirement does not apply to

NEW JERSEY

	projects within the “urban redevelopment area,” or to projects subject to restrictions related to industrial uses and other land uses producing potentially high pollutant concentrations that could impact ground water quality; also see exemptions under 7:8-5.2d.
Innovative Measures	Typical of other states
LID Requirements	*7:8-5.3 Nonstructural stormwater management strategies* requires, to the maximum extent practicable, that performance standards (N.J.A.C. 7:8-5.4 and 5.5) be met by incorporating nonstructural stormwater management strategies into the design that: • Protect areas that provide water quality benefits or areas particularly susceptible to erosion and sediment loss. • Minimize impervious surfaces and break up or disconnect the flow of runoff over impervious surfaces. • Maximize the protection of natural drainage features and vegetation. • Minimize the decrease in the time of concentration from pre-construction to postconstruction. • Minimize land disturbance including clearing and grading. • Minimize soil compaction. • Provide low-maintenance landscaping that encourages retention and planting of native vegetation and minimizes the use of lawns, fertilizers and pesticides. • Provide vegetated open-channel conveyance systems discharging into and through stable vegetated areas. The State has developed a Nonstructural Strategies Point System to assess whether developers have implemented nonstructural controls to the MEP. Alternative compliance is available with justification. Any land area used as a non structural stormwater management measure to meet the performance standards in N.J.A.C. 7:8-5.4 and 5.5 shall be dedicated to a government agency, subjected to a conservation restriction filed with the County Clerk's office, or subject to Department approved or equivalent restriction that ensures that measure or an equivalent stormwater management measure approved by the reviewing agency is maintained in perpetuity.
LID Incentives	N/A
Redevelopment	Urban redevelopment areas are exempt from recharge requirements. For redevelopment, the water quality provisions of the Stormwater Management rules only apply if the impervious surface onsite increases by at least 0.25 acres.
Links to Language	Stormwater Management Rule Related Information: http://www.state.nj.us/dep/watershedmgt/rules.htm Stormwater Management Rule: N.J.A.C. 7:8 text: http://www.nj.gov/dep/rules/adoptions/2004_0202_watershed.pdf New Jersey Stormwater Best Management Practices Manual: http://www.njstormwater.org/bmp_manual2.htm Nonstructural Strategies Point System Information: http://www.nj.gov/dep/rules/adoptions/2004_0202_watershed.pdf

OHIO

Policy Structure	In Ohio, responsibility for regulating storm water is held by both local and state authorities. Locally, municipalities, townships and counties all have authority to regulate storm water. Ohio EPA, authorized by the regulations at Chapter 6111 of the Ohio Revised Code (ORC), administers the state regulations that require storm water permits for construction sites. These requirements established the basis of the permit requirements contained in the 2003 Ohio Environmental Protection Agency General Permit for Storm Water Discharges Associated with Construction Activity under the National Pollutant Discharge Elimination System. Draft permits specific to portions of the Olentangy River watershed and portions of the Big Darby Creek Watershed are in development. In addition to the rules and general permit, Ohio specifies stormwater performance and design criteria and sediment and erosion control standards in the 2006 Rainwater and Land Development Manual. Ohio also specifies stormwater control standards in the 1980 Ohio Stormwater Control Guidebook.
Impervious Surface	N/A
Infiltration	N/A
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A
Redevelopment	Under General NPDES permit requirements in Appendix of 2006 manual: Redevelopment projects are required to either reduce the existing, pre-construction impervious area of the site by 20%, or capture and treat 20% of VWQ. Linear projects, which do not creation new impervious surfaces, are exempt from post-construction stormwater management requirements, although they are required to minimize the number and width of stream crossings.
Links to Language	Ohio Revised Code Chapter 6111: http://codes.ohio.gov/orc/6111 Rainwater and Land Development Manual: http://www.dnr.state.oh.us/default/water/rainwater/default/tabid/9186/Default.aspx

PENNSYLVANIA

Policy Structure	The Pennsylvania Storm Water Management Act of 1978 (Act 167) provides the legislative basis for statewide stormwater management. Stormwater management plans must be developed by the respective counties in a given watershed and be implemented by the affected municipalities through the adoption of stormwater ordinances. Pennsylvania provides design and review guidelines for stormwater management in its 2006 Pennsylvania Stormwater Best Management Practices Manual.
Impervious Surface	N/A
Infiltration	Strongly encouraged in the stormwater manual
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A

PENNSYLVANIA

Redevelopment	Though not required, the stormwater manual recommends the following guideline: 20 percent of existing impervious area, when present, shall be considered meadow (good condition) in the model for existing conditions for redevelopment. Ch 7 of the Stormwater manual provides guidelines for Brownfield redevelopment.
Links to Language	Pennsylvania Stormwater Management Act: http://www.dep.state.pa.us/dep/deputate/watermgt/wc/Subjects/StormwaterManagement/StormwaterMgmtAct.pdf Pennsylvania Stormwater Best Management Practices Manual and related documents: http://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/stormwatermanagement/default.htm

RHODE ISLAND

Policy Structure	The State of Rhode Island recently passed An Act Relating to Towns and Cities—Establishing the Smart Development for a Cleaner Bay Act of 2007. An updated stormwater design manual, which will incorporate these requirements, is under development. These requirements will apply to any development previously subject to stormwater review, including development within MS4s under NPDES Phase I and II jurisdiction. In addition, the Coastal Resources Protection Council administers the Special Area Management Plans (SAMPs) that include more stringent stormwater and buffer requirements. The Urban Coastal Greenways Policy applies to the cities of Cranston, East Providence, Pawtucket, and Providence.
Impervious Surface	N/A
Infiltration	Maintain pre-development groundwater recharge and infiltration on site to the MEP.
Innovative Measures	Typical of other states
LID Requirements	The state requires that low impact-design techniques be used as the primary method of stormwater control to the MEP. Under the Urban Coastal Greenways Policy, development plans must be reviewed by a professional who has completed an LID training course and has received an LID Master Design Certificate. The draft stormwater manual sets Minimum Standard 1: Nonstructural and Small-Scale Upland Management, which states that nonstructural and small-scale upland management designs must be used to the fullest extent practicable in order to reduce the generation of the water quality volume. It also requires that structural control use be avoided where the water quality volume cannot be managed via nonstructural and small-scale practices (i.e., pollution hot spots).
LID Incentives	The volume required for the permanent pool of a wet pond can be reduced if rooftop runoff is infiltrated on-site. This procedure allows rooftops to be subtracted from total impervious areas, thus reducing the total amount of runoff routed to the permanent pool. Infiltration of rooftop runoff should be restricted to residential buildings or other buildings that do not have air pollution, venting, cooling, or heating equipment located on the roof.
Redevelopment	Redevelopment appears to be treated the same as new development, where only the increase in disturbance and imperviousness is required to be treated.
Links to Language	An Act Relating to Towns and Cities—Establishing the Smart Development for a Cleaner Bay Act of 2007: http://www.rilin.state.ri.us/BillText07/SenateText07/S0808Aaa.pdf Draft Rhode Island Stormwater Design & Installation Standards Manual, Chapter 4—Nonstructural and Small-Scale Upland Management: http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/pdfs/upman.pdf

VERMONT

Policy Structure	Vermont Statues Annotated (VSA) Title 10 § 1264 authorizes the creation of state stormwater permits. Chapters 18 and 22 of the Environment Protection Rules regulate the discharge of post-construction stormwater. State post-construction stormwater standards are specified in one of two general permits depending upon the condition of the receiving water – General Permits 3-9010 and 3-9015. The Vermont Stormwater Management Manual Volumes 1 and 2 describe regulatory requirements and technical guidance, respectively.
Impervious Surface	For new development and applicable redevelopment, either (a) the existing impervious surface shall be reduced by 20% or (b) a stormwater treatment system shall be designed to capture and treat 20% of the water quality volume from the existing impervious area or (c) a combination of (a) and (b) can be used such that, when combined, a minimum 20% reduction/treatment is achieved.
Infiltration	According to the Stormwater Manual Volume I, the average annual recharge rate for the prevailing hydrologic soil group(s) shall be maintained in order to preserve existing water table elevations.
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	Stormwater credits are offered for the use of: • Natural Area Conservation • Disconnection of Rooftop Runoff • Disconnection of Non-Rooftop Runoff • Stream Buffers • Grass Channels • Environmentally Sensitive Rural Development
Redevelopment	Impervious surface and water quality treatment requirements apply to the portion of existing impervious surface that is redeveloped; the existing impervious surface only needs to comply with any previous permit requirements.
Links to Language	Stormwater Management Rule for Unimpaired Waters: http://www.vtwaterquality.org/stormwater/docs/sw_rule-unimpaired.pdf Stormwater Management Rule for Impaired Waters: http://www.vtwaterquality.org/stormwater/docs/sw_rule-impaired.pdf The Vermont Stormwater Management Manual Volume 1: http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf

VIRGINIA

Policy Structure	Stormwater management standards can be found at erosion and sediment control law [Title 10.1, Chapter 5, Article 4] and regulations [4VAC50-30] as amended by the Virginia General Assembly in July 2006. These rules establish the requirements for the state and local erosion and sediment control and storm water management programs that regulate land-disturbing activity greater than 10,000 square feet. The Chesapeake Bay Preservation Area Designation and Management Regulations [9 VAC 10-20-10 et seq.] (also known as the Bay Act), adopted in 1990 and amended in December 2001, regulate development impacts, including storm water management, within the Chesapeake Bay watershed. The Virginia Department of Environmental Quality and Department of Conservation and Recreation jointly administer the regulations. The Department of Conservation and Recreation administers the resource protection and management area regulations.

VIRGINIA

Impervious Surface	Performance-based criteria are based on a site's pre-project impervious cover compared to the average impervious cover for that land use. More stringent pollutant controls are required if the proposed development is expected to increase impervious cover over the average cover for that land use. Development is required to minimize impervious area in Resource Management Areas.
Infiltration	N/A
Innovative Measures	Typical of other states
LID Requirements	§ 10.1-603.4 of The Virginia Soil and Water Conservation Board is required by state law to: "Encourage low impact development designs, regional and watershed approaches, and nonstructural means for controlling stormwater."
LID Incentives	N/A
Redevelopment	Redevelopment is allowed in Resource Protection Areas, but no increase in imperious cover is allowed. Under Virginia Stormwater Management Regulations, local governments must enact ordinances that require redevelopment, as well as new development, to control and treat stormwater runoff beyond pre-development conditions.
Links to Language	Virginia Stormwater Management Law: http://www.dcr.virginia.gov/soil_&_water/documents/vaswmlaw.pdf Virginia Stormwater Management Regulations: http://www.dcr.virginia.gov/soil_&_water/documents/vaswmregs.pdf Virginia Stormwater Management Handbook: http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml#pubs

WISCONSIN

Policy Structure	State Statute 281.16 (2) (a) authorizes the Wisconsin Department of Natural Resources (WDNR) to promulgate water quality performance standards. Under this law, WDNR established Chapter NR 151 of the state code, which contains runoff pollutant performance standards.
Impervious Surface	N/A
Infiltration	Requirements to infiltrate to the MEP a percentage of the predevelopment runoff volume; Residential 90%; Non-residential 60% or 10% of the 2-yr, 24-hour event. As a cap, no more than 2% of the site is required as an effective infiltration area. Some exemptions apply.
Innovative Measures	Typical of other states
LID Requirements	N/A
LID Incentives	N/A
Redevelopment	For all redevelopment and infill under 5 acres, BMPs are required to control to the MEP 40% of the total suspended solids that would normally run off the site based on an average annual rainfall. Infill occurring 10 or more years after Oct. 2002 is required to meet the new development standard of 80% TSS.
Links to Language	State Code Chapter NR 151—Runoff Management: http://www.legis.state.wi.us/rsb/code/nr/nr151.pdf

FEDERAL GOVERNMENT

The "Energy Independence and Security Act of 2007," which was signed into law December 19, 2007, contains a provision in Title IV, Energy Savings in Building and Industry, Subtitle C, High Performance Federal Buildings:

Sec. 438. Storm Water Runoff Requirements for Federal Development Projects.

The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

This provision requires all Federal development and redevelopment projects with a footprint above 5,000 square feet to achieve predevelopment hydrology to the "maximum extent technically feasible." This standard may differ from the MEP standard set forth in stormwater regulations.

This provision will likely result in much more focus on LID ,with more companies interested in learning how to develop and apply "design, construction, and maintenance strategies" that preserve pre-development technology, so that they can maintain existing, or obtain new, Federal government construction contracts. Also, the establishment of these requirements for Federal facilities is expected to have the effect of "mainstreaming" LID BMPs for non-federal facilities.

LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN NEIGHBORHOOD DEVELOPMENT STANDARDS

The U.S. Green Building Council develops and maintains the Leadership in Energy and Environmental Design (LEED) rating systems that promote energy conservation and sustainable design within the building industry. USGBS formed a partnership with the Congress for the New Urbanism and the Natural Resources Defense Council to develop a LEED rating system at the neighborhood scale. A pilot version of the LEED for Neighborhood Development (LEED-ND) Rating System has been released by the partnership[17] that seeks to promote neighborhood designs that minimize resource consumption and pollution and achieve sustainability. The pilot program will be used to test and refine the standards before they are released for industry-wide application. Of the 238 pilot projects selected for the program, 40 projects are located in California.[18]

The ND standards are divided into four categories:

- The **Smart Location and Linkage (SLL)** category evaluates how a development's location impacts urban sprawl, resource use, and environmental impacts.
- The **Neighborhood Pattern and Design (NPD)** category evaluates the layout of the neighborhood and the extent that each use provides social and environmental benefits.
- The **Green Construction and Technology (GTC)** category evaluates the construction process and the design of the structures within the neighborhood, seeking to reduce environmental contamination and site disturbance while promoting resource conservation and energy efficiency.
- **Innovation and Design Process (IDP)** category provides credit to neighborhood projects that achieve greater innovation than what is required or credited in the rating system. This category also gives credit for the involvement of an accredited professional.

Under each category, the rating system specifies prerequisites and credits. Prerequisites are required before an applicant is eligible for the certification, and credits provide the applicant with points towards different certification levels (certification, silver, gold, and platinum).

[17] USGBC, CNU, and NRDC. 2007. Pilot Version LEED for Neighborhood Development Rating System. A Partnership of the U.S. Green Building Council (USGBS), the Congress for New Urbanism (CNU), and the Natural Resources Defense Council (NRDC). http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148.

[18] USGBC, CNU, and NRDC. 2007b. LEED for Neighborhood Development Registered Pilot Project List. A Partnership of the U.S. Green Building Council (USGBS), the Congress for New Urbanism (CNU), and the Natural Resources Defense Council (NRDC). https://www.usgbc.org/ShowFile.aspx?DocumentID=2960.

LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN NEIGHBORHOOD DEVELOPMENT STANDARDS

Standards that Directly Contribute to Stormwater Management

The ND standards contain a number of prerequisites and credits related to stormwater management. The following paragraphs describe each prerequisite or credit in more detail.

- **SLL Prerequisite 4: Wetland and Waterbody Conservation:** An applicant meets this standard if the site includes no land within 100 feet of wetlands or waterbodies. The standard can also be met if 1) the site is located on a previously developed site; and 2) any wetland or waterbody impacts are compensated through on-site or off-site restoration. For sites that are not previously developed and contain wetlands or waterbodies, the rating system limits the percent of on-site impacts allowed according to the street grid density of the development. The applicant is also required to retain at least 90 percent of the average annual rainfall or 1 inch of rainfall from 75 percent of the development footprint within the impacted area. Retention methods must infiltrate, reuse, or provide for the evapotranspiration of the rainfall amount. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.
- **SLL Prerequisite 6: Floodplain Avoidance:** Similar to the above prerequisite, the Floodplain Avoidance standard is met if the site does not contain any land within the 100-year floodplain. The standard is also met if the site is located on an infill or previously developed site and the National Flood Insurance Program (NFIP) requirements are followed when developing land within the 100-year floodplain. For sites that do not meet these conditions, the standard can only be met if land within the 100-year floodplain is not developed. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.
- **SLL Credit 8: Steep Slope Protection:** This standard provides credit for either avoiding development on steep slopes or restoring vegetation to previously developed steep slopes. Credit is provided according the severity of the slopes and the proportion of steeped sloped land that is protected or restored. An exemption is included for steep slopes that are isolated by more than 30 feet from other steeply sloped areas. This standard contributes to stormwater management by reducing the runoff and erosion generated on steep slopes during storm events.
- **SLL Credits 9, 10 and 11: Habitat or Wetland Conservation:** These standards provide credits for habitat or wetland conservation on the development site. To receive credit under SLL Credit 9, the applicant must inquire with a state's Natural Heritage program and other wildlife or fish agencies to determine whether significant habitat exists on the development site. The applicant must protect in perpetuity the habitat and an appropriate buffer, as delineated by a qualified professional. For previously developed sites, the applicant can receive credit for using native plants for 90 percent of the site vegetation and refraining from the use of invasive plants. The standard also provides credit for conserving wetlands and waterbodies and planning buffers around the development footprint to protect water quality, habitat, and hydrologic functions. SLL Credit 10 provides credit for habitat or wetlands restoration on an area equal to or greater than 10 percent of the development. Invasive species removal is required to achieve credit for restoration. SLL Credit 11 provides credit for developing a long-term management plan for on-site habitat, wetlands, or waterbodies. Through the conservation of habitat and wetland areas, these standards contribute to stormwater management by preserving pervious areas, natural drainage paths, and other areas that maintain pre-development hydrology and water quality functions.
- **NPD Credit 6: Reduced Parking Footprint:** This standard provides credit for limiting surface parking and using multistory or underground parking, carpool spaces, and bicycle parking. To receive credit, the applicant must limit surface parking facilities to no more than 20 percent of the total development footprint. The intent of the credit is to reduce the negative social and environmental impacts of parking areas. This standard contributes to stormwater management through reduction of impervious surface.
- **GCT Credit 6: Minimize Site Disturbance through Site Design:** Under this standard, an applicant can receive credit for preserving, in perpetuity, undeveloped land, including tree canopy, native vegetation, and pervious surfaces. The credit award depends on the extent of pervious development on the site and the planned density of the site. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.

LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN NEIGHBORHOOD DEVELOPMENT STANDARDS

- **GCT Credit 7: Minimize Site Disturbance during Construction:** This standard provides credit for establishing limits of disturbance for natural areas or preserving significant trees on the site. The standard contains specific distances required for the limits of disturbance as well as the type of trees that qualify for preservation credit. This standard contributes to stormwater management by reducing the impact to the natural hydrology and water quality functions of a development site.
- **GCT Credit 9: Stormwater Management:** This standard provides credit for applicants who implement a comprehensive stormwater management plan. The plan must effectively retain a specified amount of rainfall from the project's development footprint. The rainfall amounts vary by the humidity of the watershed's climate; developments in more humid watersheds are required to retain a greater rainfall amount than more arid watersheds. The applicant can receive from 1 to 5 points depending on how much rainfall is retained. Retention methods must infiltrate, reuse, or provide for the evapotranspiration of the rainfall amount. This standard contributes to stormwater management by reducing the stormwater runoff generated by development.

Additional Standards that Contribute to Stormwater Management

In addition to the above standards, the ND rating system contains several prerequisites and credits that more directly target smart growth and air quality goals but contribute to stormwater management in the process. Many of the credits relating to smart growth may contribute to reduced impervious surface, provided that undeveloped land is conserved in the process. Several credits promote infill and brownfield development, which decreases pressure on undeveloped land and ultimately leads to reduced stormwater impacts. Several standards promote compact development, which could lead to improved stormwater management if stormwater is controlled and treated and the compact development conserves undeveloped land in other locations. The ND standards that target automobile dependency could lead to reducing transportation-related pollutant loading as well.

Appendix C: Key Elements of Progressive Ordinances

DEVELOPMENT OF STORMWATER MANAGEMENT GOALS AND OBJECTIVES

In the case study areas, often draft goals and objectives were used to help develop stormwater management criteria and craft "scenarios" to test in watershed modeling and/or pilot-project development. Local advisory groups or boards were used to help draft the preliminary goals and objectives.

Clearly, different communities have different goal and objective statements depending on local circumstances and requirements. For example, some communities may only wish to meet Phase II requirements, while others may set higher goals than state minimum requirements due to local concerns, such as drinking water supply or habitat protection. Following are examples of goals and objectives statements from several of the case study communities. Examples 1 and 2 draw on general police powers granted local governments: protect, maintain and enhance the public health, safety, and welfare. Example 3 goes further to establish a local non-degradation goal. Finally, Example 4 sets the highest goal: maintaining and improving existing water quality.

Example Goals Statements

Example 1 (modified from Town of Chapel Hill's Land Use Management Ordinance)

"The purpose of this section is to establish minimum stormwater management requirements and controls to protect and safeguard the general health, safety, and welfare of the public residing in watersheds within this jurisdiction. This ordinance seeks to meet that purpose through the following objectives:"

Example 2 (from Charlotte-Mecklenburg Post-Construction Storm Water Ordinance, draft under public review)

"The purpose of this ordinance is to protect, maintain and enhance the public health, safety, environment and general welfare by establishing minimum requirements and procedures to control the adverse effects of increased post-development storm water runoff and non-point source pollution associated with new development and redevelopment. It has been determined that proper management of construction related and post-development storm water runoff will minimize damage to public and private property and infrastructure, safeguard the public health, safety, and general welfare, and protect water and aquatic resources."

Example 3 (modified from the Town of Huntersville Water Quality Ordinance)

"The purpose of this regulation is to establish stormwater management requirements and controls to prevent surface water quality degradation to the extent practicable in the streams and lakes within the Town Limits and Extraterritorial Jurisdiction of Huntersville and to protect and safeguard the general health, safety, and welfare of Huntersville's residents. This regulation seeks to meet this purpose by fulfilling the following objectives:"

Example 4 (modified from the City of Portland's Stormwater Management Ordinance)

"The purpose of this Stormwater Management Ordinance is to provide for the effective management of stormwater and drainage and to maintain and improve water quality in the watercourses and waterbodies within and leaving the City. This ordinance seeks to meet that purpose through the following policies and standards:"

Example Objectives Statements

Example 1 – City of Charlotte-Mecklenburg County (Note all municipalities within Mecklenburg County worked jointly with the County to develop a unified post-construction ordinance, which is currently under public review.)

"This ordinance seeks to meet its general purpose through the following specific objectives and means:

1. Establishing decision-making processes for development that protect the integrity of watersheds and preserve the health of water resources.
2. Requiring that new development and redevelopment maintain the pre-development hydrologic response in their post-development state as nearly as practicable for the applicable design storm in order to reduce flooding, streambank erosion, non-point and point source pollution and increases in stream temperature, and to maintain the integrity of stream channels and aquatic habitats.
3. Establishing minimum post-development storm water management standards and design criteria for the regulation and control of storm water runoff quantity and quality.
4. Establishing design and review criteria for the construction, function, and use of structural storm water control facilities that may be used to meet the minimum post-development storm water management standards.
5. Encouraging the use of better management and site design practices, such as the preservation of greenspace and other conservation areas, to the maximum extent practicable.
6. Establishing provisions for the long-term responsibility for and maintenance of structural and nonstructural storm water BMPs to ensure that they continue to function as designed, are maintained appropriately, and pose no threat to public safety.
7. Establishing administrative procedures for the submission, review, approval and disapproval of storm water management plans, for the inspection of approved projects, and to assure appropriate long-term maintenance."

Example 2 – (adapted from Town of Huntersville Water Quality Ordinance and from Town of Chapel Hill Land Use Management Ordinance)

a. "Minimize increases in storm water runoff from development or redevelopment in order to reduce flooding, siltation and streambank erosion, and maintain the integrity of stream channels;

b. Minimize increases in nonpoint source pollution caused by stormwater runoff from development or redevelopment that would otherwise degrade local water quality;

c. Minimize the total volume of surface water runoff that flows from any specific site during and following development in order to replicate pre-development hydrology to the maximum extent practicable;

d. Reduce stormwater runoff rates and volumes, soil erosion and nonpoint source pollution, to the extent practicable, through stormwater management controls (BMPs) and ensure that these management controls are properly maintained and pose no threat to public health or safety; and

e. Meet the requirements of the National Pollution Discharge Elimination System (NPDES) Storm Water Permit and other requirements as established by the Clean Water Act."

Example 3 – Policies and Standards (adapted from City Code, City of Portland, Oregon)

The City of Portland code lists policies rather than objectives.

a. "Stormwater shall be managed as close as is practicable to development sites, and stormwater management shall avoid a net negative impact on nearby streams, wetlands, groundwater, and other waterbodies. All local, state, and federal permit requirements related to implementation of stormwater management facilities must be met by the owner/operator prior to facility use. Surface water discharges from onsite facilities shall be conveyed via an approved drainage facility.

b. The quality of stormwater leaving the site after development shall be equal to or better than the quality of stormwater leaving the site before development, as much as is practicable.

c. The quantity of stormwater leaving the site after development shall be equal to or less than the quantity of stormwater leaving the site before development, as much as is practicable."

As shown in the above examples, the goal or purpose statement is very general. The objectives provide more detail on what implementation of the ordinance is intended to accomplish. The objectives can be regulatory based (e.g., meet Phase II requirements), resource based (e.g., minimize increases in nonpoint source pollution), or both. Importantly, the goals and objectives set the stage for selecting appropriate performance standards and criteria, and for encouraging LID.

Performance Criteria Encouraging LID Techniques

The examples below reflect key elements of progressive stormwater programs' approaches to using performance criteria to encourage LID.

Example 1 – Huntersville, North Carolina's Performance Standards

The Town of Huntersville is a developing community of about 35,000 residents and part of a regional commuter rail system planned for the metropolitan area. The town has experienced a rapid conversion from a farming community to a developing residential and commercial area. In February 2002, The Town of Huntersville adopted a moratorium on the approval of new major development plans. The moratorium allowed the town to focus on writing zoning ordinance amendments that would protect the Town's rural character and open space while allowing for high density and mixed-use development in centralized locations. Huntersville's updated zoning ordinance established 15 zoning districts.

Huntersville protects open space in the rural residential, transitional residential, and traditional neighborhood-rural districts. In these districts, permitted density depends on the amount of open space preserved. The transitional zoning district doubles the density allowed per open space percentage compared to the rural districts, but a minimum of 25 percent open space is required

The updated ordinance provides incentives for developers to dedicate permanent conservation easements. Termed conservation subdivisions, these developments will preserve the rural appearance of the land when viewed from public roads and adjacent properties. In turn, the developments are exempt from lot frontage, sidewalk, planting, and other requirements. The preservation of existing, mature trees is emphasized in the conservation easement provisions.

The Huntersville zoning districts include several mixed-use and residential districts designed to encourage quality of life and convenient access to employment and services. These districts include the Neighborhood Residential, Neighborhood Center, Town Center, and Transit-Oriented districts. Automobile-oriented and industrial developments are restricted to other zoning districts so that the Town can develop pedestrian-friendly town and neighborhood centers. These zoning districts were designed to encourage convenient walking distances between residential and commercial uses. Three zones allowing varying development intensity were designated (see Figure A-1).

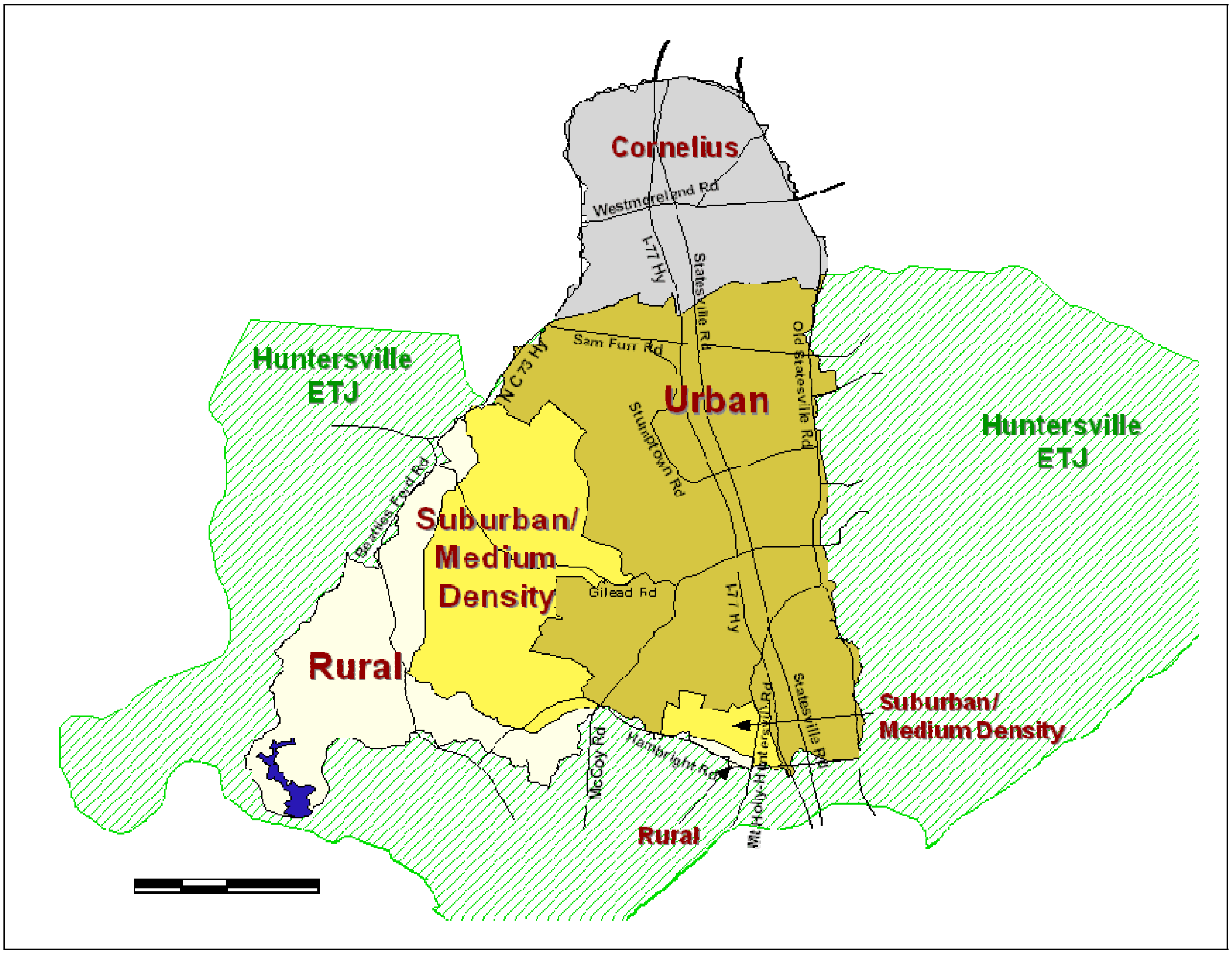

Figure A-1. Town of Huntersville's Development Zones

Huntersville included water quality measures in its ordinance, and adopted a water quality goal of no future degradation. The Town analyzed the water quality and hydrology benefits of alternative performance standards as well as the estimated cost to the landowner or developer in meeting the performance criteria and to build understanding about the cost implications of adopting more protective stormwater requirements in the Town's Ordinance. After that analysis, the Town adopted the following performance standards and required the use of LID in meeting these standards.

a. "All stormwater treatment systems used to meet these performance criteria shall be designed to achieve average annual 85 percent Total Suspended Solids (TSS) removal for the developed area of a site. Areas designated as open space that are not developed do not require stormwater treatment. All sites must employ LID practices to control and treat runoff from the first inch of rainfall.

b. LID practices or a combination of LID practices and conventional stormwater management practices shall be used to control and treat the increase in stormwater runoff volume associated with post-construction conditions as compared with pre-construction (existing) conditions for the 2-yr frequency, 24-hr duration storm event in the Rural and Transitional Zoning Districts. All other zoning districts shall meet this standard for the 1-yr frequency, 24-hr duration event.

c. Where any stormwater BMP employs the use of a temporary water quality storage pool as a part of the treatment system, the drawdown time shall be a minimum of 48 hours and a maximum of 120 hours.

d. Peak stormwater runoff rates shall be controlled for all development above 12 percent imperviousness (for the 2-yr, 24-hr and the 10-yr, 24-hr storm events). The emergency overflow and outlet works shall be capable of safely passing a discharge with a minimum recurrence frequency of 50 years.

e. No one BMP shall receive runoff from an area greater than 5 acres."

The town's Open Space performance standards are shown in Table A-1. Note that both the open space and water quality performance standards vary by planning district to meet the Town's overall smart growth objectives.

To ease overall administration and to ensure accountability, the Town developed a Stormwater BMP Design Manual and a Site Evaluation Tool that developers are required to use in project design and documenting compliance with the performance standards. (See Program Administration for more information on the Site Evaluation Tool).

Table A-1. Open Space and Density Requirements for Huntersville's Rural Residential and Traditional Neighborhood-Rural Zoning Districts

Amount of Open Space Provided	Density Permitted
0% unless tract is within a proposed greenway in which case the greenway shall be designated as open space	0.33 units per Adjusted Tract Acreage
25% - 29.9% Open Space	0.4 units per Adjusted Tract Acreage
30% - 34.9% Open Space	0.6 units per Adjusted Tract Acreage
35% - 39.9% Open Space	0.8 units per Adjusted Tract Acreage
40% - 44.9% Open Space	1.0 unit per Adjusted Tract Acreage
45%+ Open Space	1.2 units per Adjusted Tract Acreage

The performance standards required by the Town of Chapel Hill are similar to the Huntersville standards, with the following exceptions: Chapel Hill requires volume control for the 2-yr, 24-hr storm event throughout its jurisdiction. The stormwater runoff rate is controlled for the 1-, 2-, and 25-yr, 24-hr storm event (rather than the 2-yr and 10-yr storm events). The Town of Chapel Hill encourages rather than requires LID to meet its performance standards.

Each of the programs described above stipulates certain activities or types of development that are exempt from the guidelines and regulations described above. Those regulatory exemptions are as follows:

Town of Huntersville: Any new development, redevelopment or expansions that include the creation or addition of less than 5,000 sq ft of new imperviousness.

Town of Chapel Hill: Single family and two family developments and redevelopments that do not disturb more than 5,000 sq ft of land area, provided they are not part of a larger common development plan, are exempted.

Example 2 – City of Charlotte, NC and Mecklenburg County

The Charlotte-Mecklenburg Post-Construction Storm Water Ordinance (draft under public review) divides the County into five districts, each having unique performance standards. As discussed below, the performance standards necessitate the use of LID in order to meet the standards on site.

One of the first items agreed to by the stakeholders' group helping to guide development of the post-construction ordinance was the need to divide Mecklenburg County into districts. It was decided that a one size fits all approach was not appropriate, but instead districts should be drawn based upon need for protection and other criteria. An example of one of the criteria used was the presence of a federally endangered species in Goose Creek District and the Yadkin-Southeast Catawba District, which resulted in more stringent controls on new development. Areas with a very high percentage of existing development (i.e., the City of Charlotte) resulted in less stringent controls in new development. Figure A-2 shows the configuration of the districts, which were drawn along watershed boundaries. Other factors, such as close proximity to drinking water reservoirs, resulted in more stringent levels of control. Recognizing that certain areas in Mecklenburg County had unique characteristics and needs, the stakeholder group then debated basic criteria that would provide the foundation of the ordinance and meet the goals and objectives. The main categories for new performance standards were:

- Structural Water Quality BMPs: These controls are intended to remove water quality pollutants from stormwater runoff. The ordinance targets Total Phosphorus (TP) and Total Suspended Solids (TSS).
- Stream Buffers: These controls require that areas directly adjacent to streams be set aside as natural areas. Limited disturbance many be allowed depending on the distance from the stream.
- Volume and Peak Control: The controls require that the additional stormwater runoff volume and peak flow rates generated by land development activities be held back and released slowly over time so as to not cause downstream erosion and flooding.
- Open Space Requirements: These controls require that a certain percentage of a developed site be preserved as undisturbed area unless mitigation is provided.

Each District has a unique combination of these controls, depending on the level of protection needed. (See Table A-2, Summary of Performance Criteria for the Charlotte-Mecklenburg Post Construction Ordinance). It is important to note, however, that the performance standard for phosphorus removal (70 percent removal for runoff from the first inch of rainfall) applies to 4 of the 5 districts and necessitates the use of a treatment train approach using LID techniques in order to meet this standard onsite. The TP performance standard was based on an evaluation of streams in the County and loading rates needed to support designated uses (including healthy aquatic communities).

Because meeting the TP performance standard can be quite expensive for developments with high imperviousness (much more expensive on a cost per pound removed basis than developments with lower imperviousness), the Ordinance allows a flexible "buy down" option from 70 percent TP removal to 50 percent removal, and allows the City or County to use the revenue to construct BMP retrofits offsite to "make up the difference" in phosphorus loading. To reduce the cost of meeting the open space requirements, the Ordinance has offsite mitigation and onsite mitigation techniques, as well as payment-in-lieu.

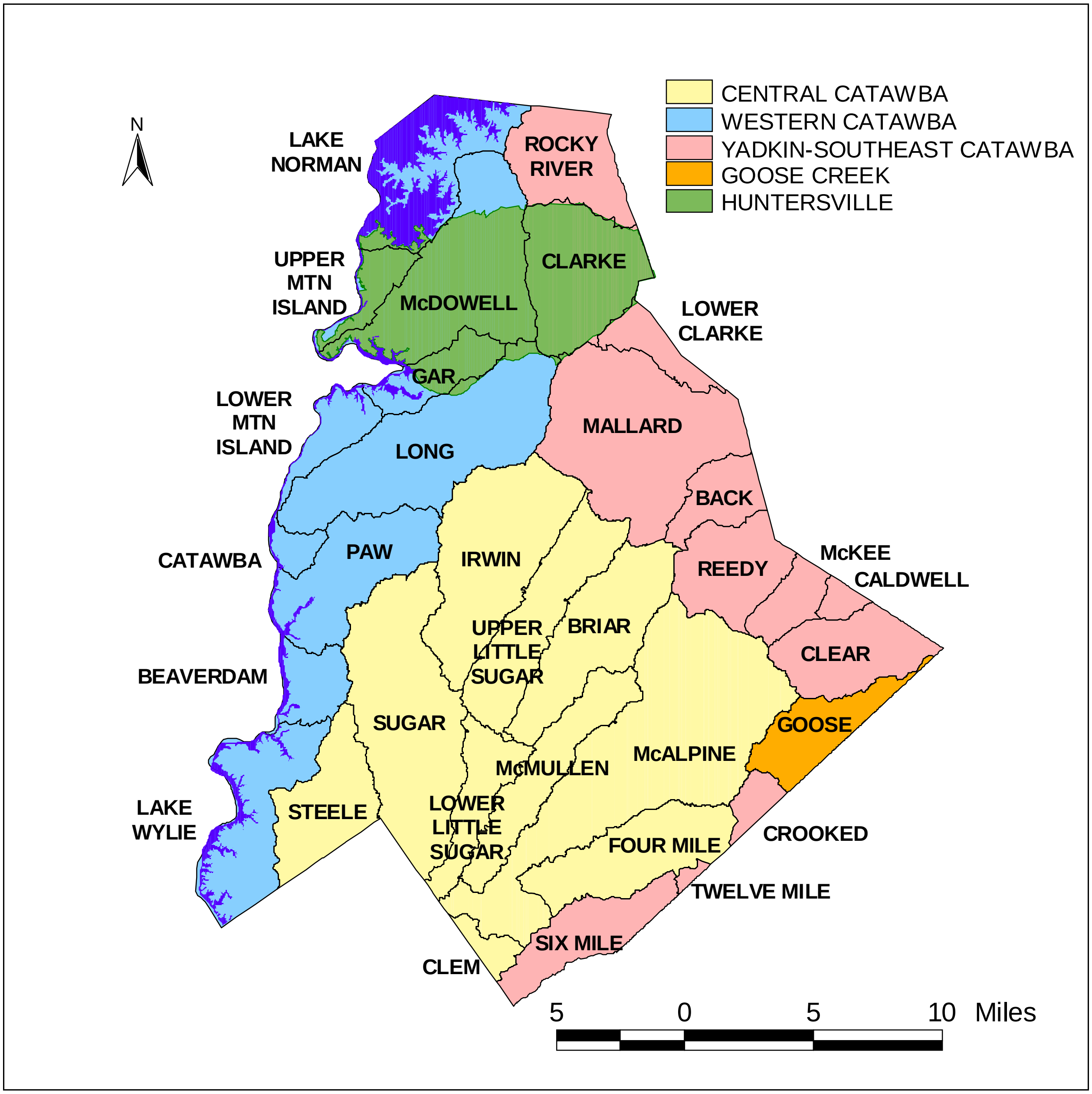

Figure A-2. Watershed Districts for Charlotte Mecklenburg Post Construction Ordinance

Table A-2. Summary of Performance Criteria for the Post-Construction Ordinance

Watershed District	Structural Water Quality BMPs	Buffers(1)	Volume & Peak Control	Open Space Requirements
Central Catawba	>24% BUA requires 85% TSS removal for runoff from 1st inch of rainfall; LID optional	30 ft. no build zone on intermittent and perennial streams draining < 50 acres 35 ft. (2 zones) on perennial streams draining <300 acres 50 ft (3 zones) on streams draining ≥300 acres 100 ft + 50% of floodfringe on streams draining ≥640 acres	Volume (Commercial & Residential): >24% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >24% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms Peak for Commercial: >24% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Open space is undisturbed area <24% BUA = 25% open space ≥24% and <50% BUA = 17.5% open space ≥50% BUA = 10% open space
Western Catawba	>12% BUA requires 85% TSS and 70% TP removal for runoff from 1st inch of rainfall; LID optional; BUA area caps apply in water supply watersheds	30 ft. no build zone on intermittent and perennial streams draining < 50 acres 35 ft. (2 zones) on perennial streams draining <300 acres 50 ft (3 zones) on streams draining ≥300 acres 100 ft + 50% of floodfringe on streams draining ≥640 acres	Volume (Commercial & Residential): >12% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >12% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms Peak for Commercial: >12% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Same as Central Catawba
Yadkin-Southeast Catawba	>10% BUA requires 85% TSS and 70% TP removal for runoff from 1st inch of rainfall; LID optional	50 ft undisturbed forested buffers on intermittent and perennial streams draining < 50 acres 100 ft undisturbed forested buffers plus remainder of floodplain on perennial and intermittent streams draining	Volume (Commercial & Residential): >10% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >10% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Same as Central Catawba

Table A-2. Summary of Performance Criteria for the Post-Construction Ordinance

Watershed District	Structural Water Quality BMPs	Buffers[1]	Volume & Peak Control	Open Space Requirements
		≥ 50 acres	Peak for Commercial: >10% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	
Goose Creek	>6% BUA requires 85% TSS and 70% TP removal for runoff from 1st inch of rainfall; LID optional; 24% BUA cap on single family residential, 50% on all other development	100 ft. undisturbed forested buffer on perennial and intermittent streams draining < 50 acres 200 ft. undisturbed forested buffer plus remainder of floodplain on perennial and intermittent streams draining ≥ 50 acres	Volume (Commercial & Residential): >6% BUA control entire volume for 1-yr, 24-hr storm Peak for Residential: >6% BUA perform a downstream flood analysis to determine whether peak control is needed and if so, for what level of storm frequency (i.e., 10, 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms Peak for Commercial: >6% BUA control the peak for the 10-yr, 6-hr storm **AND** perform a downstream flood analysis to determine whether additional peak control is needed and if so, for what level of storm frequency (i.e., 25, 50 or 100-yr, 6-hr) **OR** if a downstream analysis is not performed control the peak for the 10-yr and 25-yr, 6-hr storms	Same as Central Catawba
Huntersville	For developments with greater than or equal to 5,000 square feet of BUA, install LID practices to achieve 85% TSS removal for runoff from the 1st inch of rainfall; BUA area caps apply in water supply watersheds	30 ft. no build zone on intermittent and perennial streams draining < 50 acres[2] 35 ft. (2 zones) on perennial and intermittent streams draining <300 acres 50 ft. (3 zones) on streams draining ≥300 acres 100 ft. or entire floodplain on streams draining ≥640 acres	Volume: For developments with greater than or equal to 5,000 square feet of BUA, control increase in volume for 1-yr, 24-hr storm or 2-yr, 24-hr storm, depending on zoning district Peak: >12% BUA control 2-yr & 10-yr, 24-hr storm	Varies by zoning district

(1) Water supply watershed buffer requirements apply in the Western and Huntersville districts. These buffers are sometimes more restrictive than the S.W.I.M. buffer requirements, in which case the watershed buffers would apply.

(2) Will require a change to the existing Huntersville Ordinance in order to comply with minimum Phase II Post-Construction rules.

Rockdale County, GA combines the Charlotte-Mecklenburg County and Town of Huntersville approaches. Based on its watershed study, the county established performance standards for new development by planning district:

- *Urban Area.* 56 percent removal TP, 78 percent removal TSS, 57 percent removal Copper. These standards must be met by new developments in the City of Conyers (existing municipal jurisdiction and planned, long-term sewer service area).
- *Suburban/Rural Area*. 52 percent removal TP, 72 percent removal TSS, 51 percent removal Copper. These standards must be met by new developments in the county jurisdiction, excluding the drinking water supply watershed and urban area.
- *Rural Residential (Water Supply Watershed) Area.* 1 unit / 3 acres.

Rockdale County encourages LID in meeting these standards.

Each of the programs described above stipulates certain activities or types of development that are <u>exempt from the guidelines and regulations described above</u>. Those regulatory exemptions are as follows:

- *Charlotte-Mecklenburg, NC.* Residential development that cumulatively disturbs less than one acre and cumulatively creates less than 24% built upon area based on lot size or the lot is less than 20,000 square feet; commercial and industrial development that cumulatively disturbs less than one acre and cumulatively creates less than 24% built upon area based on lot size or the lot is less than 20,000 square feet; redevelopment that disturbs less than 20,000 square feet, does not decrease existing stormwater controls, and renovation costs do not exceed 100% of the tax value of the property; common law vested right established.
- *Rockdale County, GA.* Any development or redevelopment less than 7 percent imperviousness is exempted from enhanced volume control. Otherwise, GA Phase II stormwater control thresholds apply.

Example 3 - Portland, Oregon

The City of Portland's Sewer Development Services Administrative Rules require that the City's Bureau of Environmental Services (BES) review building permits during building plan reviews for compliance with the City's Stormwater Management Manual. Adopted in September 2004, the Stormwater Manual has the following performance criteria.

"The quality of stormwater leaving the site after development shall be equal to or better than the quality of stormwater leaving the site before development, as much as is practicable, based on the following criteria:

a. Water quality control facilities required for development shall be designed, installed and maintained in accordance with the Stormwater Management Manual, which is based on achieving at least 70 percent removal of the Total Suspended Solids from the flow entering the facility for the design storm specified in the Stormwater Management Manual.

b. Land use activities of particular concern as pollution sources shall be required to implement additional pollution controls, including, but not limited to, those management practices specified in the Stormwater Management Manual.

c. Development in a watershed that drains to streams with established Total Maximum Daily Load limitations, as provided under the Federal Clean Water Act, Oregon Law, Administrative Rules, and other legal mechanisms shall assure that water quality control facilities meet the requirements for pollutants of concern, as stated in the Stormwater Management Manual."

d. Note: additional criteria follow related to implementing these criteria onsite or on an offsite facility. Otherwise, there is an option for payment in lieu.

“The quantity of stormwater leaving the site after development shall be equal to or less than the quantity of stormwater leaving the site before development, as much as is practicable, based on the following criteria:

a. Development shall mitigate all project impervious surfaces through retention and onsite infiltration to the maximum extent practicable. Where onsite retention is not possible, development shall detain stormwater through a combination of provisions that prevent an increased rate of flow leaving the site during a range of storm frequencies as specified in the Stormwater Management Manual.

b. The Director may exempt areas of the City from the requirement a. above if flow control is not needed or desirable and if stormwater is discharged to a large waterbody directly through a private outfall or if stormwater is discharged to a waterbody directly through a separated public storm sewer having adequate capacity to convey the additional flow.

c. Any development that contributes discharge to a tributary to the Willamette River shall design facilities such that the rate of flow discharging from water quantity control facilities for up to the two-year storm does not lengthen the period of time the channel sustains erosion-causing flows, as determined by the Bureau. (Note: This criterion is required due to evidence of excessive stream bank erosion and channel erosion in most tributary streams in Portland.)

d. Facilities shall be designed to safely convey the less frequent, higher flows through or around facilities without damage.

“Note: additional criteria follow related to implementing these criteria onsite or on an offsite facility. Otherwise, there is an option for payment in lieu. The City also provided incentives for reduction of stormwater runoff and impervious area through stormwater discounts.

<u>“Regulatory Exemptions:</u>

“Developments less than 15,000 sq.ft. are exempted from detention (devices with orifices); development less than 500 sq.ft. is exempted from retention.”

The City is currently revising its Stormwater Management Manual and will release the updated manual in late fall 2007. The revisions are intended to clarify the intent of the current standards.

Example 4 – Grand Rapids, Michigan

The city of Grand Rapids, Michigan is introducing an analytic method for calculating the amount of stormwater impacts prevented by installation of higher floor area ratios. The rationale for the policy is that, although higher density development will have a greater percentage of impervious area per acre of development, the total impervious area per residence actually will be less. This overall watershed benefit is typically not recognized in site level hydrology assessments.

The runoff reduction of a higher density project is estimated by subtracting from one, the ratio of the site’s actual impervious area (AIsite) divided by the impervious area (AiLD) of a low density development having the same number of units, and converted to a percentage.

Percent Runoff Reduction = (1 – AIsite / AiLD) x 100%

The city established a performance standard of 80 percent reduction of runoff based on the performance of a vegetated roof. The city then used the same 80 percent (80%) runoff reduction as the threshold for the granting of a waiver for high density developments. The city evaluated the typical impervious surface coverage of lower density development, as shown in 0.

Table A-3. Typical Impervious Area Values for Low Density Development Types

Low Density Development Type	Average Impervious Area	Development Unit
Residential	4,700 square feet	Residence
Parking Lot	275 square feet	Park-Loading Space
Office/Commercial	1 square foot	Gross Floor Area

The analysis showed that the reduction rates allow a waiver when the follow intensity is met:

- Residential projects – 38 units/acre (compared to 5 units per acre as the low density complement)
- Parking – 744 spaces per acre or a 5-deck or higher parking structure
- Office/Commercial – Floor area ratio of 5 floors or higher

Note that the analysis did not take into account related offsite public impervious surfaces such as sidewalks, access lanes and street frontage. Because higher density development projects have smaller frontage lengths, the roadway length serving the site is less (Lemoine, to be published October 2007).

Example 5 - San Jose, California

In a 2001 Order to its co-permittees, the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) modified its C.3. regulatory requirements related to new and redevelopment. (The C.3 requirements are contained in the San Francisco Regional Water Quality Board's permit and deal with stormwater treatment).

The 2001 Order required changes to the Urban Runoff Management Plan, including some of the following elements:

- *Performance Standard Implementation.* Use planning and outreach programs to help implement the new requirements.
- *Development Project Approval Process*. Modify project review processes to incorporate new requirements. The order recommended incorporation of :
    - *Site design measures.* Address the generation of excess impervious surface coverage through site and neighborhood planning. Examples cited in the 2001 Order include minimizing land disturbance, minimizing impervious surfaces (e.g., roadway width, driveway area), minimum-impact street design (e.g., neo-traditional street design standards), and parking lot design standards.
    - *Source control measures.* Prevent stormwater pollution by mitigating pollutant loading from certain uses, such as restaurants, automobile services, and landscaping.
    - *Treatment measures.* Integrate measures into site and development plans to infiltrate or filter stormwater.
- *Limitation on Increase of Peak Stormwater Runoff Discharge Rates.* Hydrograph Modification Management Plans (HMMP) was introduced to limit discharge rates. The 2001 Order recognized that certain projects, such as transit villages, may not be able to meet all of the performance standards, but since most transit villages occur in already-developed areas, the redevelopment would be unlikely to change the stormwater characteristics of the site.
- *Waiver Based on Impracticability and Compensatory Mitigation.* The 2001 Order requires that the co-permittees establish a definition for impracticability or infeasibility, and a process to

decide which alternative compliance measures could be incorporated into the site design or decision-approval process for new development and significant redevelopment projects.

- *Update General Plans.* The order recommends looking at large scale plans for opportunities to minimize the impacts of stormwater runoff at the regional or watershed scale.

In response to the revised permit, the city of San Jose sought to incorporate the new guidance into a local stormwater ordinance that would work in concert with other rules and its long-term Visioning Plan (the 2020 Plan), as well as other smart growth initiatives.

San Jose developed rules specifying that all new and redevelopment projects had to implement Post-Construction Best Management Practices (BMPs) and Treatment Control Measures (TCMs) to the maximum extent practicable. San Jose structured its policy so that deviations from the standard requirements could be established through a finding of impracticality. San Jose's policy includes some of the more common challenges, such as soil type or legacy pollutants. The city echoed the regional policy of favoring landscape-based controls, such as biofiltering and swales. However, the city also recognized some urban areas with site constraints can make landscaped-based controls expensive or impossible for the types of projects that deliver a range of economic, housing and transportation benefits.

The San Jose policy allows flexibility and several alternative measures that complement smart growth projects. First, a project can participate in a regional or shared TCM. Instead of requiring each and every project to address its own stormwater onsite, a shared TCM can lower costs and make more efficient use of land in urban areas. The city also established a category of projects called "Water Quality Benefit Projects." According to the policy:

> "Water Quality Benefit Project – In its discretion, the City may find that Smart Growth Projects provide equivalent water quality benefit. For other projects the City may find equivalent stormwater benefits where the project sponsor provides project and/or environmental documentation showing the development of the site itself, the nature of the site design, its location in the watershed, and/or proposed change in use protects/enhances water quality."

Further, the city defined "Smart Growth Projects" as a project meeting one or more of the following criteria:

a. Significant Redevelopment Project within the Urban Core

b. Low-income, moderate income, or senior housing Development Project, meeting one of the criteria listed in other sections of the city's code

c. Brownfields Projects.

For more information, see the Santa Clara Valley Urban Runoff Pollution Prevention Program (http://www.scvurppp.org/). Also, in 2007, SCVURPPP issued an update of the Guidelines of Site Design Examples. The guidebook presents examples of built projects, BMPs and a description of BMP design. See http://www.scvurppp-w2k.com/pdfs/0607/SC_Site_Design_Manual_Final_0207.pdf . The San Jose 2020 General Plan can be found at http://www.sanjoseca.gov/planning/gp/2020_text/index_htm.htm.

Example 5 – Palo Alto, California

Within the Zoning Chapter related to Off Street Parking and Loading Regulations, the city has adopted the following language:

> "Automobile and bicycle parking requirements prescribed by this chapter may be adjusted by the director of planning and community environment in the following instances and in accord with the prescribed limitations, when in his/her opinion such adjustment will be in accord with the purposes of this chapter and will not create undue

impact on existing or potential uses adjoining the site or in the general vicinity. (f) Transportation and Parking Alternatives. Upon demonstration to the director of planning and community environment that effective alternatives to automobile access are in effect, the director of planning and community environment may defer by not more than twenty percent the parking requirement otherwise prescribed for any use, or combination of uses on the same or adjoining sites, to an extent commensurate with the permanence, effectiveness, and the demonstrated reduction of off-street parking demand effectuated by such alternative programs. Land area required for provision of deferred parking stalls shall be maintained in reserve and shall be landscaped pursuant to a plan approved by the architectural review board demonstrating that ultimate provision of the deferred stalls will meet all requirements of this chapter. The director of planning and community environment shall set such conditions as necessary to guarantee provision of such deferred stalls whenever the building official determines the need to exist. Alternative programs which may be considered by the director of planning and community environment under this provision include, but are not limited to the following: (1) Immediate proximity to pubic transportation facilities serving a significant portion of residents, employees, and/or customers; (2) Operation of effective private or company carpool, vanpool, bus, or similar transportation programs; (3) Evidence that a proportion of residents, employees, and/or customers utilize, on a regular basis, bicycle transportation commensurate with reduced parking requirements."

(Source: Municipal Code Title 18. Zoning Chapter 18.83 Off Street Parking and Loading Regulations Section 18.83.120 www.smartcommunities.ncat.org/codes/paloalto3.shtml.)

In addition, the city allows permeable paving under the following parameters:

> "City of Palo Alto. Municipal Code. Title 18. Zoning Chapter 18-12 R-1 Single-Family Residence District Regulations Section 18.12.050 Site Development Regulations The following site development regulations shall apply in the R-1 single-family residence district. Modifications of some regulations may be applicable if the R-1 single-family residence district is combined with the special building site combining district. More restrictive regulations may be recommended by the architectural review board and approved by the director of planning and community environment, pursuant to Chapter 16.48: (r) Parking and driveway surfaces may have either permeable or impermeable paving. Gravel and similar loose materials shall not be used for driveway or parking surfaces within ten feet of the public right of way."

PROGRAM ADMINISTRATION

Stormwater management or water quality ordinances must also lay out the key elements of program administration. These include, but are not limited to, BMP operation, inspection, maintenance; enforcement; BMP design; methods for evaluating compliance with performance standards; administrative fees; etc. While detailed requirements for these elements are specified in administrative manuals which are referenced in the ordinance (e.g., BMP Design Manual), the ordinance must address program administration in order to provide enabling authority for staff and clarify overall program requirements. Below we have highlighted some of the key requirements for an effective stormwater ordinance as it relates to program administration.

BMP Operations, Inspection Maintenance and Local Enforcement

Regarding regular operations, inspections, and maintenance of BMPs, the first question that a local government needs to answer is, "Who will be required to carry out these duties?" Most local governments have stipulated that property owners are required to carry out inspections/maintenance and ensure that the BMP is operating properly.

Concerned about whether residential homeowners and homeowners' associations will actually be able to conduct inspections and maintenance over the long-term, the City of Charlotte/Mecklenburg County has said that it will accept maintenance responsibilities from single family detached residential developments and town homes if the BMPs have been satisfactorily maintained during the two-year warranty period by the owner or designee; meet all requirements of the stormwater management ordinance and Design Manual; and include adequate and perpetual access for inspections, maintenance, repair, or reconstruction. For other residential and non-residential developments, the property owner will be required to operate and maintain the BMP facilities. The logic behind this public-private division of labor is that the commercial establishments with professional property managers are capable of carrying out inspections and maintenance duties. More and more jurisdictions with stormwater utilities are questioning whether in the future the utility should assume operations and maintenance of the stormwater BMPs and charge a stormwater utility fee to recoup the cost.

<u>What is required of property owners when they are in charge of maintenance?</u> Progressive ordinances require the following:

Operations and Maintenance Agreement. This legal instrument requires the property owner and its successors, heirs, and assigns to regularly inspect, maintain, and repair stormwater facilities; provides a timeframe for performing needed repairs after inspections; attaches a schedule of long-term maintenance activities to be performed; allows the local government rights of ingress and egress for inspections and monitoring; outlines the requirements for notice of violation; allows the local government to perform needed maintenance if the property owner fails to do so, and requires the property owner to reimburse the local government for all costs incurred. The inspections and maintenance requirements of the agreement depend on the BMPs onsite, but inspections are required at least annually. (Note: Such requirements are also usually outlined in the local government's Construction or Design Manual.)

Annual Inspections and Maintenance Report. This must be submitted to the jurisdiction from a qualified engineer or landscape architect.

Access Easement for Inspections of BMPs. This is a separate legal instrument which is recorded with the deed.

Performance Security for Installation and Maintenance. The local government may require submittal of a performance security or bond with surety, cash escrow, letter of credit, or other legal arrangement prior to issuance of a stormwater management permit. Typically, the local government requires such performance security for the period of BMP installation and a minimum performance bond to cover maintenance or replacement costs after construction has been completed for a certain period of time (e.g., 5 or 10 years). Durham County North Carolina requires that stormwater management permit holders maintain an approved plan and performance security for the life of the project.

<u>What is required of the local government?</u> Through the ordinance, the local government provides enabling authority for local staff (or the jurisdiction's designee) to carry out an inspections program including routine inspections, random inspections, and inspections based on complaints. These inspections may include reviewing maintenance and repair records; sampling discharges, surface water, water in BMPs, etc.; and evaluating the condition of the BMPs. The purpose of the inspection is to determine if the activity onsite is being conducted in accordance with the ordinance and design manual and whether the measures required in the stormwater management plan of the site are effective.

The Ordinance must also specify the consequences of noncompliance, including notice of violation, penalties (e.g., civil penalty), and remedies (e.g., withholding or disapproval of subsequent permits or certificates, injunctions, costs as lien, restoration of areas affected by failure to comply).

Design Manual for BMPs

An effective BMP design manual is a critical feature of a progressive stormwater ordinance. It is more than a set of instructions for constructing a practice to meet a regulation – it must bridge the gaps between the concepts of LID, the goals of the local stormwater management program, and the way the management practices are to be constructed. The manual should communicate the importance of the stormwater management goals, and provide education and detailed guidance to those that use it. Engineers may be accustomed to a cookie-cutter approach to design, and may not understand the reasons for a different approach, nor be familiar with LID goals of retaining stormwater onsite versus the standard approach of moving it off as quickly as possible. With these goals in mind, this section will discuss the following elements:

- How should the BMP design manual be linked to the ordinance?
- What are the important elements of the manual? What should it contain?
- What incentives can be used to encourage the use of innovative practices?

<u>How should the BMP design manual be linked to the ordinance?</u>

The BMP design manual and any other technical documents should be linked to the ordinance by reference. For example, the Town of Huntersville's Water Quality Ordinance says, "Specific requirements regarding the design, installation and maintenance of LID structures and a discussion of LID site planning is contained in the Huntersville Water Quality Design Manual."

It is critically important that the ordinance **does not** include details about design guidelines that achieve performance standards, nor specific assumptions about BMP performance. Current research may indicate that a particular practice achieves a certain level of pollutant removal, or that retention of a particular storm event runoff volume will prevent downstream channel erosion. However, the science of stormwater management is young and rapidly evolving. Current BMP designs may need to be updated. New research may show that a particular BMP does not remove as much of a pollutant as previously thought. Performance standards themselves may need to be changed, if over time they are not working as expected. For this reason, it is more important for the ordinance to refer to the goals of the performance standards (e.g., reduce nutrient runoff from development to protect downstream water resources, reduce impacts of stormwater volume to prevent stream channel erosion and protect biological resources). Separate documents can then be updated as needed to support the ultimate goals. If a specific design is cited in the ordinance as meeting performance standards, it will be much more difficult to change the ordinance itself.

<u>What are the important elements of the manual? What should it contain?</u>

BMP design manuals are quite common, and have typically grown out of a history of engineering requirements for stormwater management. Some are limited in nature. The most basic focus on design elements for peak flow control, and provide little or no context for their purpose. In locations where pollutant impacts from stormwater became an issue, practitioners began developing a larger toolbox of practices, and provided more robust design manuals with background and guidance. North Carolina's BMP manual published in 1999 (NCDENR, 1999) was produced to support recently enacted water supply watershed regulations, which required removal of 85 percent of post-construction sediment loads. The 1999 manual is 85 pages in length, covers eight separate BMPs (including bioretention areas, stormwater wetlands, and infiltration devices), and has detailed narrative about the practices, design calculations with examples, costs, and maintenance. Interest in innovative stormwater management has grown in NC, and the scope of regulation increased when a large portion of the state came under nutrient management regulations resulting from nitrogen TMDLs for large river basins. As a result, the 2007 manual (NCDENR, 2007) has grown to several hundred pages in length, covers 13 practices (including the addition of permeable pavement, green roofs, cisterns, and restored forest buffers), and has an in-depth discussion of BMP design considerations. While the NC design manual does not promote LID per se, it does show the importance of providing a large toolbox of practices, and educating practitioners about their importance.

An LID stormwater manual should therefore provide the entire holistic framework, starting with a detailed discussion of LID, its goals, and how it represents a fundamentally different way of managing site hydrology. Performance standards specific to the managing authority should also be covered, including why they are needed and how they protect the intended resources. Finally, detailed design guidelines and examples should be provided for each BMP.

For example, Prince George's County (MD) provides two guidance documents, one with an overview of the approach (Prince George's County, 1999a) and one with details about hydrologic analysis (Prince George's County, 1999b). While it the guidance documents are not linked to any specific performance standards, they do discuss in detail the goal of mimicking pre-development site hydrology. The State of Georgia's stormwater management manual includes both a policy/overview document and a detailed design manual (Atlanta Regional Commission, 2001). The design manual provides details about the management goals, including performance standards related to storm event runoff volume, and design guidelines, specifications, and performance standard calculations for 19 BMPs.

What incentives can be used to encourage the use of innovative practices?

One of the fundamental principles of LID is to micromanage runoff and to prevent it from leaving the site. A site that uses a full suite of LID practices should have a greatly reduced volume of runoff, even during a large storm event. Performance standards often require storage and treatment of a significant volume of runoff. By receiving credit for using LID practices, developers can reduce the cost of other practices by reducing their size.

Knox County (TN) has a draft stormwater manual with good examples of how stormwater credits can be used to provide incentives for LID practices. The County's new ordinance (adopted September 2007) includes a performance standard of capturing and treating the runoff from the first 1.1 inches of rainfall, called the Water Quality Volume (WQv). The manual allows for a reduction of the WQv via six practices:

1. Natural area preservation
2. Managed area preservation (open space)
3. Routing runoff to stream and vegetated buffers
4. Using specially designed grass swales for treatment
5. Disconnection of impervious surfaces
6. Large lot neighborhoods

Each has very specific design guidelines and limitations, but used separately or together they may potentially reduce the volume of runoff that must be treated with structural practices, thus reducing the cost to the developer. The last option incorporates low housing densities requirements with other practices, and allows the developer to completely waive the WQv requirement.

Methods for Evaluating Performance Standards and Water Quality Objectives

Assessing performance standards adds a layer of complexity to the process of development review, both for the developer and the regulator. If the calculation of the site targets and how the site meets those practices is complicated, developers may find it difficult to test a variety of innovative designs, and may elect to choose a conventional design. Likewise, the reviewing authority must spend additional time reviewing the calculations and assumptions submitted by the developer for errors.

In some cases, simple calculations or spreadsheet tools may be sufficient. For instance, sediment loads could be estimated from proportions of the site under various land covers (i.e., forest, developed pervious, and impervious) using predetermined factors. A BMP or a set of BMPs treat a portion of the land covers, and the sediment they remove should be calculated using predetermined removal rates. From that, the final sediment load can be estimated.

However, when there are multiple performance standards, this can become difficult. Simple performance standard models can be used to reduce both administrative burden, and to allow the developer to explore a wider range of options. These models do not have to be complicated to learn or use. For example, the City of Huntersville uses the SET, a Microsoft Excel based spreadsheet that was developed to assess the impacts of development, including sediment and nutrient loading, on a site scale. It provides a better environment for testing multiple management practices and site configurations than do simple export calculations, and it incorporates several principles of hydraulic and water quality modeling for more realistic BMP response solutions. The tool lets the user define pre- and post-treated land use/land cover, allowing for multiple drainage areas and various combinations of practices. An important benefit of SET is that the user can test management practices in combination with each other, of a site or small catchment. In addition, both structural and nonstructural practices can be represented, offering a suite of options for evaluation. The Huntersville version of the SET calculates loads and removal for sediment, nutrients, and fecal coliform bacteria, as well as calculating a runoff volume performance standard linked to the location of the development. Other versions of the SET also calculate storm event peak flow. The SET also estimates pre- and post-development annual runoff, an important measure for LID.

LAND USE CODES ALLOWING EFFECTIVE SITE DESIGN

A strong stormwater ordinance is only half of the equation for effective stormwater management. A local government also needs to have a development ordinance that allows or even encourages effective site design for reducing or managing stormwater. While strong stormwater performance standards can provide an impetus for developers to minimize impervious area, maximize undisturbed area, and other good site design techniques, often local codes erect barriers and disincentives to implementing LID.

Local governments and developers practicing LID design over the last decade have developed some tools and methods for doing so. They have provided useful guidelines for low-impact site design, which include the following steps (Prince George’s County, 1999a):

1. Identify applicable zoning, land use, subdivision, and other local regulations.
2. Define development envelope and protected areas (reduce limits of clearing and grading; use site fingerprinting).
3. Use drainage/hydrology as a design element.
4. Reduce/minimize total impervious area.
5. Develop integrated preliminary site plan.
6. Minimize directly connected impervious areas.
7. Modify/increase drainage flow paths.
8. Compare pre- and post-development hydrology (using hydrologic analysis).
9. Complete site plan.

Based on local governments’ experience, USEPA, the Center for Watershed Protection, and others have developed a number of “how to” LID design documents. In taking the first step toward LID, i.e., identifying applicable zoning and land use regulations, the Center for Watershed Protection has developed *Better Site Design: A Handbook for Changing Development Rules in Your Community* (1998). The Guide includes a Code and Ordinance Worksheet, which is a tool for reviewing the standards, ordinances, and codes that shape how development occurs in a community and how the local rules compare to the principles of better site design. In addition, the USEPA has produced a series of documents on LID. The first in the series is *Low-Impact Development Design Strategies, An Integrated Approach* (1999). This and other LID manuals are at: http://www.epa.gov/owow/nps/urban.html.

The Smart Growth Leadership Institute has conducted code audits for larger scale code and land development standards. These codes are based on concepts related to smart growth and comprehensive planning. To see their worksheet, go to http://www.epa.gov/smartgrowth/scorecards/sglicodeaudit.pdf. Also, the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) developed an audit procedure for code language for its 17 member cities, the Santa Clara Water District, and the County. Visit the “Summary of Findings” link at http://www.scvurppp-w2k.com/compare_contrast.htm (the worksheet begins on page II.14).

Tetra Tech recommends making the ordinance revisions highlighted above, either through a holistic “roundtable process” described in the *Better Site Design Handbook*, or incrementally through text amendments. However, as noted in conversations with staff of many local governments, many LID elements are currently allowed in the local ordinances, but are not encouraged and in some cases discouraged. Therefore, Tetra Tech recommends that each jurisdiction work interdepartmentally—with the Planning, Engineering and Public Works Departments—to resolve issues and remove barriers which are blocking use of the above LID practices.

Below is a checklist, Opportunities for Low-Impact Development Design Techniques, that can be used in the local ordinance review and roundtable discussion process. This checklist is adapted from *Low-Impact Development Design Strategies*, Prince George’s County MD; *Better Site Design: A Handbook for Changing Development Rules in Your Community*, Center for Watershed Protection; and *State of North Carolina Model Ordinance for Water Supply Watershed Protection*. In reviewing summaries of roundtable discussions and recommendations for better site design, these are the types of issues that need to be addressed in local ordinances to remove barriers to LID.

Checklist: Opportunities for Low-Impact Development Design Techniques

Clearing and Grading

- Is disturbance of vegetated areas and riparian areas minimized?
- Do the building envelopes avoid sensitive environmental areas such as riparian areas, wetlands, high infiltration soils, steep slopes, etc.?
- Is total site disturbance minimized?

Minimizing Impervious or Built Upon Area

<u>Streets</u>

- For low volume residential roads and streets, are the street pavement widths between 18 to 22 feet?
- Do regulations promote or allow the most efficient street layout to reduce overall street length? This may include revising frontage requirements.
- Can the culs-de-sac radius be 35 feet or less?
- Are landscaped island or bioretention islands allowed or encouraged in culs de sac?
- Are grass swales or bioretention swales used instead of curb and gutter where slopes allow?

Parking/Driveways/Sidewalks

- For office buildings, is the parking ratio 3.0 spaces per 1000 sq.ft. of gross floor area or less?
- For commercial centers, is the parking ratio 2 to 4.5 spaces per 1,000 sq.ft. of gross floor area or less?
- Is a mass transit stop provided or nearby (if applicable)?
- Can a proposed development take advantage of opportunities for shared parking?
- Is the minimum stall width for a standard parking space 9 feet or less?
- Can parking medians (if required) have bioretention cells where feasible?
- Are driveways 9 feet or less in width?
- Are shared driveways used?
- Is on-street parking considered and imperviousness minimized (no on-street or single-side parking where allowed)?
- Are sidewalks (if required) designed to the narrowest allowable width?
- Can developments provide sidewalks on one side of street only?

Clustering Development

- To encourage clustering and open space design, are setbacks minimized (e.g., for residential lots that are ½ acre or less in size is the front setback 20 feet or less, the rear setback 25 feet or less, and the side setback 8 feet or less)?
- Does the design focus development on areas of lesser slopes and farther from watercourses?

Preserving Sensitive Areas

Wetlands

- Are existing wetlands preserved?
- Will the site design minimize hydrologic alteration to existing wetlands?

Steep Slopes

- Does the ordinance encourage or require that building footprints be concentrated on slopes 10 percent or less?
- Is disturbance minimized on slopes 15 percent to 25 percent and revegetation proposed where disturbance occurs?
- Does the ordinance promote preservation of areas with 25 percent or greater slope?

Soils

- Do the building footprints avoid highly erodible soils?
- Do the building footprints avoid soils with high permeability?

Stream Buffer

- Does the ordinance encourage or require that a 50 to 75 foot stream buffer be provided?
- Will the stream buffer remain in a natural state?

Managing Open Space

- Does the ordinance promote or require open space preservation?
- Will the preserved open space be managed in a natural condition?
- Will there be a Homeowners Association or other association that can effectively manage the open space?

After reviewing the summary of roundtable discussions and recommendations from a number of communities, it appears that some of the most challenging issues to reach consensus on include:

- *Residential street and roads widths*. The recommendation for 18 to 22 feet streets widths (for low volume traffic) often conflicts with state minimum road and street design requirements, which are in turn adopted and required by local governments before accepting a street for public maintenance. Fire departments also object to the narrower streets because they believe they are not wide enough for fire trucks to navigate.
- *Culs-de-sac.* The recommendation that a cul-de-sac have a radius of 35 feet or less can conflict with state DOT standards. For example PennDOT requires use of a circular turn around with a 40-foot minimum radius in order for municipalities to receive state funding. This standard is related to transport of liquid fuels.
- *Use of grass swales and bioretention areas rather than curb and gutter.* The major objection to this recommendation comes from local engineering and public works departments that are concerned about the maintenance of the swales and street edges and the use of swales on steeply sloped areas.
- *Use of one sidewalk rather than two.* Planning departments often object to this ordinance revision because they believe it conflicts with their goal of providing walkable communities.
- *Reducing residential setback and frontage requirements to encourage cluster development*. Planning Departments are concerned that the reduced setback/frontage requirements would be incompatible with exiting neighborhoods built under traditional subdivision requirements.

Clearly, in many cases, state DOT standards will need to be addressed in order for local governments to eliminate barriers in their ordinances related to street design. In most cases, the resistance to ordinances changes arises from competing local government departmental objectives and concerns. The planning, public works, and fire departments have to resolve these internal issues to determine the extent to which LID techniques can be incorporated into the subdivision and zoning ordinances and used in the community. For each issue, it will be important to show how other communities have overcome barriers through creative design, construction standards, approval process requirements, etc.

Appendix D: LID Grant Solicitation Draft Language and Evaluation Criteria

PURPOSE

This section includes language that could be used in a grant solicitation or request for proposals (RFP) to encourage implementation of LID at the local level. Two types of projects are envisioned: planning projects for municipalities to audit and update codes and ordinances that allow or encourage LID, and implementation projects in which communities would install LID features as part of capital improvements. Included in this grant solicitation language is a checklist for communities to quantify the extent to which codes and ordinances allow, encourage, or require LID and related measures. This checklist and other details of the grant solicitation language are intended to divide the grant applicants into categories based on progress achieved thus far. Ultimately, this solicitation language would reward communities that have already audited and updated codes and ordinances, while still providing an opportunity for financial support to communities who would like to implement code and ordinance changes but may not have had the impetus or resources in the past. Note that additional details, such as criteria and a ranking system to evaluate proposed implementation projects, would need to be included before a solicitation of this type is issued.

APPLICABLE PROJECTS

Grants under this type of solicitation would be for two types of projects: (1) planning projects that will bring about changes in codes and development of LID performance standards, and (2) implementation projects, namely capital improvement projects that have one or more LID components.

Planning Projects

These projects will involve performing a detailed audit (see Appendix A) of all zoning and development-related codes to identify conflicts with LID principles, or conducting studies to establish at the local level where barriers or long-standing practices have been identified and prevent adoption of LID (e.g., a parking utilization study). The result will be to revise code language and develop stormwater performance standards for new and redevelopment projects. Additional planning projects can include development of a performance standard for LID techniques or development of an active monitoring program for LID practices.

Implementation Projects

These projects will require that one or more LID practices be incorporated into a capital improvement project. Alternatively, the project may involve the retrofit of an existing municipal property with one or more LID practices. Examples of LID practices include porous pavement, ecoroofs, bioretention, downspout disconnection, conversion of impervious surfaces to pervious surfaces, regrading and amending soils for enhanced stormwater capture, and other integrated stormwater management techniques.

EVALUATION CRITERIA

To be evaluated for an award, applicants are required to perform a self-audit of local codes and standards using the checklist included in Appendix A. For each affirmative answer, applicants should provide a citation for the applicable development code or standard (page, section, or line number).

Eligibility

Applicants will be eligible for grant funding for planning or implementation projects based on the self-audit responses as follows:

Score of 0 to 10 points:

Applicants that score between 0 and 10 points on the self-audit are not eligible for implementation project grants. However, they are eligible for a grant to revise codes/ordinances and develop guidelines to increase their self-audit score to 15.

Score of 11 to 24 points:

Applicants that score between 11 and 24 points are eligible for implementation project grants with the condition that they revise codes/ordinances and develop guidelines to increase their self-audit score to 25.

Score of 25 or more points:

Applicants who score 25 or more points on the self-audit are eligible for an LID implementation project grant without conditions.

For planning assistance, applicants must submit a letter of good faith from the planning director or other municipal executive stating that they support code revision and standards development as proposed in the grant application.

Project Merit

Grant applications will be assessed based on project merit. In your grant application, please describe the following for each type of project:

Planning Projects:

Describe proposed changes to codes and standards to improve the self-audit score to the required minimum. List code/standard language that is in conflict with LID and discuss possible changes to remove conflicts. Describe studies that might be needed to obtain stakeholder buy-in, such as parking utilization studies or demonstration projects with emergency responders. Describe the administrative process to implement changes, including the process through which stakeholders (other municipal departments, citizen groups, developers, etc.) will be involved.

Implementation Projects:

Describe the capital improvement project and identify the LID component(s) to be incorporated. Identify the waterbody or waterbodies affected by stormwater runoff from the site and discuss how the LID features will address recognized pollutants of concern for the waterbody or waterbodies. Estimate reductions in directly connected impervious surfaces that result from LID practice implementation. Describe how the LID project fits into the larger watershed management system. Outline a plan to assess the performance of the project over the long term, and identify whether monitoring will be performed as part of this assessment. Describe how maintenance of the LID project will be assured over the long term.

Applicants proposing planning and implementation projects must submit descriptions for both project types as described above.

Low Impact Development Code and Ordinance Self-Audit

To be evaluated for an award, applicants are required to perform a self-audit of local codes and standards using the following checklist. For each affirmative answer, applicants should provide a citation for the applicable development code or standard (page, section, or line number). Applicants will be eligible for grant funding for planning or implementation projects based on the self-audit responses as follows:

<u>Score of 0 to 10 points:</u>
Applicants can apply for a grant to revise codes/ordinances and develop guidelines to increase the score to a minimum of 15.

<u>Score of 11to 24 points:</u>
Applicants can apply for a grant to revise codes/ordinances to increase the score to a minimum of 25 and propose an LID implementation project.

<u>Score of 25 or more points:</u>
Applicants can apply for a grant for an LID implementation project.

A. General Information

Name of Applicant: ____

List Citations for Codes/Ordinances Relevant to Stormwater and Smart Growth: ____________________

____

____

____

B. Stormwater Ordinance

How have post-construction stormwater requirements been incorporated into local ordinances?

- ❑ A stand-alone post-construction stormwater ordinance has been developed (2 points)
- ❑ Post-construction stormwater requirements have been integrated into a development ordinance or another type of ordinance (2 points)
- ❑ Post-construction stormwater requirements were included in several different ordinances (2 points)

Attach copies of the official approval (e.g., letter, meeting minutes) showing adoption of the ordinance(s) by the municipal governing body.

- ❑ Post-construction stormwater requirements are not yet included in local ordinances (0 points)

C. General Plans

How has post-construction stormwater management, natural drainage, or low impact development been incorporated into your General Plan?

- ❑ The General Plan has been reviewed and General Plan Elements have been amended to include natural drainage, low impact development, and post-construction stormwater management (2 points)
- ❑ The City/County is in the process of identifying where natural drainage, low impact development, and post-construction stormwater management should be included in the next update of the General Plan (1 point) Date of next General Plan update: ___________________________________
- ❑ The City/County has not yet initiated a review of the General Plan for inclusion of natural drainage, low impact development, and post-construction stormwater management (0 points)

D. Code Language

Please review the list of stormwater- and smart growth-related code language and check all that are included in existing codes or ordinances. If a change has been implemented already, provide a section, page, or line reference for the code change. Note this may include zoning codes, specific plans or standards issued by Transportation and Fire Protection Districts.

The items below are scored at 1 point each.

Clearing and Grading

- ❑ Do codes/ordinances regulate the disturbance of vegetated areas and riparian areas? Indicate the extent to which disturbance is limited: ____ (Reference: _________________)
- ❑ Do codes/ordinances regulate the total amount of site disturbance? Indicate the extent to which disturbance is limited: ____ (Reference: _________________)

Minimizing Impacts of Impervious or Built Area

Streets

- ❑ For low-volume residential roads and streets, are the street pavement widths required to be between 18 and 22 feet? (Reference: _________________)
- ❑ Do codes/ordinances promote or allow the most efficient street layout to reduce overall street length? This may include revising frontage requirements. (Reference: _________________)
- ❑ Do codes/ordinances allow a cul-de-sac radius to be 35 feet or less? (Reference: _________________)
- ❑ Are landscaped islands or bioretention islands allowed or encouraged in culs-de-sac? (Reference: _________________)
- ❑ Are LID techniques (e.g., grass swales, bioretention swales, tree planters, etc.) allowed, encouraged, or required to be used instead of curb and gutter where slopes allow? (Reference: _________________)

Parking/Driveways

- ❑ Has a parking utilization study been performed and were results incorporated into codes/ordinances? (Reference: _________________)
- ❑ Do codes/ordinances provide incentives for shared parking? (Reference: _________________)
- ❑ Is the minimum stall width for a standard parking space allowed, encouraged, or required to be 9 feet or less? (Reference: _________________)
- ❑ Can parking medians (if required) have bioretention cells where feasible? (Reference: _________________)
- ❑ Is porous pavement allowed, encouraged, or required? (Reference: _________________)
- ❑ Are driveways allowed, encouraged, or required to be 9 feet or less in width? (Reference: _________________)
- ❑ Are shared driveways allowed, encouraged, or required? (Reference: _________________)
- ❑ Is imperviousness associated with on-street parking required to be minimized (e.g., no on-street parking, or single-side parking where allowed)? (Reference: _________________)

Buildings/Landscape

- ❑ Are green roofs allowed, encouraged, or required? (Reference: _________________)
- ❑ Is roof runoff allowed, encouraged, or required to be directed to bioretention planter boxes, bioswales, bioretention cells, or other landscaped/pervious area? (Reference: _________________)
- ❑ Are cisterns, rain barrels, or other methods for water reuse allowed, encouraged, or required? (Reference: _________________)
- ❑ Has the master landscaping code been revised (or have revisions been initiated) to integrate water conservation, water reuse, and stormwater handling within landscaped areas? (Reference: _________________)

Preserving Sensitive Areas

Wetlands/Floodplains

- ❑ Do codes/ordinances require prevention or mitigation of hydrologic impacts on existing wetlands and floodplains? (Reference: _________________)
- ❑ Are site designs required to mitigate the impacts of hydrologic alteration to existing wetlands/floodplains by including such areas in stormwater management calculations? (Reference: _________________)

Steep Slopes

- ❑ Do codes/ordinances encourage or require that building footprints be concentrated on slopes 10 percent or less? (Reference: _________________)
- ❑ Do codes/ordinances require that disturbance be minimized on slopes 15 percent to 25 percent and revegetation proposed where disturbance occurs? (Reference: _________________)
- ❑ Do codes/ordinances require preservation of areas with 25 percent or greater slope? (Reference: _________________)

Soils

- ❑ Are building footprints required to avoid highly erodible soils? (Reference: ________________)
- ❑ Are building footprints required to avoid soils with high permeability (e.g., Soil Conservation Service Soil Group A)?
(Reference: ________________)

Stream Buffers

- ❑ Do codes/ordinances encourage or require a scientifically defensible wetland/riparian buffer setback? (Reference: ________________)
- ❑ Do codes/ordinances limit activities (e.g., material storage, mowing, etc.) in wetland/riparian buffer zones?
(Reference: ________________)

Managing Open Space

- ❑ Have local park and open space plans been revised to incorporate stormwater management features into pervious and landscaped areas?
(Reference: ________________)
- ❑ Have codes/ordinances governing open space for multi-family residential development been revised to include on-site water quality and quantity management of stormwater?
(Reference: ________________)
- ❑ Do codes/ordinances encourage or require open space preservation based on a regional or watershed-scale plan?
(Reference: ________________)
- ❑ To encourage clustering and open space design, are setbacks allowed, encouraged, or required to be minimized? (Reference: ________________)
- ❑ Do codes/ordinances encourage or require that development be directed to already-developed areas (e.g., infill sites or corridor redevelopment areas)? (Reference: ________________)

E. SCORING AND PROJECT CATEGORY

Applicants will be eligible for grant funding for planning or implementation projects as follows:

<u>Score of 0 to 10 points:</u>
Applicants can apply for a grant to revise codes/ordinances and develop guidelines to increase the score to a minimum of 15.

<u>Score of 11to 24 points:</u>
Applicants can apply for a grant to revise codes/ordinances to increase the score to a minimum of 25 and propose an LID implementation project.

<u>Score of 25 or more points:</u>
Applicants can apply for a grant for an LID implementation project.

Total Number of Points: ___________________

Please Mark the Appropriate Project Category:

❑ Planning (0-10 pts) ❑ Planning/Implementation (11-24 pts) ❑ Implementation (>25 pts)

State of North Carolina

Office of Administrative Hearings

County of Wake

NORTH CAROLINA WILDLIFE FEDERATION CENTRAL PIEDMONT GROUP OF THE NC SIERRA CLUB, Petitioner,
v.
N.C. DIVISION OF WATER QUALITY, Respondent.

05 EHR 2055, 06 EHR 0164

Hearing Dates: July 19 and 20, 2006
Decision Date: October 13, 2006

DECISION

This contested case was heard by Fred G. Morrison Jr., Senior Administrative Law Judge, on July 19 and 20, 2006, in Raleigh, North Carolina. The parties filed proposed Decisions and Memoranda of Law on September 15, 2006.

APPEARANCES

For Petitioners: John Suttles

Amy Pickle

Kay Bond

Southern Environmental Law Center

200 West Franklin Street, Suite 330

Chapel Hill, North Carolina 27516.

For Respondent: Donald W. Laton

Assistant Attorney General

NC Department of Justice

9001 Mail Service Center

Raleigh, North Carolina 27699-9001

ISSUES

This matter is an appeal by Petitioners of the National Pollutant Discharge Elimination System ("NPDES") Phase II stormwater permits issued to three local governments located in the Goose Creek watershed in Mecklenburg and Union Counties. The final NPDES Phase II stormwater permit for Mecklenburg County, including the Town of Mint Hill, was issued on June 15, 2005, with effective dates from July 1, 2005, through June 30, 2010. The final NPDES Phase II stormwater permit for the Town of Indian Trail was issued on September 1, 2005, with effective dates from October 1, 2005, through September 30, 2010. The final NPDES Phase II stormwater permit for the Town of Stallings was issued on September 7, 2005, with effective dates from October 1, 2005, through September 30, 2010.

The parties submitted a Pretrial Order that included their contentions regarding the issues to be decided. The undersigned determines that the issues to be decided are:

1. Whether Respondent exceeded its authority or jurisdiction, acted erroneously, failed to use proper procedure, acted arbitrarily and capriciously, or failed to act as required by law or rule (hereinafter "err") in issuing NPDES Permit Nos. NCS000453, NCS000454, and NCS000395 without ensuring the permits will comply with all applicable state water quality standards as required by 40 C.F.R. § 122.44(d) (2006) and N.C. Gen. Stat. § 143.215.1(a)(6)(2006)?

2. Whether Respondent erred in issuing NPDES Permit Nos. NCS000453, NCS000454, and NCS000395 without requiring measures that will reduce discharges of pollutants to the maximum extent practicable as required by 40 C.F.R. § 122.34(a) (2005)?

3. Whether Respondent erred in issuing NPDES Permit Nos. NCS000453, NCS000454, and NCS000395 without including effluent limitations and conditions necessary to meet the requirements of the waste load allocation in the Goose Creek Total Maximum Daily Load as required by 40 C.F.R. § 122.44(d)(1)(vii)(B) (2006)?

WITNESSES

For Petitioners: Thomas Stewart Blue and John Fridell

For Respondent: Michael F. Randall, Kenneth Bruce Pickle, Tilman Bradley Bennett, and Thomas Reeder

EXHIBITS RECEIVED INTO EVIDENCE

Petitioner: Note: Petitioners' exhibits were admitted into evidence without objection as four notebooks containing the documents listed below.

P-1 O5 EHR 2055 Petitioners' Prehearing Statement (Jan. 6, 2006)
P-2 06 EHR 0164 Petitioners' Prehearing Statement (Mar. 6, 2006)
P-3 05 EHR 2055 Respondent's Prehearing Statement (Jan. 6, 2006)
P-4 06 EHR 0164 Respondent's Prehearing Statement (Mar. 6, 2006)

P-5 40 C.F.R. § 122.4 (2006)
P-6 40 C.F.R. § 122.21 (2006)
P-7 40 C.F.R. § 122.26 (2006)
P-8 40 C.F.R. § 122.34 (2006)
P-9 40 C.F.R. § 122.44 (2006)
P-10 40 C.F.R. § 122.32 (2006)
P-11 40 C.F.R. § 130.2 (2006)
P-12 40 C.F.R. § 130.12 (2006)
P-13 40 C.F.R. § 131.12 (2006)
P-14 38 Fed. Reg. 13,528 (May 22, 1973)
P-15 50 Fed. Reg. 1774 (Jan. 11, 1985)
P-16 52 Fed. Reg. 36,034 (Sept. 25, 1987)
P-17 58 Fed. Reg. 34,926 (June 30, 1993)
P-18 64 Fed. Reg. 235 (Dec. 8, 1999)
P-19 67 Fed. Reg. 127 (July 2, 2002)
P-20 58 Fed. Reg. 124 (June 30, 1993)
P-21 33 U.S.C. § 1251 (2006)
P-22 33 U.S.C. § 1311 (2006)
P-23 33 U.S.C. § 1313 (2006)
P-24 33 U.S.C. § 1342 (2006)
P-25 33 U.S.C. § 1362 (2006)
P-26 N.C. Gen. Stat. § 143-213 (2006)
P-27 N.C. Gen. Stat. § 143.215.1 (2006)
P-28 15A N.C. Admin. Code 2B.0110 (2006)
P-29 15A N.C. Admin. Code 2B.0201 (2006)
P-30 15A N.C. Admin. Code 2B.0202 (2006)
P-31 15A N.C. Admin. Code 2B.0211 (2006)
P-32 15A N.C. Admin. Code 2H.0112 (2006)
P-33 Haeuser v. Dept. of Law, Gov.'t of Guam, 97 F.3d 1152 (9th Cir. 1996)
P-34 Rybachek v. US EPA, 904 F.2d 1276 (9th Cir. 1989)
P-35 Association of Pacific Fisheries v. US EPA, 615 F.2d 794 (9th Cir. 1980)
P-36 Environmental Defense Center, Inc. v. US EPA, 319 F.3d 398 (9th Cir. 2001)
P-37 Arkansas v. Oklahoma, 112 S. Ct. 1046 (1991)
P-38 Champion International Corporation v. US EPA, 648 F.Supp. 1390 (D.N.C. 1986)
P-39 NPDES Phase II Stormwater Permit No. NCS000453 for Indian Trail (Sept. 1, 2005)
P-40 NPDES Phase II Stormwater Permit No. NCS000454 for Stallings (Sept. 7, 2005)
P-41 NPDES Phase II Stormwater Permit No. NCS000395 for Mecklenburg County, Towns of Cornelius, Davidson, Huntersville, Matthews, Mint Hill, and Pineville (July 1, 2005)
P-42 NPDES Phase II Stormwater Permit Application for Indian Trail (Mar. 28, 2003)
P-43 NPDES Phase II Stormwater Permit Application for Stallings (Mar. 28, 2003)
P-44 NPDES Phase II Stormwater Permit Application for Mecklenburg County (March 4, 2003), including the attached Stormwater Management Program Report (Feb. 25, 2003)
P-45 Draft Technical Support Document for Consideration of Federally-listed Threatened or Endangered Aquatic Species in Water Quality Management Planning for the Goose Creek Watershed (July 2005)
P-46 N.C. Wildlife Resources Commission, Guidance Memorandum to Address and Mitigate Secondary and Cumulative Impacts to Aquatic and Terrestrial Wildlife Re-

sources and Water Quality (Aug. 2002)

P-47 Total Maximum Daily Loads for Fecal Coliform for Goose Creek, North Carolina, Final Report, April 2005 (Approved July 08, 2005)

P-48 North Carolina Water Quality Assessment and Impaired Waters List (2002 Integrated 305(b) and 303(d) Report) (Feb. 2003)

P-49 N.C. Division of Water Quality, Review of Effectiveness of Coastal Stormwater Rules, PowerPoint Presentation (Nov. 2005)

P-50 N.C. Division of Water Quality, Universal Stormwater Management Program (UDPA1) Draft Rules, PowerPoint Presentation (Oct. 12, 2005)

P-51 Letter from P. Benjamin and B. Cole, U.S. Fish and Wildlife Service, to B. Bennett, NC Division of Water Quality (Dec. 29, 2004)

P-52 R.A. Fischer, C.O. Martin, and J.C. Fischenich, Improving riparian buffer strips and corridors for water quality and wildlife, in PROCEEDINGS OF THE AMERICAN WATER RESOURCES ASSOCIATION INTERNATIONAL CONFERENCE ON RIPARIAN ECOLOGY AND MANAGEMENT IN MULTI-LAND USE WATERSHEDS, 457-462, American Water Resources Association, Portland, Oregon (2000).

P-53 D.L. Correll., Buffer zones and water quality protection: general principles, in PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON BUFFER ZONES, Quest Environmental, Harpenden, Hertfordshire, UK (1997).

P-54 R.A. Fischer, C. O. Martin, D. Q. Barry, K. Hoffman, K. L. Dickson, E. G. Zimmerman, and D.A. Elrod, Corridors and Vegetated Buffer Zones: A Preliminary Assessment and Study Design, Technical Report EL-99-3. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS (1999).

P-55 A.H. Todd, Making decisions about riparian buffer width, in PROCEEDINGS OF THE AMERICAN WATER RESOURCES ASSOCIATION INTERNATIONAL CONFERENCE ON RIPARIAN ECOLOGY AND MANAGEMENT IN MULTI-LAND USE WATERSHEDS, 445-450 American Water Resources Association, Portland, Oregon (2000).

P-56 C.W. May, & R.R. Horner, The cumulative impacts of watershed urbanization on stream-riparian ecosystems, in PROCEEDINGS OF THE AMERICAN WATER RESOURCES ASSOCIATION INTERNATIONAL CONFERENCE ON RIPARIAN ECOLOGY AND MANAGEMENT IN MULTI-LAND USE WATERSHEDS, American Water Resources Association, Portland, Oregon (2000).

P-57 R.J. Naiman, H. Decamps, & M. Pollock., The role of riparian corridors in maintaining regional biodiversity, 3 ECOLOGICAL APPLICATIONS 209, 209-212 (1993).

P-58 G.J. Kauffman, & T. Brant, The role of impervious cover as a watershed-based zoning tool to protect water quality in the Christina River Basin of Delaware, Pennsylvania, and Maryland, Paper presented at Watershed 2000 Management Conference, Water Environment Federation, Alexandria, Virginia (2000).

P-59 C.L. Arnold, Jr., & J.C. Gibbons, Impervious surface coverage: the emergence of a key environmental indicator, 62 JOURNAL OF THE AMERICAN PLANNING ASSOCIATION 243, 243-258 (1996).

P-60 B.A. Doll, et. al., Hydraulic geometry relationships for urban streams throughout the piedmont of North Carolina, 38 JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION 641, 641-651 (2002).

P-61 A.J. Castelle, A.W. Johnson, & C. Conolly, Wetland and stream buffer size requirements: a review, 23 JOURNAL OF ENVIRONMENTAL QUALITY 878, 878- 882 (1994).

P-62 A E.H. Livingston, J.R. Maxted, R.R. Horner, & C.W. May, BMPs, impervious cover, and biological integrity of small streams (on file with the author) (1999).

P-63 Tom Schueler, The importance of imperviousness, 1 WATERSHED PROTECTION TECHNIQUES 100, 100-111 (1994).

P-64 Belinda Hatt, et. al., The Influence of Urban Density and Drainage Structure on the Concentrations and Loads of Pollutants in Small Streams, 34 ENVIRONMENTAL MANAGEMENT 1, 112-124 (2004).

P-65 Sarah Gergel, et. al., Landscape indicators of human impact to riverine systems, AQUATIC SCIENCES 64, 118-28 (2002).

P-66 Chandler Morse, et. al., Impervious Surface Area as a Predictor of the Effects of Urbanization on Stream Insect Communities in Maine, U.S.A., ENVIRONMENTAL MONITORING AND ASSESSMENT 89, 95-127 (2003).

P-67 Lizhu Wang, et. al., Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales, 28 ENVIRONMENTAL MANAGEMENT 2, 255-66 (2001).

P-68 Joong Lee & James Heaney, Estimation of Urban Imperviousness and its Impacts on Stormwater Systems, 129 JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT 5, 419 (2003).

P-69 Seth Rose & Norman Peters, Effects of Urbanization on streamflow in the Atlanta Area (Georgia, U.S.A.), HYDROLOGICAL PROCESSES 15, 1441-57 (2001).

P-70 Derek B. Booth, et. al., Reviving Urban Streams: Land Use, Hydrology, Biology, and Human Behavior, JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION (2004).

P-71 U.S. Environmental Protection Agency, Annotated Bibliography of Urban Wet Weather Flow Literature from 1996-2000.

P-72 Deposition of Thomas Reeder (July 7, 2006)

P-73 Deposition of Michael Randall (July 6, 2006)

P-74 Deposition of Kenneth Pickle (June 30, 2006)

P-75 Deposition of Bradley Bennett (June 30, 2006)

Respondent:

R-1 NPDES Permit No. NCS000395 for Mecklenburg County, Town of Cornelius, Davidson, Huntersville, Matthews, Mint Hill and Pineville (July 1, 2005)

R-2 NPDES Permit No. NCS000453 for Town of Indian Trail (Sept. 1, 2005)

R-3 NPDES Permit No. NCS000454 for Town of Stallings (Sept. 1, 2005)

R-4 July 2005 Review Draft Goose Creek Technical Support Document

R-5 Wildlife Resources Commission, Guidance Memorandum to Address and Mitigate Secondary and Cumulative Impacts to Aquatic and Terrestrial Wildlife Resources and Water Quality (Aug. 2002).

R-6 Total Maximum Daily Loads for Fecal Coliform for Goose Creek Final Report (Apr. 2004)

R-7 Response to Comments Summary, North Carolina MS4, Phase II Individual Permits

R-8 N.C. Admin. Code 02B Rules

STATUTES AND RULES IN ISSUE

33 U.S.C. § 1251 (2006)
33 U.S.C. § 1311 (2006)
33 U.S.C. § 1342 (2006)
33 U.S.C. § 1362 (2006)
40 C.F.R. § 122.21 (2006)
40 C.F.R. § 122.32 (2006)
40 C.F.R. § 122.34 (2006)
40 C.F.R. § 122.44 (2006)
40 C.F.R. § 130.2 (2006)
40 C.F.R. § 131.12 (2006)
N.C. Gen. Stat. 143-213 (2006)
N.C. Gen. Stat. 143-215.1 (2006)
N.C. Admin. Code 02B.0110 (2005)
N.C. Admin. Code 02B.0200 (2005)
N.C. Admin. Code 02B.0201 (2005)

N.C. Admin. Code 02B.0211 (2005)
N.C. Admin. Code 02H.0112 (2005)

MOTIONS

On March 10, 2006, Petitioners and Respondent filed a Joint Motion to Consolidate Cases, Continue Hearing, and Amend Scheduling Order and Deadlines in 05 EHR 2055 and 06 EHR 0164. The two cases collectively involved Petitioners' appeals of three NPDES Phase II stormwater permits in the Goose Creek watershed. On March 23, 2006, Chief Administrative Law Judge Julian Mann granted the motion to consolidate and reassigned the cases to Senior Administrative Law Judge Fred G. Morrison Jr.

On June 1, 2006, Respondent filed a Motion to Join Additional Parties. Respondent requested that the County of Mecklenburg, North Carolina, and the Towns of Cornelius, Davidson, Huntersville, Matthews, Mint Hill, Pineville, North Carolina; Indian Trial, North Carolina; and Stallings, North Carolina, be joined as necessary parties or, in the alternative, as permissive parties. In response, Petitioners opposed the motion and contended that the additional parties were not necessary parties. Petitioners also contended that the parties should not be joined as permissive parties because it would cause undue delay and prejudice to Petitioners. Of the proposed parties to be joined, only Mecklenburg County and the Town of Mint Hill filed a response. Both parties opposed the motion to be joined as additional parties to the litigation. Oral argument was held via teleconference on June 9, 2006. The undersigned denied the motion after considering written memos supporting and opposing the motion and at the conclusion of oral argument on July 5, 2006.

On June 30, Petitioners filed a Motion for Summary Judgment on Aggrieved Party Status. Following oral argument and prior to a ruling from the Court, Respondent agreed to stipulate to Petitioners' aggrieved party status in the Pretrial Order. Therefore, the undersigned did not rule on this motion.

Pursuant to N.C. Gen. Stat. § 150B-34 and-36, the ruling on the Motion to Join Additional Parties is a part of this Decision. All such rulings are hereby incorporated herein.

STIPULATIONS

In the Pretrial Order, the parties agreed to and the undersigned approved the following stipulations:

Procedural Stipulations from Pretrial Order:

1. North Carolina Wildlife Federation and Central Piedmont Group of the NC Sierra Club ("Petitioners") are entitled to bring these consolidated contested cases as "person[s] aggrieved" within the meaning of N.C. Gen. Stat. §§ 150B-2(6) and 23 (2006).

2. Petitioners timely filed Petitions for Contested Case Hearings to challenge three Phase II Stormwater Permits identified as NPDES Permit No. NCS000453 issued to the Town of Stallings, NPDES Permit No. NCS000454 issued to the Town of Indian

Trail, and NPDES Permit No. NCS000395 issued to Mecklenburg County.

3. Petitioners have the burden of proof to establish facts that Respondent has erred in one or more of the ways set forth in N.C. Gen. Stat. § 150B-23(a).

4. Presentation of Evidence:
(a) Petitioners shall present evidence first to show that the three stormwater permits do not "reasonably ensure compliance with applicable water quality standards and regulations of all affected states." N.C. Admin. Code tit. 15A, r. 02H.0112(c) (2006).
(b) If necessary, Respondent may then present evidence to show that the three stormwater permits at issue "reasonably ensure compliance with applicable water quality standards and regulations of all affected states."

5. Each of the Exhibits identified above is an authentic copy of the original, is a public record or a business or agency record kept in the ordinary course of business, and may be introduced into evidence without further identification of proof, all subject to objections for relevance.

Factual Stipulations from Pretrial Order:

1. The federal Clean Water Act requires certain governmental entities to control stormwater pollution into public waters. 33 U.S.C. § 1342(p)(2) (2005).

2. These governmental entities are required to obtain National Pollutant Discharge Elimination System ("NPDES") permits to eliminate or reduce to the maximum extent practicable discharges of pollution from stormwater.

3. The permitting program for stormwater discharges has been implemented in two phases. In Phase II, certain municipalities designated as "urbanizing" that serve less than 100,000 are required to obtain NPDES Phase II stormwater permits.

4. To meet federal Clean Water Act and state law requirements, the Towns of Indian Trail and Stallings, and Mecklenburg County, including the town of Mint Hill, were required to obtain Phase II stormwater discharge permits.

5. The federal regulations governing Phase II require owners and operators of municipal storm sewer systems ("MS4s") to apply for NPDES permits which require the implementation of six minimum measures within their stormwater systems to control pollution. 40 C.F.R. § 122.21(a) (2005). The six minimum measures consist of: (1) public education and outreach on stormwater impacts; (2) public involvement and participation in program design; (3) illicit discharge detection and elimination; (4) construction site stormwater pollution control; (5) post-construction stormwater management; and (6) pollution prevention and good housekeeping measures. 40 C.F.R. § 122.34(b) (2005).

6. Respondent issued a final NPDES Phase II stormwater permit to Mecklenburg County, including the Town of Mint Hill, on June 15, 2005, with effective dates from July 1, 2005, through June 30, 2010.

7. Respondent issued a final NPDES Phase II stormwater permit to the Town of Indian Trail on September 1, 2005, with effective dates from October 1, 2005, through September 30, 2010.

8. Respondent issued a final NPDES Phase II stormwater permit to the Town of Stallings on September 7, 2005, with effective dates from October 1, 2005, through September 30, 2010.

9. Goose Creek is a perennial stream fed by a number of perennial, intermittent and ephemeral tributaries. Goose Creek is a tributary to the Rocky River, which is in turn a tributary to the Pee Dee River (the lower portion of the Yadkin River). The Goose Creek watershed is located in southeastern Mecklenburg County and northwestern Union County, North Carolina. Portions of the Towns of Indian Trail, Stallings, and Mint Hill drain into the Goose Creek watershed.

10. The Carolina heelsplitter is a species of freshwater mussel. The U.S. Fish & Wildlife Service ("USFWS") listed the Carolina heelsplitter as endangered pursuant to the provisions of the Endangered Species Act on June 30, 1993. 58 Fed. Reg. 34,926 (June 30, 1993).

11. The Goose Creek watershed contains one of only seven remaining populations of the Carolina heelsplitter. In July 2002, the USFWS designated critical habitat for the Carolina heelsplitter, including portions of the main stems of Goose Creek and Duck Creek in Union County. 67 Fed. Reg. 44,502- 44,521 (July 2, 2002) Since the USFWS listed the Carolina heelsplitter as endangered, it has discovered two additional populations, raising the total to nine.

12. Goose Creek has its headwaters in southeastern Mecklenburg County within the jurisdiction of the Town of Mint Hill. Stormwater runoff from Mint Hill flows into Goose Creek at its headwaters and travels downstream into the critical habitat for the Carolina heelsplitter. Stormwater runoff from Indian Trail and Stallings flows into Goose Creek and travels downstream into the critical habitat for the Carolina heelsplitter.

13. The North Carolina Wildlife Resources Commission ("WRC") and the USFWS have jointly submitted to Respondent a draft technical support document containing their recommendations for a site-specific management plan to protect and preserve habitat for threatened or endangered species in Goose Creek.

14. The WRC, in coordination with the USFWS, also has issued guidance regarding water quality conditions required to sustain and recover federally listed endangered species, including the Carolina heelsplitter.

15.The NPDES Phase II stormwater permits Respondent issued to the Towns of Indian Trail and Stallings and Mecklenburg County, set the imperviousness threshold at twenty-four percent and require thirty-foot buffers on perennial and intermittent streams in the Goose Creek watershed.

16. Under the NPDES Phase II stormwater permits Respondent issued to the Towns of Indian Trail and Stallings and Mecklenburg County, developments with a built upon area less than twenty-four percent are not required to implement engineered storm-

water management controls to treat stormwater pollution.

17. Goose Creek does not meet water quality standards for fecal coliform. In 1998, Respondent placed Goose Creek on the 303(d) list of impaired waters due to fecal coliform violations. According to Respondent's listing document, the causes of water quality impairment in Goose Creek include construction activities and urban runoff/storm sewers. Goose Creek remains on the 303(d) list of impaired waters through the present.

18. On April 20, 2005, Respondent finalized and submitted to the U.S. EPA Total Maximum Daily Loads ("TMDL") for Fecal Coliform for Goose Creek. The TMDL allocates allowable pollutant loads from known sources so that required actions may be taken to restore the water to its intended uses.

19. The U.S. EPA approved and finalized the Goose Creek TMDL without substantial change on July 8, 2005.

20. The waste load allocation in the Goose Creek TMDL requires a ninety-two point five percent reduction of fecal coliform discharges from existing MS4s. EPA approved and finalized the Goose Creek TMDL without substantial change on July 8, 2005.

21. The Goose Creek TMDL specifically requires a ninety-two point five percent reduction of fecal coliform discharges from the MS4s in Indian Trail, Stallings, and Mint Hill, in order to meet water quality standards.

22. Petitioners voluntarily agree to dismiss as a non-suit and without prejudice claims brought under Section 9 of the Endangered Species Act in these consolidated cases.

23. Each of the Exhibits identified above is an authentic copy of the original, is a public record or a business or agency record kept in the ordinary course of business, and may be introduced into evidence without further identification of proof, all subject to objections for relevance.

FINDINGS OF FACT

1. Petitioner Central Piedmont Group of the North Carolina Sierra Club is a nonprofit organization. Central Piedmont Group is the local Sierra Club member group in Mecklenburg County. Central Piedmont Group members use, enjoy, and benefit aesthetically and recreationally from the Goose Creek watershed. Central Piedmont Group also has members who live within the Goose Creek watershed.

2. Petitioner North Carolina Wildlife Federation is a not-for-profit corporation founded in 1945. NCWF, which is an affiliate of the National Wildlife Federation ("NWF"), has 17,000 members in North Carolina. NWF has approximately 5 million members, including 25,000 members in North Carolina. NCWF has members who use, enjoy, and benefit aesthetically and recreationally from the Goose Creek watershed. NCWF also has members who live within the Goose Creek watershed.

3. Respondent North Carolina Department of Environment and Natural Resources ("NCDENR") Division of Water Quality ("DWQ") is the state agency charged with protecting water quality and has been delegated the authority to issue NPDES permits under the Clean Water Act.

4. Petitioners' witness, Thomas Stewart Blue, is an expert in the field of stormwater engineering and hydrology with a particular expertise in engineered stormwater controls, impervious surface limits, land development, and water quality modeling related to developing Total Maximum Daily Loads ("TMDL").

5. Petitioners' witness, John Fridell, a wildlife biologist with the United States Fish and Wildlife Service ("USFWS"), is an expert in wildlife biology with a particular expertise in the protection and recovery of the federally endangered Carolina heelsplitter.

6. Respondent's witness, Michael F. Randall, is an environmental engineer with the Division of Water Quality's Stormwater Permitting Unit. Mr. Randall was involved in discussions regarding the development of the three challenged NPDES permits, but was not in charge of drafting any of them.

7. Respondent's witness, Kenneth Bruce Pickle, is an environmental engineer with the Division of Water Quality's Stormwater Permitting Unit. Mr. Pickle was involved in drafting and noticing the NPDES Phase II stormwater permits for the Town of Indian Trail and the Town of Stallings.

8. Respondent's witness, Tilman Bradley Bennett, is the supervisor of the Division of Water Quality's Stormwater Permitting Unit. Mr. Bennett's responsibilities include oversight for all of the state's stormwater permitting programs, including the NPDES Phase II program.

9. Respondent's witness, Thomas Reeder, is the manager of the Division of Water Quality's Wetlands and Stormwater Branch. Mr. Reeder's responsibilities include oversight of any programs that are associated with wetlands and stormwater management in the state.

10. None of Respondent's witnesses were offered as experts or qualified as experts in the field of stormwater management or wildlife biology.

11. Water quality degradation occurs when alterations are made to the natural character of the watershed. The natural character of a watershed includes its physical integrity, such as the way in which water travels downstream and the amount of groundwater recharging the stream's base flow; its biological integrity, such as the biological diversity of organisms living in the streams; and its chemical integrity, such as the distribution of chemicals in the water. A system is considered degraded when one of these characteristics is altered by non-natural activities. For example, a stream may no longer be able to support the natural biological diversity in the stream.

12. Land development is one type of non-natural activity that causes water quality degradation. In particular, increased stormwater runoff arising from construction and post-construction land development activities causes significant water

quality degradation and aquatic habitat loss, resulting in lowered biological integrity for aquatic systems.

13. Stormwater runoff occurs when impervious surfaces increase within a watershed and rainfall can no longer infiltrate into soils. Surfaces that water cannot effectively pass through, such as asphalt, concrete, roof shingles, metal, gravel, and compacted soils.

14. Impervious surfaces collect pollutants, such as nutrients, sediment, petroleum products, and fecal coliform, deposited from other sources. During storm events, these collected pollutants are washed into aquatic systems as stormwater runoff.

15. Numerous scientific studies have shown that increased impervious surface in a watershed is correlated with water quality degradation. These studies have documented significant water quality degradation in streams draining watersheds with impervious surface area from zero to thirteen percent. One such study found that there is no safe threshold for impervious surface area because any increase in impervious surface results in detrimental impacts to sensitive aquatic species.

16. Increased stormwater runoff from impervious surfaces also causes increased runoff volume which detrimentally affects channel stability in aquatic systems. Stream channels will either widen their stream banks, down cut the stream bed, or do both to accommodate larger and more severe runoff events. The sediment from the eroded stream banks and bed will increase sediment loading in the stream.

17. Because increased impervious surfaces reduce the amount of natural infiltration in a watershed, groundwater recharge is also reduced. Groundwater contributes to a stream's base flow, which is the portion of water that comes from sources other than surface runoff. Thus, when groundwater recharge is reduced, base flow in streams is also reduced.

18. The NPDES Phase II stormwater permits at issue in these proceedings are intended to regulate new discharges of stormwater pollution from urban land development and to ameliorate the effects of stormwater pollution. Each permit contains six minimum measures consisting of: (1) public education; (2) public involvement in designing program; (3) illicit discharge detection and elimination; (4) construction site stormwater pollution control; (5) post-construction stormwater management; and (6) pollution prevention.

19. The NPDES Phase II stormwater permits at issue in these proceedings establish model practices for post-construction stormwater controls that constitute the minimum measures that must be implemented under the NPDES Phase II program. These model practices include a low-density option and a high-density option for stormwater controls in new development.

20. The low-density option applies to any new development that involves up to, but no more than, twenty-four percent impervious surface area or "built-upon area." Under this option, the only post-construction stormwater management measures are vegetated conveyances for transporting stormwater to the nearest stream and a thirty-foot setback from the stream for all impervious surfaces.

21. The high-density option applies to any new development that involves more than twenty-four percent impervious surface area. Under this option, the stormwater measures require a thirty-foot setback from the stream for all impervious surfaces and require the installation of engineered structural controls. The structural controls must treat the difference between the pre-and post-development runoff for a certain design storm and remove eighty-five percent of all total suspended solids ("TSS"). The design storm included in the model practices is the one year, twenty-four hour storm.

22. All three of the challenged NPDES Phase II stormwater permits incorporate these model practices as the post-construction measures included in the permits themselves. These three NPDES Phase II stormwater permits authorize discharges of stormwater pollution into the Goose Creek watershed from the following sources: (1) Mecklenburg County, specifically as it includes discharges from the Town of Mint Hill; (2) the Town of Indian Trail; and (3) the Town of Stallings.

23. Goose Creek is a perennial stream with its watershed located in southeastern Mecklenburg County and northwestern Union County, North Carolina. Goose Creek has its headwaters in southeastern Mecklenburg County within the jurisdiction of the Town of Mint Hill. Stormwater runoff from portions of the Towns of Indian Trail, Stallings, and Mint Hill drains into Goose Creek. Duck Creek is the other main tributary in the Goose Creek watershed and is a perennial stream.

24. Goose Creek depends on base flow, particularly during dry or drought periods. Without adequate base flow, streams in the Goose Creek watershed will not be able to maintain adequate flows during dry or drought periods and will become an intermittent stream.

25. Stormwater runoff from Mint Hill flows into Goose Creek at its headwaters and travels downstream into the critical habitat for the Carolina heelsplitter. Stormwater runoff from Indian Trail and Stallings flows into Goose Creek and travels downstream into the critical habitat for the Carolina heelsplitter.

26. The Carolina heelsplitter is a species of mussel and was federally listed by the USFWS as endangered pursuant to the provisions of the Endangered Species Act on June 30, 1993. The Goose Creek watershed contains one of only nine remaining populations of the Carolina heelsplitter mussel.

27. Urban land development is the most significant land use change in the Goose Creek watershed.

28. As urban development and impervious cover increases in the Goose Creek watershed, the upper reaches of Goose and Duck Creeks have experienced significant stream bank and stream bed erosion due to increased stormwater runoff.

29. Increased urban development has also caused base flow in Goose and Duck Creeks to decline. The USFWS has seen portions of Duck Creek completely dry up during dry periods due to low groundwater recharge levels.

30. Increased urban development has also caused the levels of several pollutants associated with stormwater to increase in the Goose Creek watershed. These pollutants include fecal coliform, ammonia, phosphorus, nitrate-nitrite, copper, and sediment. Although a TMDL has been developed to deal with fecal coliform issues, water quality standards are not in place for ammonia, phosphorus, nitrate-nitrite, copper, or sediment in the Goose Creek watershed.

31. As stated above, all three permits include the minimum model practices as the post-construction measures specified within the permits. Respondent issued the three NPDES Phase II stormwater permits with an imperviousness threshold for structural stormwater controls at twenty-four percent and a thirty-foot setback on perennial and intermittent streams in the Goose Creek watershed. For developments at or below twenty-four percent imperviousness, the only requirement beyond the thirty-foot setback is the use of vegetated conveyances. For developments above twenty-four percent imperviousness, the required measures include structural stormwater controls to treat the difference in pre-and post-development runoff for the one year, twenty-four hour storm and the controls must be designed to remove at least eighty-five percent TSS.

32. It is undisputed that water quality is degraded at impervious surface levels ranging between six to thirteen percent. It is also undisputed that there are many pollutant constituents in stormwater runoff beyond TSS. Those pollutants include nutrients, fecal coliform, pesticides, and petroleum products.

33. Because the permits do not adequately regulate impervious surfaces and pollutant constituents in stormwater runoff, the permits as drafted will not protect the biological integrity of the Goose Creek watershed and will result in water quality degradation.

34. Furthermore, it is undisputed that protection of biological integrity also requires the protection of the most sensitive species in a stream. It is also undisputed that protecting the biological integrity in the Goose Creek watershed includes protecting the Carolina heelsplitter.

35. The historic range of the federally endangered Carolina heelsplitter included wide portions of the Catawba, Pee Dee, Savannah, and Saluda river basins.

36. The current range of the Carolina heelsplitter is limited to nine surviving populations in the Catawba, Pee Dee, and Savannah river basins. One of the populations is found in the Goose Creek watershed.

37. Because the federally endangered Carolina heelsplitter is found in so few places today, the USFWS has determined that "any factors that adversely modify habitat or water quality in the stream reaches it now inhabits could further endanger the species."

38. The USFWS also has determined that "channel and streambank scouring associated with increased storm-water run-off; and the run-off of silt, fertilizers, pesticides, and other pollutants from various land disturbance activities with inadequate or poorly maintained erosion and stormwater control" are among the factors that adversely modify Carolina heelsplitter habitat.

39. The USFWS has documented a correlation between increased urban development and Carolina heelsplitter habitat degradation in the Goose Creek watershed. As urban development has increased in the upper portion of the watershed, Carolina heelsplitter habitat is being eliminated. Surveys conducted by the USFWS of Carolina heelsplitter habitat from the time of listing through 2005 show that habitat has steadily decreased as urban development has increased in the watershed.

40. The federally endangered Carolina heelsplitter lives in the gravelly, rocky substrate found along the stream bed in Goose and Duck Creeks in the Goose Creek watershed. The majority of the substrate in the upper reaches of both creeks has been eroded away by increased stormwater runoff, thereby significantly reducing the available habitat for the endangered mussel.

41. Pollutants, such as sediment, ammonia, phosphorus, nitrate-nitrite, and copper, found in stormwater runoff have been determined to be harmful to the Carolina heelsplitter.

42. Sediment from stormwater runoff affects the Carolina heelsplitter in four ways. First, because the mussels are filter feeders, the increased sediment loading in stormwater runoff can clog their gills affecting their respiration and feeding. Increased sediment in the streams can ultimately suffocate the mussels by accumulating on top of the mussels' habitat and burying the mussels. Second, sediment affects the stability of the stream bottom and can result in mussels being washed out of their habitat because the substrate becomes unstable. Third, other pollutants bind to sediment particles and get carried down into the substrate as the sediment settles out of the water column, thereby increasing the mussels' exposure to the pollutant. Finally, sediment detrimentally affects the health of fish in streams. The mussels rely upon a fish host in order to reproduce by having mussel larvae attach to the fish's gill to mature.

43. Ammonia is a pollutant that has been associated with stormwater runoff and is of particular concern with regard to mussels. Ammonia is extremely toxic to freshwater mussels. Ammonia levels in the Goose Creek watershed have been identified as already exceeding the levels of concern for mussels and monitoring indicates that the levels are on an increasing trend in the watershed.

44. Phosphorus and nitrate-nitrite are also associated with stormwater runoff. Both pollutants are nutrients and at excessive levels in a watershed can lead to algal blooms, which deplete the oxygen levels in the streams. Low oxygen levels detrimentally affect the Carolina heelsplitter. Algal blooms from excessive nutrient levels have been documented in the Goose Creek watershed. Monitoring in the watershed also indicates that phosphorus and nitrate-nitrite levels in the watershed are on an increasing trend.

45. Copper is also a constituent in stormwater runoff and has been found harmful to mussels at high concentrations. Copper levels exceeding the concern level for mussels have been documented in the Goose Creek watershed.

46. The USFWS, in conjunction with the N.C. Wildlife Resources Commission and the N.C. Natural Heritage Program, has identified measures for controlling stormwater

runoff and mitigating its detrimental impacts to the Carolina heelsplitter and its habitat in the Goose Creek watershed.

47. The USFWS provided Respondent with its determinations prior to the issuance of the three NPDES Phase II permits challenged in this proceeding, in the form of a letter and a draft site specific management plan.

48. Based on a review of scientific literature regarding appropriate buffer widths and on the field observations of the USFWS's own experts, the USFWS determined that two-hundred foot undisturbed riparian buffers on perennial streams and one-hundred foot undisturbed riparian buffers on intermittent streams are required to protect the Carolina heelsplitter in Goose Creek.

49. Based on a review of scientific literature regarding impervious surface or disturbance in the floodplain, and on the field observations of the USFWS's own experts, the USFWS determined that impervious surface, active management, and other land disturbances, such as sewer lines and water lines, should be prohibited in the Goose Creek floodplain.

50. Based on a review of scientific literature regarding impervious surface thresholds and on the field observations of the USFWS's own experts, the USFWS determined that any further increases in impervious surface in the Goose Creek watershed should be required to implement engineered stormwater controls to offset impacts to the stream.

51. Based on a review of scientific literature regarding impervious surface thresholds and on the field observations of the USFWS's own experts, the USFWS determined that water quality standards for phosphorus, nitrate-nitrite, copper, and ammonia should be in place in the Goose Creek watershed to protect the Carolina heelsplitter from toxic levels of these pollutants. For ammonia, the USFWS has determined that an acute water quality standard of 1.75 milligrams per liter and a chronic water quality standard of 0.50 milligrams per liter are necessary to protect the Carolina heelsplitter in the Goose Creek watershed. The USFWS has determined that a phosphorus water quality standard of 0.1 milligrams per liter and a nitrate-nitrite water quality standard of 0.4 milligrams per liter are necessary to protect the Carolina heelsplitter in the Goose Creek watershed. For copper, the USFWS has determined that an acute water quality standard of 3.6 micrograms per liter and a chronic water quality standard of 2.2 micrograms per liter are necessary to protect the Carolina heelsplitter in the Goose Creek watershed. Acute water quality standards constitute the level of a particular pollutant that can be tolerated for a short period of time. Chronic water quality standards constitute the level of a particular pollutant that can be tolerated repeatedly over time.

52. In issuing the three challenged NPDES Phase II permits, Respondent did not include the determinations made by the USFWS and did not include adequate protections for the federally endangered Carolina heelsplitter.

53. If development is allowed in the Goose Creek watershed pursuant to post-construction conditions and limitations in these three permits, the Carolina heelsplitter population in Goose Creek will be extirpated in two to five years.

54. As noted above and not disputed by any of Respondent's witnesses, stormwater pollution causes water quality degradation by increasing the volume of water entering an aquatic system, decreasing groundwater recharge and base flow, increasing pollutant loadings to streams, and detrimentally impacting biological communities within the aquatic system.

55. As stated above, under the low-density development option, the permits allow development up to and including twenty-four percent impervious surface without any stormwater management measures other than a vegetated conveyance and a thirty-foot setback. Scientific studies documenting the correlation between increases in impervious surface area and decreases in water quality have shown that impervious surface areas between six and thirteen percent result in significant water quality degradation. Thus, the low-density option in the three challenged NPDES permits will also result in further water quality degradation in the Goose Creek watershed.

56. The permits state that vegetated conveyances must be used to the maximum extent practicable, but do not include any design requirements and are not required to be constructed as to remove any of the major pollutant constituents of stormwater (e.g., sediment, nutrients, fecal coliform, heavy metals, and pesticides).

57. Vegetated conveyances have been shown to cause a net increase in pollutant loading in streams from stormwater runoff. The grassed areas become an attractant for water fowl and other wildlife, which then defecate in the conveyances causing a net increase in fecal coliform, ammonia, and nitrogen loading.

58. Under the high-density development option (for development above twenty-four percent impervious surface), the permits require that new developments include stormwater structural controls designed to treat the difference in the pre-and post-development runoff for the one year, twenty-four hour storm event and remove eighty-five percent of total suspended solids.

59. TSS are particles of soil or sediment suspended in the water column. TSS have a variety of effects on water quality. TSS can transport into streams other pollutants that attach to the solids. When it settles out of the water column, TSS can settle out to the bottom of the stream affecting the stability of the stream bed. TSS also affects the health of fish and can impair the biological integrity of an aquatic system.

60. Although the structural controls are required to be designed to remove eighty-five percent TSS, the permits do not have any requirements to ensure that the structural controls actually continue to perform at an eighty-five percent removal rate during the terms.

61. The permits require that the structural controls be designed to treat the difference in pre-and post-development runoff for the one year, twenty-four hour storm event. In Goose Creek, the one year, twenty-four hour storm event is a rainfall event with about 2.9 inches of rain.

62. The structural controls will not be able to remove eighty-five percent TSS in storm events larger than the one year, twenty-four hour storm event.

63. The one year, twenty-four hour storm event as a design standard is not sufficient to protect water quality in Goose Creek from degradation because it does not take into account antecedent conditions on a site, such as saturated soils from previous storm events.

64. The permits do not contain any volumetric requirements to protect channel stability, maintain base flow, or groundwater recharge for low-density or high-density development. Under the permits, the volume of stormwater during storm events will increase in the Goose Creek watershed and base flow to the watershed will be significantly reduced.

65. The three challenged NDPES stormwater permits do not have specific requirements directing how a structural control is to reduce the discharge of stormwater pollutants to the maximum extent practicable.

66. The three challenged NPDES Phase II stormwater permits do not require specific stormwater control measures to be in place for a particular development.

67. Rather than include specific requirements, the permits require the permittees to develop a stormwater management plan at some point in the future to reduce the discharge of pollutants to the maximum extent practicable.

68. The stormwater management plan is to contain more specific terms and provisions for controlling pollutants and can include additional measures to treat stormwater runoff. The terms include "effluent limitations" in the form of best management practices.

69. Although Respondent contends that the stormwater management plans are enforceable parts of the NPDES Phase II permits, the stormwater management plans are not attached or annexed to the NPDES Phase II stormwater permits.

70. Respondent did not include the stormwater management plans in the public notices for the draft permits.

71. When members of the public requested copies of the draft permits to comment upon, Respondent provided only the draft permit and not the stormwater management plan.

72. Goose Creek does not meet water quality standards for fecal coliform. In 1998, Respondent placed Goose Creek on the 303(d) list of impaired waters due to fecal coliform violations. According to Respondent's listing document, the causes of water quality impairment in Goose Creek include construction activities and urban runoff/storm sewers. Goose Creek remains on the 303(d) list of impaired waters through the present.

73. Respondent submitted the Total Maximum Daily Loads ("TMDL") for Fecal Coliform for Goose Creek to the U.S. Environmental Protection Agency ("EPA") for final approval on April 20, 2005. The TMDL allocates allowable fecal coliform loads from known sources so that remedial measures may be implemented to remove the water quality impairment.

74. The EPA approved and finalized the Goose Creek TMDL without substantial change on July 8, 2005.

75. The finalized waste load allocation in the Goose Creek TMDL requires a ninety-two point five percent (92.5%) reduction of current fecal coliform discharges from existing municipal separate storm sewer systems

76. Indian Trail, Stallings, and Mecklenberg County own and operate MS4s in the Goose Creek watershed.

77. The Goose Creek TMDL specifically requires a ninety-two point five percent (92.5%) reduction of current fecal coliform discharges from Indian Trail, Stallings, and the portions of Mecklenburg County within the Goose Creek watershed, in order to meet water quality standards.

78. The three NPDES Phase II stormwater permits for Indian Trail, Stallings, and Mecklenburg County, do not contain terms and conditions that would require reductions from current loadings of fecal coliform from stormwater runoff.

79. If development continues in the Goose Creek watershed as permitted under these three NDPES Phase II stormwater permits, fecal coliform loading will increase.

BASED UPON the foregoing Stipulations and Findings of Fact, the undersigned makes the following:

CONCLUSIONS OF LAW

1. The Office of Administrative Hearings has jurisdiction to hear this case pursuant to N.C. Gen. Stat. § 150B-23 (2006).

2. Petitioners are persons aggrieved by the issuance of these three NPDES Phase II permits within the meaning of the Administrative Procedure Act.

3. All parties have been correctly designated and are properly before the Office of Administrative Hearings. The Office of Administrative Hearings has jurisdiction over the parties and the subject matter.

4. Petitioners bear the burden of proof on the issues.

5. Pursuant to the federal Clean Water Act, certain governmental entities are required to obtain NPDES Phase II stormwater permits to reduce and control stormwater pollution into public waters. 33 U.S.C. § 1342 (p)(2) (2006). In particular, with regard to the issues in this case, Mecklenburg County and the Towns of Mint Hill, Indian Trail, and Stallings are required to obtain NPDES Phase II stormwater permits for discharges of stormwater pollution from new development. 40 C.F.R. § 122.32 (2006).

Contested Issue No. 1:

6. Pursuant to 40 C.F.R. § 122.44(d) (2006) and N.C. Gen. Stat. § 143.215.1(a)(6) (2006), Respondent was responsible for ensuring that the NPDES Phase II permits for Indian Trail, Stallings, and Mecklenburg County complied with all applicable state water quality requirements.

7. North Carolina's state water quality regulations recognize the protection of biological integrity as a state water quality standard and as a best usage of all freshwaters. 15A N.C. Admin. Code 02B.0211(1) (2006).

8. North Carolina regulations require that "[t]he water shall be suitable for aquatic life propagation and maintenance of biological integrity, wildlife, secondary recreation, and agriculture. Sources of water pollution which preclude any of these uses on either a short-term or long-term basis shall be considered to be violating a water quality standard." 15A N.C. Admin. Code 02B.0211(2) (2006).

9. Biological integrity is "the ability of an aquatic ecosystem to support and maintain a balanced and indigenous community of organisms having species composition, diversity, population densities and functional organization similar to that of reference conditions." 15A N.C. Admin. Code 02B.0200(11) (2006). Respondent's legal obligation to protect biological integrity necessarily includes the protection of the most sensitive species within a watershed. Id. Therefore, in the Goose Creek watershed, biological integrity encompasses the ability of the watershed to maintain the federally endangered Carolina heelsplitter population.

10. Furthermore, North Carolina's antidegradation policy requires that "existing uses" of all waters must be maintained. 15A N.C. Admin. Code 02B.0201(b) (2006). North Carolina water quality standards recognize that an existing use of a water body includes providing habitat for endangered or threatened species. 15A N.C. Admin. Code 02B.0110 (2006). Since providing habitat for the Carolina heelsplitter is an existing use in the Goose Creek watershed, the NPDES Phase II stormwater permits must ensure that habitat for the Carolina heelsplitter is maintained and protected. 15A N.C. Admin. Code 02B.0201(b) (2006).

11. Respondent violated the Clean Water Act and N.C. Gen. Stat. § 143.215.1(a)(6) (2006) when it issued the permits without ensuring compliance with all applicable state water quality standards. This conclusion is supported by numerous Findings of Fact, which will not be recited again in detail here but which may be summarized as follows:

a. The USFWS determined that certain stormwater mitigation measures were necessary to protect the federally endangered Carolina heelsplitter in Goose Creek. These measures include two-hundred-foot buffers on perennial streams and one-hundred-foot buffers on intermittent streams, a zero to six percent impervious surface threshold for triggering the need for structural stormwater controls, and water quality standards for the major constituents of concern.

b. The USFWS provided its determinations to Respondent in the form of a draft Technical Support Document for the Goose Creek Site-Specific Management Plan well before the permits were issued.

c. Respondent issued the three challenged NPDES Phase II stormwater permits with measures that fall well short of the USFWS's determinations. The permits set the impervious surface threshold at twenty-four percent and only require a thirty-foot setback of impervious surfaces from streams. According to the USFWS, the Carolina heelsplitter population in Goose Creek will be extirpated within two to five years if development is allowed as permitted by the three challenged NPDES Phase II stormwater permits.

12. Respondent also violated the state antidegradation policy when it issued the permits without ensuring that the existing use of providing habitat for the federally endangered Carolina heelsplitter was adequately protected from stormwater discharges. Again, as detailed in the Findings of Fact, Respondent ignored the determinations made by the USFWS regarding stormwater measures that would be necessary to protect the Carolina heelsplitter population in Goose Creek.

13. Because Respondent violated its own rules in issuing the permits without ensuring compliance with all state water quality standards and the state antidegradation policy, Respondent acted arbitrarily and capriciously in issuing the three challenged NPDES stormwater permits. N.C. Gen. Stat. § 150B-23(a)(4) (2006). An agency action is arbitrary and capricious if it clearly shows "a lack of fair and careful consideration or want of impartial, reasoned decision-making." Comm'r. of Ins. v. Rate Bureau, 300 N.C. 381, 269 S.E. 2d 547 (1980). When an agency's decision is not in accordance with its own rules or policies, the agency has shown a lack of fair and careful consideration and has acted arbitrarily and capriciously. Joyce v. Winston-Salem State University, 91 N.C. App. 153 (1988).

14. Because Respondent violated its own regulations and the requirements of the federal Clean Water Act, Respondent also exceeded its statutory authority, failed to use proper procedure, and acted contrary to law. N.C. Gen. Stat. § 150B-23(a)(1)-(5) (2006).

Contested Issue No. 2:

15. The federal regulations implementing the Phase II permitting program require regulated entities to "develop, implement, and enforce a stormwater management program designed to reduce the discharge of pollutants ... to the maximum extent practicable, to protect water quality, and to satisfy the appropriate requirements of the Clean Water Act." 40 C.F.R. § 122.34(a) (2006).

16. The requirement to reduce discharges to the maximum extent practicable is distinct from other requirements under 40 C.F.R. § 122.34(a) (2006). Under this requirement, permittees may be required to go beyond compliance with state water quality standards and implement stormwater measures that are more than standard practice.

17. "Maximum extent practicable" means to the fullest degree technologically feasible for the protection of water quality, except where costs are wholly disproportionate to the potential benefits. See Haeuser v. Department of Law, 97 F.3d 1152, 1155 (9th Cir. 1996); Rybachek v. United States E.P.A., 904 F.2d 1276, 1289 (9th Cir. 1990); Ass'n of Pac. Fisheries v. United States E.P.A., 615 F.2d 794, 805 (9th Cir. 1980). This standard requires more of permittees than mere compliance with water quality standards or numeric effluent limitations designed to meet such standards. Envtl. Def. Center, Inc. v. United States E.P.A., 319 F.3d 398, 425-26 (9th Cir. 2003).

18. The term "maximum extent practicable" in the stormwater context implies that the mitigation measures in a stormwater permit must be more than simply adopting standard practices. This definition applies particularly in areas where standard practices are already failing to protect water quality, such as the Goose Creek watershed.

19. Respondent violated 40 C.F.R. § 122.34(a) (2006) because it failed to require stormwater measures that achieve the maximum extent practicable standard. As set out more fully in the Findings of Fact, the permits set the impervious surface thresholds for structural controls at twenty-four percent and require only thirty-foot setbacks. These limits do not reduce discharge to the maximum extent practicable. The USFWS has provided Respondent with measures that, if implemented, would reduce stormwater pollution into Goose Creek to the maximum extent practicable. Those measures include a zero (or at a minimum a six percent) impervious surface threshold for structural stormwater controls, two-hundred foot undisturbed riparian buffers on perennial streams, one-hundred foot undisturbed riparian buffers on intermittent streams, setbacks on all new disturbances in the one-hundred year floodplain, and water quality standards for ammonia, phosphorus, nitrate-nitrite, and copper. Those measures constitute what is "technologically feasible" in Goose Creek and thus should have been incorporated into the permits. Furthermore, other types of structural controls are available, such as infiltration measures, which would reduce discharges more than the measures contained in the permits. The limits in the permits are no more than standard practice and as such do not meet the maximum extent practicable standard.

20. The Clean Water Act requires that all effluent limitations and pollution control terms or limitations must be included in the NPDES permit. See 33 U.S.C. §§ 1311(a)-(b), 1342(a) (2006).

21. An effluent limitation is "any restriction established by a State ... on quantities, rates, and concentrations of chemical, physical, biological, and other constituents which are discharged from point sources." 33 U.S.C. § 1362(11) (2006).

22. The challenged permits require the permittees to develop and implement stormwater management plans "to reduce the discharge of pollutants ... to the maximum extent practicable, to protect water quality, and to satisfy the applicable water quality requirements of the Clean Water Act." As explained more fully in Findings of Fact 66-71, these stormwater management plans contain effluent limitations which are not a part of the NPDES permit because Respondent did not attach or annex the stormwater management plans to the permits. Therefore, Respondent violated 33 U.S.C. §§ 1311(a)-(b) and 1342(a) in issuing the NPDES Phase II stormwater permits to Indian Trail, Stallings, and Mecklenburg County.

23. The Clean Water Act further requires that state agencies issuing NPDES permits follow certain notice and comment procedures in developing new permits. "[P]ublic participation in the development, revision, and enforcement of any regulation, standard, effluent limitation, plan or program established by ... any State under this Act shall be provided for, encouraged, and assisted by ... the States." 33 U.S.C. § 1251(e) (2006).

24. The Second Circuit Court of Appeals recently invalidated federal regulations governing NPDES permitting for confined animal operations that did not require nutrient management plans to be included in the permit and noticed to the public. Waterkeeper Alliance, Inc., et. al. v. EPA, 2005 U.S. App. LEXIS 6533, 6540 (2nd Cir. 2005). "Since nutrient management plans embody all the relevant 'site specific management practices,' it is clear that...nutrient management plans are a sine qua non of the 'regulation, standard, plan, or program' " under 33 U.S.C. § 1251(e) (2006). The Court held that because the management plans contained non-numerical effluent limitations in the form of best management practices, the rule "by failing to require that the terms of the nutrient management plans be included in NPDES permits - violates the Clean Water Act and is otherwise arbitrary and capricious in violation of the Administrative Procedure Act."

25. In the stormwater permitting context, stormwater management plans are equivalent to nutrient management plans. The stormwater management plans are supposed to contain "all relevant 'site specific management measures' " that will be implemented in the Goose Creek watershed to reduce the discharge of stormwater pollution. Waterkeeper Alliance, Inc, 2005 U.S. App. LEXIS at 43. Therefore, Respondent violated 33 U.S.C. §§ 1311(a)-(b) and 1342(a) by not including the plans in the NPDES Phase II stormwater permits.

26. As a necessary part of the NPDES permits, the stormwater management plans should also have been subject to the public participation requirement under 33 U.S.C. § 1251(e) (2006). Pursuant to 33 U.S.C. § 1342(j) (2006), "a copy of each permit application and each permit issued under this section shall be available to the public." Since the three challenged NPDES Phase II permits were noticed without including the stormwater management plans, Respondent violated 33 U.S.C. §§ 1251(e), 1311, 1342(a) (2006). Further, Respondent violated 33 U.S.C. § 1342(j) (2006) by failing to provide copies of the stormwater management plans to members of the public who requested copies of the draft permit.

27. Because Respondent violated the requirements of the federal Clean Water Act and the federal regulations implementing the Phase II program, Respondent exceeded its statutory authority, failed to use proper procedure, acted contrary to law, and acted arbitrarily and capriciously. N.C. Gen. Stat. § 150B-23(a)(1)-(5) (2006).

Contested Issue No. 3:

28. NPDES permits must contain "any more stringent limitation ... necessary to meet water quality standards." 33 U.S.C. § 1311(b)(1)(C) (2006). Pursuant to this requirement, NPDES permits for discharges to waters for which a TMDL has been established must be consistent with the waste load allocation in the TMDL. 40 C.F.R. §§ 122.44(d)(a)(vii)(B); 130.12(a) (2006).

29. As discussed more fully in the Findings of Fact 72-79, Goose Creek is subject to a final TMDL for fecal coliform discharges. The waste load allocation in the Goose Creek TMDL calls for a ninety-two point five percent (92.5%) reduction in current fecal coliform discharges.

30. The challenged permits do not contain limits and conditions that will reduce current discharges. The permits as written will in fact increase fecal coliform

discharges.

31. By not including limits and conditions that will reduce current discharges of fecal coliform, Respondent has violated 33 U.S.C. § 1311(b)(1)(C) and 40 C.F.R. §§ 122.44 (d)(a)(vii)(B) and 130.12(a).

32. Because Respondent violated the requirements of the federal Clean Water Act, Respondent also exceeded its statutory authority, failed to use proper procedure, acted contrary to law, and acted arbitrarily and capriciously. N.C. Gen. Stat. § 150B-23(a)(1)-(5) (2006).

BASED UPON the foregoing Stipulations, Findings of Fact and Conclusions of Law, the undersigned renders the following:

DECISION

That Respondent must reopen, amend, and reissue the NPDES permits to incorporate the USFWS's determinations of measures necessary to protect the habitat for the Carolina heelsplitter. Those measures are two-hundred foot buffers for perennial streams, one-hundred foot buffers for intermittent streams, a zero percent impervious surface threshold for structural stormwater controls, no new impervious surface in the one-hundred year floodplain, and water quality standards for ammonia, copper, nitrate-nitrite, and phosphorus.

NOTICE

The agency making the final decision in this contested case is required to give each party an opportunity to file exceptions to this Decision and to present written arguments to those in the agency who will make the final decision. N. C. Gen. Stat. § 150B-36(a). In accordance with N.C. Gen. Stat. § 150B-36, the agency shall adopt each finding of fact contained in the Administrative Law Judge's decision unless the finding is clearly contrary to the preponderance of the admissible evidence, giving due regard to the opportunity of the Administrative Law Judge to evaluate the credibility of witnesses. For each finding of fact not adopted by the agency, the agency shall set forth separately and in detail the reasons for not adopting the finding of fact and the evidence in the record relied upon by the agency. Every finding of fact not specifically rejected as required by Chapter 150B shall be deemed accepted for purposes of judicial review. For each new finding of fact made by the agency that is not contained in the Administrative Law Judge's decision, the agency shall set forth separately and in detail the evidence in the record relied upon by the agency establishing that the new finding of fact is supported by a preponderance of the evidence in the official record.

The agency that will make the final decision in this case is the North Carolina Department of Environment and Natural Resources. The agency is required by N.C.G.S. 150B-36(b) to serve a copy of the final decision on all parties and to furnish a copy to the parties' attorneys of record and to the Office of Administrative Hearings.

This the 13th day of October, 2006.

Fred G. Morrison Jr.

Senior Administrative Law Judge

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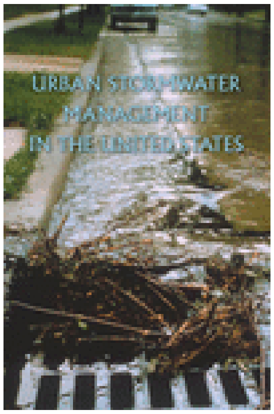

Urban Stormwater Management in the United States

Committee on Reducing Stormwater Discharge Contributions to Water Pollution, National Research Council

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URBAN STORMWATER MANAGEMENT IN THE UNITED STATES

Committee on Reducing Stormwater Discharge
Contributions to Water Pollution

Water Science and Technology Board

Division on Earth and Life Studies

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COMMITTEE ON REDUCING STORMWATER DISCHARGE CONTRIBUTIONS TO WATER POLLUTION

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Preface

Stormwater runoff from the built environment remains one of the great challenges of modern water pollution control, as this source of contamination is a principal contributor to water quality impairment of waterbodies nationwide. In addition to entrainment of chemical and microbial contaminants as stormwater runs over roads, rooftops, and compacted land, stormwater discharge poses a physical hazard to aquatic habitats and stream function, owing to the increase in water velocity and volume that inevitably result on a watershed scale as many individually managed sources are combined. Given the shift of the world's population to urban settings, and that this trend is expected to be accompanied by continued wholesale landscape alteration to accommodate population increases, the magnitude of the stormwater problem is only expected to grow.

In recognition of the need for improved control measures, in 1987 the U.S. Congress mandated the U.S. Environmental Protection Agency (EPA), under amendments to the Clean Water Act, to control certain stormwater discharges under the National Pollutant Discharge Elimination System. In response to this federal legislation, a permitting program was put in place by EPA as the Phase I (1990) and Phase II (1999) stormwater regulations, which together set forth requirements for municipal separate storm sewer systems and industrial activities including construction. The result of the regulatory program has been identification of hundreds of thousands of sources needing to be permitted, which has put a strain on EPA and state administrative systems for implementation and management. At the same time, achievement of water quality improvement as a result of the permit requirements has remained an elusive goal.

To address the seeming intractability of this problem, the EPA requested that the National Research Council (NRC) review its current permitting program for stormwater discharge under the Clean Water Act and provide suggestions for improvement. The broad goals of the study were to better understand the links between stormwater pollutant discharges and ambient water quality, to assess the state of the science of stormwater management, and to make associated policy recommendations. More specifically, the study was asked to:

(1) Clarify the mechanisms by which pollutants in stormwater discharges affect ambient water quality criteria and define the elements of a "protocol" to link pollutants in stormwater discharges to ambient water quality criteria.

(2) Consider how useful monitoring is for both determining the potential of a discharge to contribute to a water quality standards violation and for determining the adequacy of stormwater pollution prevention plans. What specific parameters should be monitored and when and where? What effluent

limits and benchmarks are needed to ensure that the discharge does not cause or contribute to a water quality standards violation?

(3) Assess and evaluate the relationship between different levels of stormwater pollution prevention plan implementation and in-stream water quality, considering a broad suite of best management practices (BMPs).

(4) Make recommendations for how to best stipulate provisions in stormwater permits to ensure that discharges will not cause or contribute to exceedances of water quality standards. This should be done in the context of general permits. As a part of this task, the committee will consider currently available information on permit and program compliance.

(5) Assess the design of the stormwater permitting program implemented under the Clean Water Act.

There are a number of related topics that one might expect to find in this report that are excluded, because EPA requested that the study be limited to problems addressed by the agency's stormwater regulatory program. Specifically, nonpoint source pollution from agricultural runoff, septic systems, combined sewer overflows, sanitary sewer overflows, and concentrated animal feeding operations are not addressed in this report. In addition, alteration of the urban base-flow hydrograph from a number of causes that are not directly related to storm events (e.g., interbasin transfers of water, leakage from water supply pipes, lawn irrigation, and groundwater withdrawals) is a topic outside the scope of the report and therefore not included in any depth.

In developing this report, the committee benefited greatly from the advice and input of EPA representatives, including Jenny Molloy, Linda Boornazian, and Mike Borst; representatives from the City of Austin; representatives from King County, Washington, and the City of Seattle; and representatives from the Irvine Ranch Water District. The committee heard presentations by many of these individuals in addition to Chris Crockett, City of Philadelphia Water Department; Pete LaFlamme and Mary Borg, Vermont Department of Environmental Conservation; Michael Barrett, University of Texas at Austin; Roger Glick, City of Austin; Michael Piehler, UNC Institute of Marine Sciences, Keith Stolzenbach, UCLA; Steve Burges, University of Washington; Wayne Huber, Oregon State University; Don Theiler, King County; Charlie Logue, Clean Water Services, Hillsboro, Oregon; Don Duke, Florida Gulf Coast University; Mike Stenstrom, UCLA; Gary Wolff, California Water Board; Paula Daniels, City of Los Angeles Public Works; Mark Gold, Heal the Bay; Geoff Brosseau, California Stormwater Quality Association; Steve Weisberg, Southern California Coastal Water Research Project; Chris Crompton, Southern California Stormwater Monitoring Coalition; David Beckman, NRDC; and Eric Strecker, Geosyntec. We also thank all those stakeholders who took time to share with us their perspectives and wisdom about the various issues affecting stormwater.

The committee was fortunate to have taken several field trips in conjunction with committee meetings. The following individuals are thanked for their participation in organizing and guiding these trips: Austin (Kathy Shay, Mike Kelly, Matt Hollon, Pat Hartigan, Mateo Scoggins, David Johns, and Nancy McClintock); Seattle (Darla Inglis, Chris May, Dan Powers, Scott Bawden, Nat Scholz, John Incardona, Kate McNeil, Bob Duffner, and Curt Crawford); and Los Angeles (Peter Postlmayr, Matthew Keces, Alan Bay, and Sat Tamaribuchi).

Completion of this report would not have been possible without the Herculean efforts of project study director Laura Ehlers. Her powers to organize, probe, synthesize, and keep the committee on track with completing its task were simply remarkable. Meeting logistics and travel arrangements were ably assisted by Ellen De Guzman and Jeanne Aquilino.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Michael Barrett, University of Texas; Bruce Ferguson, University of Georgia; James Heaney, University of Florida; Daniel Medina, CH2MHILL; Margaret Palmer, University of Maryland Chesapeake Biological Laboratory; Kenneth Potter, University of Wisconsin; Joan Rose, Michigan State University; Eric Strecker, Geosyntec; and Bruce Wilson, Minnesota Pollution Control Agency.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Michael Kavanaugh, Malcolm Pirnie, Inc., and Richard Conway, Union Carbide Corporation, retired. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and institution.

Claire Welty,
Committee Chair

Contents

Summary

Urbanization is the changing of land use from forest or agricultural uses to suburban and urban areas. This conversion is proceeding in the United States at an unprecedented pace, and the majority of the country's population now lives in suburban and urban areas. The creation of impervious surfaces that accompanies urbanization profoundly affects how water moves both above and below ground during and following storm events, the quality of that stormwater, and the ultimate condition of nearby rivers, lakes, and estuaries.

The National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act (CWA) is the primary federal vehicle to regulate the quality of the nation's waterbodies. This program was initially developed to reduce pollutants from industrial process wastewater and municipal sewage discharges. These point sources were known to be responsible for poor, often drastically degraded conditions in receiving waterbodies. They were easily regulated because they emanated from identifiable locations, such as pipe outfalls. To address the role of stormwater in causing or contributing to water quality impairments, in 1987 Congress wrote Section 402(p) of the CWA, bringing stormwater control into the NPDES program, and in 1990 the U.S. Environmental Protection Agency (EPA) issued the Phase I Stormwater Rules. These rules require NPDES permits for operators of municipal separate storm sewer systems (MS4s) serving populations over 100,000 and for runoff associated with industry, including construction sites five acres and larger. In 1999 EPA issued the Phase II Stormwater Rule to expand the requirements to small MS4s and construction sites between one and five acres in size.

With the addition of these regulated entities, the overall NPDES program has grown by almost an order of magnitude. EPA estimates that the total number of permittees under the stormwater program at any time exceeds half a million. For comparison, there are fewer than 100,000 non-stormwater (meaning wastewater) permittees covered by the NPDES program. To manage the large number of permittees, the stormwater program relies heavily on the use of general permits to control industrial, construction, and Phase II MS4 discharges. These are usually statewide, one-size-fits-all permits in which general provisions are stipulated.

To comply with the CWA regulations, industrial and construction permittees must create and implement a stormwater pollution prevention plan, and MS4 permittees must implement a stormwater management plan. These plans document the stormwater control measures (SCMs) (sometimes known as best management practices or BMPs) that will be used to prevent stormwater emanating from these sources from degrading nearby waterbodies. These SCMs range from structural methods such as detention ponds and bioswales to non-structural methods such as designing new development to reduce the percentage of impervious surfaces.

A number of problems with the stormwater program as it is currently implemented have been recognized. First, there is limited information available on the effectiveness and longevity of many SCMs, thereby contributing to uncertainty in their performance. Second, the requirements for monitoring vary depending on the regulating entity and the type of activity. For example, a subset of industrial facilities must conduct "benchmark monitoring" and the results often exceed the values established by EPA or the states, but it is unclear whether these exceedances provide useful indicators of potential water quality problems. Finally, state and local stormwater programs are plagued by a lack of resources to review stormwater pollution prevention plans and conduct regular compliance inspections. For all these reasons, the stormwater program has suffered from poor accountability and uncertain effectiveness at improving the quality of the nation's waters.

In light of these challenges, EPA requested the advice of the National Research Council's Water Science and Technology Board on the federal stormwater program, considering all entities regulated under the program (i.e., municipal, industrial, and construction). The following statement of task guided the work of the committee:

(1) Clarify the mechanisms by which pollutants in stormwater discharges affect ambient water quality criteria and define the elements of a "protocol" to link pollutants in stormwater discharges to ambient water quality criteria.

(2) Consider how useful monitoring is for both determining the potential of a discharge to contribute to a water quality standards violation and for determining the adequacy of stormwater pollution prevention plans. What specific parameters should be monitored and when and where? What effluent limits and benchmarks are needed to ensure that the discharge does not cause or contribute to a water quality standards violation?

(3) Assess and evaluate the relationship between different levels of stormwater pollution prevention plan implementation and in-stream water quality, considering a broad suite of SCMs.

(4) Make recommendations for how to best stipulate provisions in stormwater permits to ensure that discharges will not cause or contribute to exceedances of water quality standards. This should be done in the context of general permits. As a part of this task, the committee will consider currently available information on permit and program compliance.

(5) Assess the design of the stormwater permitting program implemented under the CWA.

Chapter 2 of this report presents the regulatory history of stormwater control in the United States, focusing on relevant portions of the CWA and the federal and state regulations that have been created to implement the Act. Chapter 3 reviews the scientific aspects of stormwater, including sources of pollutants in stormwater, how stormwater moves across the land surface, and its impacts on receiving waters. Chapter 4 evaluates the current industrial and MS4 monitoring requirements, and it considers the multitude of models available for linking stormwater discharges to ambient water quality. Chapter 5 considers the vast suite of both structural and nonstructural measures designed to control stormwater and reduce its pollutant loading to waterbodies. In Chapter 6, the limitations and possibilities associated with a new regulatory approach are explored, as are those of a more traditional but enhanced scheme. This new approach, which rests on the broad foundation of correlative studies demonstrating the effects of urbanization on aquatic ecosystems, would reduce the impact of stormwater on receiving waters beyond any efforts currently in widespread practice.

THE CHALLENGE OF REGULATING STORMWATER

Although stormwater has been long recognized as contributing to water quality impairment, the creation of federal regulations to deal with stormwater quality has occurred only in the last 20 years. Because this longstanding environmental problem is being addressed so late in the development and management of urban areas, the laws that mandate better stormwater control are generally incomplete and are often in conflict with state and local rules that have primarily stressed the flood control aspects of stormwater management (i.e., moving water away from structures and cities as fast as possible). Many prior investigators have observed that stormwater discharges would ideally be regulated through direct controls on land use, strict limits on both the quantity and quality of stormwater runoff into surface waters, and rigorous monitoring of adjacent waterbodies to ensure that they are not degraded by stormwater discharges. Future land-use development would be controlled to minimize stormwater discharges, and impervious cover and volumetric restrictions would serve as proxies for stormwater loading from many of these developments. Products that contribute pollutants through stormwater—like de-icing materials, fertilizers, and vehicular exhaust—would be regulated at a national level to ensure that the most environmentally benign materials are used.

Presently, however, the regulation of stormwater is hampered by its association with a statute that focuses primarily on specific pollutants and ignores the volume of discharges. Also, most stormwater discharges are regulated on an individualized basis without accounting for the cumulative contributions from multiple sources in the same watershed. Perhaps most problematic is that the requirements governing stormwater dischargers leave a great deal of discretion to the dischargers themselves in developing stormwater pollution prevention plans and self-monitoring to ensure compliance. These problems are exacerbated by the fact that the dual responsibilities of land-use planning and stormwater management within local governments are frequently decoupled.

EPA's current approach to regulating stormwater is unlikely to produce an accurate or complete picture of the extent of the problem, nor is it likely to adequately control stormwater's contribution to waterbody impairment. The lack of rigorous end-of-pipe monitoring, coupled with EPA's failure to use flow or alternative measures for regulating stormwater, make it difficult for EPA to develop enforceable requirements for stormwater dischargers. Instead, the stormwater permits leave a great deal of discretion to the regulated community to set their own standards and to self-monitor. Current statistics on the states' implementation of the stormwater program, discharger compliance with stormwater requirements, and the ability of states and EPA to incorporate stormwater permits with Total Maximum Daily Loads are uniformly discouraging. Radical changes to the current regulatory program (see Chapter 6) appear necessary to provide meaningful regulation of stormwater dischargers in the future.

Flow and related parameters like impervious cover should be considered for use as proxies for stormwater pollutant loading. These analogs for the traditional focus on the "discharge" of "pollutants" have great potential as a federal stormwater management tool because they provide specific and measurable targets, while at the same time they focus regulators on water degradation resulting from the increased volume as well as increased pollutant loadings in stormwater runoff. Without these more easily measured parameters for evaluating the contribution of various stormwater sources, regulators will continue to struggle with enormously expensive and potentially technically impossible attempts to determine the pollutant loading from individual dischargers or will rely too heavily on unaudited and largely ineffective self-reporting, self-policing, and paperwork enforcement.

EPA should engage in much more vigilant regulatory oversight in the national licensing of products that contribute significantly to stormwater pollution. De-icing chemicals, materials used in brake linings, motor fuels, asphalt sealants, fertilizers, and a variety of other products should be examined for their potential contamination of stormwater. Currently, EPA does not apparently utilize its existing licensing authority to regulate these products in a way that minimizes their contribution to stormwater contamination. States can also enact restrictions on or tax the application of pesticides or other particularly toxic products. Even local efforts could ultimately help motivate broader scale, federal restrictions on particular products.

The federal government should provide more financial support to state and local efforts to regulate stormwater. State and local governments do not have adequate financial support to implement the stormwater program in a rigorous way. At the very least, Congress should provide states with financial support for engaging in more meaningful regulation of stormwater discharges. EPA should also reassess its allocation of funds within the NPDES program. The agency has traditionally directed funds to focus on the reissuance of NPDES wastewater permits, while the present need is to advance the NPDES stormwater program because NPDES stormwater permittees outnumber wastewater permittees more than five fold, and the contribution of diffuse sources of pollution to degradation of the nation's waterbodies continues to increase.

EFFECTS OF URBANIZATION ON WATERSHEDS

Urbanization causes change to natural systems that tends to occur in the following sequence. First, land use and land cover are altered as vegetation and topsoil are removed to make way for agriculture, or subsequently buildings, roads, and other urban infrastructure. These changes, and the introduction of a constructed drainage network, alter the hydrology of the local area, such that receiving waters in the affected watershed experience radically different flow regimes than prior to urbanization. Nearly all of the associated problems result from one underlying cause: loss of the water-retaining and evapotranspirating functions of the soil and vegetation in the urban landscape. In an undeveloped area, rainfall typically infiltrates into the ground surface or is evapotranspirated by vegetation. In the urban landscape, these processes of evapotranspiration and water retention in the soil are diminished, such that stormwater flows rapidly across the land surface and arrives at the stream channel in short, concentrated bursts of high discharge. This transformation of the hydrologic regime is a wholesale reorganization of the processes of runoff generation, and it occurs throughout the developed landscape. When combined with the introduction of pollutant sources that accompany urbanization (such as lawns, motor vehicles, domesticated animals, and industries), these changes in hydrology have led to water quality and habitat degradation in virtually all urban streams.

The current state of the science has documented the characteristics of stormwater runoff, including its quantity and quality from many different land covers, as well as the characteristics of dry weather runoff. In addition, many correlative studies show how parameters co-vary in important but complex and poorly understood ways (e.g., changes in macroinvertebrate or fish communities associated with watershed road density or the percentage of impervious cover). Nonetheless, efforts to create mechanistic links between population growth, land-use change, hydrologic alteration, geomorphic adjustments, chemical contamination in stormwater, disrupted energy flows and biotic interactions, and changes in ecological communities are still in development. Despite this assessment, there are a number of overarching truths that remain poorly integrated into stormwater management decision-making, although they have been robustly characterized for more than a decade and have a strong scientific basis that reaches even farther back through the history of published investigations.

There is a direct relationship between land cover and the biological condition of downstream receiving waters. The possibility for the highest levels of aquatic biological condition exists only with very light urban transformation of the landscape. Conversely, the lowest levels of biological condition are inevitable with extensive urban transformation of the landscape, commonly seen after conversion of about one-third to one-half of a contributing watershed into impervious area. Although not every degraded waterbody is a product of intense urban development, all highly urban watersheds produce severely degraded receiving waters.

The protection of aquatic life in urban streams requires an approach that incorporates all stressors. Urban Stream Syndrome reflects a multitude of effects caused by altered hydrology in urban streams, altered habitat, and polluted runoff. Focusing on only one of these factors is not an effective management strategy. For example, even without noticeably elevated pollutant concentrations in receiving waters, alterations in their hydrologic regimes are associated with impaired biological condition. More comprehensive biological monitoring of waterbodies will be critical to better understanding the cumulative impacts of urbanization on stream condition.

The full distribution and sequence of flows (i.e., the flow regime) should be taken into consideration when assessing the impacts of stormwater on streams. Permanently increased stormwater volume is only one aspect of an urban-altered storm hydrograph. It contributes to high in-stream velocities, which in turn increase streambank erosion and accompanying sediment pollution of surface water. Other hydrologic changes, however, include changes in the sequence and frequency of high flows, the rate of rise and fall of the hydrograph, and the season of the year in which high flows can occur. These all can affect both the physical and biological conditions of streams, lakes, and wetlands. Thus, effective hydrologic mitigation for urban development cannot just aim to reduce post-development peak flows to predevelopment peak flows.

Roads and parking lots can be the most significant type of land cover with respect to stormwater. They constitute as much as 70 percent of total impervious cover in ultra-urban landscapes, and as much as 80 percent of the directly connected impervious cover. Roads tend to capture and export more stormwater pollutants than other land covers in these highly impervious areas, especially in regions of the country having mostly small rainfall events. As rainfall amounts become larger, pervious areas in most residential land uses become more significant sources of runoff, sediment, nutrients, and landscaping chemicals. In all cases, directly connected impervious surfaces (roads, parking lots, and roofs that are directly connected to the drainage system) produce the first runoff observed at a storm-drain inlet and outfall because their travel times are the quickest.

MONITORING AND MODELING

The stormwater monitoring requirements under the EPA Stormwater Program are variable and generally sparse, which has led to considerable skepticism about their usefulness. This report considers the amount and value of the data collected over the years by municipalities (which are substantial on a nationwide basis) and by industries, and it makes suggestions for improvement. The MS4 and particularly the industrial stormwater monitoring programs suffer from a paucity of data, from inconsistent sampling techniques, and from requirements that are difficult to relate to the compliance of individual dischargers. For these reasons, conclusions about stormwater management are usually made with incomplete information. Stormwater management would benefit most substantially from a well-balanced monitoring program that encompasses chemical, biological, and physical parameters from outfalls to receiving waters.

Many processes connect sources of pollution to an effect observed in a downstream receiving water—processes that can be represented in watershed models, which are the key to linking stormwater dischargers to impaired receiving waters. The report explores the current capability of models to make such links, including simple models and more involved mechanistic models. At the present time, stormwater modeling has not evolved enough to consistently say whether a particular discharger can be linked to a specific waterbody impairment. Some quantitative predictions can be made, particularly those that are based on well-supported causal relationships of a variable that responds to changes in a relatively simple driver (e.g., modeling how a runoff hydrograph or pollutant loading change in response to increased impervious land cover). However, in almost all cases, the uncertainty in the modeling and the data (including its general unavailability), the scale of the problems, and the presence of multiple stressors in a watershed make it difficult to assign to any given source a specific contribution to water quality impairment.

Because of a 10-year effort to collect and analyze monitoring data from MS4s nationwide, the quality of stormwater from urbanized areas is well characterized. These results come from many thousands of storm events, systematically compiled and widely accessible; they form a robust dataset of utility to theoreticians and practitioners alike. These data make it possible to accurately estimate stormwater pollutant concentrations from various land uses. Additional data are available from other stormwater permit holders that were not originally included in the database and from ongoing projects, and these should be acquired to augment the database and improve its value in stormwater management decision-making.

Industry should monitor the quality of stormwater discharges from certain critical industrial sectors in a more sophisticated manner, so that permitting authorities can better establish benchmarks and technology-based effluent guidelines. Many of the benchmark monitoring requirements and effluent guidelines for certain industrial subsectors are based on inaccurate and old information. Furthermore, there has been no nationwide compilation and analysis of industrial benchmark data, as has occurred for MS4 monitoring data, to better understand typical stormwater concentrations of pollutants from various industries.

Continuous, flow-weighted sampling methods should replace the traditional collection of stormwater data using grab samples. Data obtained from too few grab samples are highly variable, particularly for industrial monitoring programs, and subject to greater uncertainly because of experimenter error and poor data-collection practices. In order to use stormwater data for decision making in a scientifically defensible fashion, grab sampling should be abandoned as a credible stormwater sampling approach for virtually all applications. It should be replaced by more accurate and frequent continuous sampling methods that are flow weighted. Flow-weighted composite monitoring should continue for the duration of the rain event. Emerging sensor systems that provide high temporal resolution and real-time estimates for specific pollutants should be further investigated, with the aim of providing lower costs and more extensive monitoring systems to sample both streamflow and constituent loads.

Watershed models are useful tools for predicting downstream impacts from urbanization and designing mitigation to reduce those impacts, but they are incomplete in scope and do not offer definitive causal links between polluted discharges and downstream degradation. Every model simulates only a subset of the multiple interconnections between physical, chemical, and biological processes found in any watershed, and they all use a grossly simplified representation of the true spatial and temporal variability of a watershed. To speak of a "comprehensive watershed model" is thus an oxymoron, because the science of stormwater is not sufficiently far advanced to determine causality between all sources, resulting stressors, and their physical, chemical, and biological responses. Thus, it is not yet possible to create a protocol that mechanistically links stormwater dischargers to the quality of receiving waters. The utility of models with more modest goals, however, can still be high—as long as the questions being addressed by the model are in fact relevant and important to the functioning of the watershed to which that model is being applied, and sufficient data are available to calibrate the model for the processes included therein.

STORMWATER MANAGEMENT APPROACHES

A fundamental component of EPA's stormwater program is the creation of stormwater pollution prevention plans that document the SCMs that will be used to prevent the permittee's stormwater discharges from degrading local waterbodies. Thus, a consideration of these measures—their effectiveness in meeting different goals, their cost, and how they are coordinated with one another—is central to any evaluation of the stormwater program. The statement of task asks for an evaluation of the relationship between different levels of stormwater pollution prevention plan implementation and in-stream water quality. Although the state of knowledge has yet to reveal the mechanistic links that would allow for a full assessment of that relationship, enough is known to design systems of SCMs, on a site-scale or local watershed scale, that can substantially reduce the effects of urbanization.

The characteristics, applicability, goals, effectiveness, and cost of nearly 20 different broad categories of SCMs to treat the quality and quantity of stormwater runoff are discussed in Chapter 5, organized as they might be applied from the rooftop to the stream. SCMs, when designed, constructed, and maintained correctly, have demonstrated the ability to reduce runoff volume and peak flows and to remove pollutants. A multitude of case studies illustrates the use of SCMs in specific settings and demonstrates that a particular SCM can have a measurable positive effect on water quality or a biological metric. However, the implementation of SCMs at the watershed scale has been too inconsistent and too recent to be able to definitively link their performance to the prolonged sustainment—at the watershed level—of receiving water quality, in-stream habitat, or stream geomorphology.

Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds. SCM implementation needs to be designed as a system, integrating structural and nonstructural SCMs and incorporating watershed goals, site characteristics, development land use, construction erosion and sedimentation controls, aesthetics, monitoring, and maintenance. Stormwater cannot be adequately managed on a piecemeal basis due to the complexity of both the hydrologic and pollutant processes and their effect on habitat and stream quality. Past practices of designing detention basins on a site-by-site basis have been ineffective at protecting water quality in receiving waters and only partially effective in meeting flood control requirements.

Nonstructural SCMs such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from a new development. Such SCMs should be considered first before structural practices. For example, lead concentrations in stormwater have been reduced by at least a factor of 4 after the removal of lead from gasoline. Not creating impervious surfaces or removing a contaminant from the runoff stream simplifies and reduces the reliance on structural SCMs.

SCMs that harvest, infiltrate, and evapotranspirate stormwater are critical to reducing the volume and pollutant loading of small storms. Urban municipal separate stormwater conveyance systems have been designed for flood control to protect life and property from extreme rainfall events, but they have generally failed to address the more frequent rain events (<2.5 cm) that are key to recharge and baseflow in most areas. These small storms may only generate runoff from paved areas and transport the "first flush" of contaminants. SCMs designed to remove this class of storms from surface runoff (runoff-volume-reduction SCMs—rainwater harvesting, vegetated, and subsurface) can also help address larger watershed flooding issues.

Performance characteristics are starting to be established for most structural and some nonstructural SCMs, but additional research is needed on the relevant hydrologic and water quality processes within SCMs across

different climates and soil conditions. Typical data such as long-term load reduction efficiencies and pollutant effluent concentrations can be found in the International Stormwater BMP Database. However, understanding the processes involved in each SCM is in its infancy, making modeling of these SCMs difficult. Seasonal differences, the time between storms, and other factors all affect pollutant loadings emanating from SCMs. Research is needed that moves away from the use of percent removal and toward better simulation of SCM performance. Research is particularly important for nonstructural SCMs, which in many cases are more effective, have longer life spans, and require less maintenance than structural SCMs. EPA should be a leader in SCM research, both directly by improving its internal modeling efforts and by funding state efforts to monitor and report back on the success of SCMs in the field.

The retrofitting of urban areas presents both unique opportunities and challenges. Promoting growth in these areas is desirable because it takes pressure off the suburban fringes, thereby preventing sprawl, and it minimizes the creation of new impervious surfaces. However, it is more complex than Greenfields development because of the need to upgrade existing infrastructure, the limited availability and affordability of land, and the complications caused by rezoning. These sites may be contaminated, requiring cleanup before redevelopment can occur. Both innovative zoning and development incentives, along with the careful selection SCMs, are needed to achieve fair and effective storm-water management in these areas. For example, incentive or performance zoning could be used to allow for greater densities on a site, freeing other portions of the site for SCMs. Publicly owned, consolidated SCMs should be strongly considered as there may be insufficient land to have small, on-site systems. The performance and maintenance of the former can be overseen more effectively by a local government entity. The types of SCMs that are used in consolidated facilities—particularly detention basins, wet/dry ponds, and stormwater wetlands—perform multiple functions, such as prevention of streambank erosion, flood control, and large-scale habitat provision.

INNOVATIVE STORMWATER MANAGEMENT AND REGULATORY PERMITTING

There are numerous innovative regulatory strategies that could be used to improve the EPA's stormwater program. The course of action most likely to check and reverse degradation of the nation's aquatic resources would be to **base all stormwater and other wastewater discharge permits on watershed boundaries instead of political boundaries.** Watershed-based permitting is the regulated allowance of discharges of water and wastes borne by those discharges to waters of the United States, with due consideration of: (1) the implications of those discharges for preservation or improvement of prevailing ecological conditions in the watershed's aquatic systems, (2) cooperation among political jurisdictions sharing a watershed, and (3) coordinated regulation and management of all discharges having the potential to modify the hydrology and water quality of the watershed's receiving waters.

Responsibility and authority for implementation of watershed-based permits would be centralized with a municipal lead permittee working in partnership with other municipalities in the watershed as co-permittees. Permitting authorities (designated states or, otherwise, EPA) would adopt a minimum goal in every watershed to avoid any further loss or degradation of designated beneficial uses in the watershed's component waterbodies and additional goals in some cases aimed at recovering lost beneficial uses. Permittees, with support by the states or EPA, would then move to comprehensive impact source analysis as a foundation for targeting solutions. The most effective solutions are expected to lie in isolating, to the extent possible, receiving waterbodies from exposure to those impact sources. In particular, low-impact design methods, termed Aquatic Resources Conservation Design in this report, should be employed to the fullest extent feasible and backed by conventional SCMs when necessary.

The approach gives municipal co-permittees more responsibility, with commensurately greater authority and funding, to manage all of the sources discharging, directly or through municipally owned conveyances, to the waterbodies comprising the watershed. This report also outlines a new monitoring program structured to assess progress toward meeting objectives and the overlying goals, diagnosing reasons for any lack of progress, and determining compliance by dischargers. The proposal further includes market-based trading of credits among dischargers to achieve overall compliance in the most efficient manner and adaptive management to determine additional actions if monitoring demonstrates failure to achieve objectives.

As a first step to taking the proposed program nationwide, a pilot program is recommended that will allow EPA to work through some of the more predictable impediments to watershed-based permitting, such as the inevitable limits of an urban municipality's authority within a larger watershed.

Short of adopting watershed-based permitting, other smaller-scale changes to the EPA stormwater program are possible. These recommendations do not preclude watershed-based permitting at some future date, and indeed they lay the groundwork in the near term for an eventual shift to watershed-based permitting.

Integration of the three permitting types is necessary, such that construction and industrial sites come under the jurisdiction of their associated municipalities. Federal and state NPDES permitting authorities do not presently have, and can never reasonably expect to have, sufficient personnel to inspect and enforce stormwater regulations on more than 100,000 discrete point source facilities discharging stormwater. A better structure would be one where the NPDES permitting authority empowers the MS4 permittees to act as the first tier of entities exercising control on stormwater discharges to the MS4 to protect water quality. The National Pretreatment Program, EPA's successful treatment program for municipal and industrial wastewater sources, could serve as a model for integration.

To improve the industrial, construction, and MS4 permitting programs in their current configuration, EPA should (1) issue guidance for MS4, industrial, and construction permittees on what constitutes a design storm for water quality purposes; (2) issue guidance for MS4 permittees on methods to identify high-risk industrial facilities for program prioritization such as inspections; (3) support the compilation and collection of quality industrial stormwater effluent data and SCM effluent quality data in a national database; and (4) develop numerical expressions of the MS4 standard of "maximum extent practicable." Each of these issues is discussed in greater detail in Chapter 6.

***

Watershed-based permitting will require additional resources and regulatory program support. Such an approach shifts more attention to ambient outcomes as well as expanded permitting coverage. Additional resources for program implementation could come from shifting existing programmatic resources. For example, some state permitting resources may be shifted away from existing point source programs toward stormwater permitting. Strategic planning and prioritization could shift the distribution of federal and state grant and loan programs to encourage and support more watershed-based stormwater permitting programs. However, securing new levels of public funds will likely be required. All levels of government must recognize that additional resources may be required from citizens and businesses (in the form of taxes, fees, etc.) in order to operate a more comprehensive and effective stormwater permitting program.

1
Introduction

URBANIZATION AND ITS IMPACTS

The influence of humans on the physical and biological systems of the Earth's surface is not a recent manifestation of modern societies; instead, it is ubiquitous throughout our history. As human populations have grown, so has their footprint, such that between 30 and 50 percent of the Earth's surface has now been transformed (Vitousek et al., 1997). Most of this land area is not covered with pavement; indeed, less than 10 percent of this transformed surface is truly "urban" (Grübler, 1994). However, urbanization causes extensive changes to the land surface beyond its immediate borders, particularly in ostensibly rural regions, through alterations by agriculture and forestry that support the urban population (Lambin et al., 2001). Within the immediate boundaries of cities and suburbs, the changes to natural conditions and processes wrought by urbanization are among the most radical of any human activity.

In the United States, population is growing at an annual rate of 0.9 percent (U.S. Census Bureau, *http://www.census.gov/compendia/statab/2007edition.html*); the majority of the population of the United States now lives in suburban and urban areas (Figure 1-1). Because the area appropriated for urban land uses is growing even faster, these patterns of growth all but guarantee that the influences of urban land uses will continue to expand over time. Cities and suburbia obviously provide the homes and livelihood for most of the nation's population. But, as this report makes clear, these benefits have been accompanied by significant environmental change. Urbanization of the landscape profoundly affects how water moves both above and below ground during and following storm events; the quality of that stormwater (defined in Box 1-1); and the ultimate condition of nearby rivers, lakes, and estuaries. Unlike agriculture, which can display significant interchange with forest cover over time scales of a century (e.g., Hart, 1968), there is no indication that once-urbanized land ever returns to a less intensive state. Urban land, however, does continue to change over time; by one estimate, 42 percent of land currently considered "urban" in the United States will be redeveloped by 2030 (Brookings Institute, 2004). In their words, "nearly half of what will be the built environment in 2030 doesn't even exist yet" (p. vi). This truth belies the common belief that efforts to improve management of stormwater are doomed to irrelevancy because so much of the landscape is already built. Opportunities for improvement have indeed been lost, but many more still await an improved management approach.

Measures of urbanization are varied, and the disparate methods of quantifying the presence and influence of human activity tend to confound analyses of environmental effects. Population density is a direct metric of human presence, but it is not the most relevant measure of the influence of those people on their surrounding landscape. Expressions of the built environment, most commonly

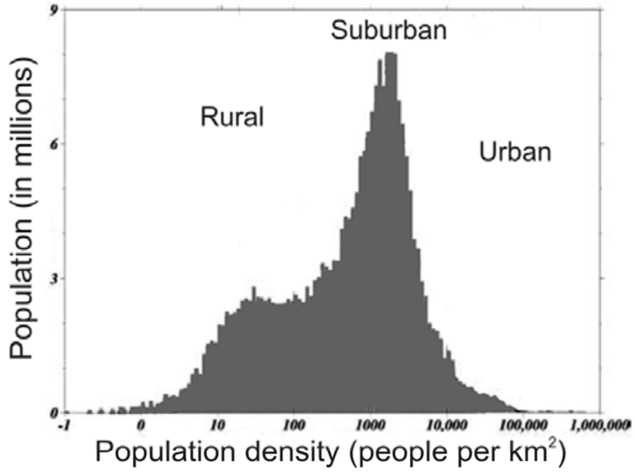


FIGURE 1-1 Histogram of population for the United States, based on 2000 census data. The median population density is about 1,000 people/km^2. SOURCE: Modified from Pozzi and Small (2005), who place the rural–suburban boundary at 100 people/km^2. Reprinted, with permission, from ASPRS (2005). Copyright 2005 by the American Society for Photogrammetry and Remote Sensing.

BOX 1-1
What Is "Stormwater"?

"Stormwater" is a term that is used widely in both scientific literature and regulatory documents. It is also used frequently throughout this report. Although all of these usages share much in common, there are important differences that benefit from an explicit discussion.

Most broadly, stormwater runoff is the water associated with a rain or snow storm that can be measured in a downstream river, stream, ditch, gutter, or pipe shortly after the precipitation has reached the ground. What constitutes "shortly" depends on the size of the watershed and the efficiency of the drainage system, and a number of techniques exist to precisely separate stormwater runoff from its more languid counterpart, "baseflow." For small and highly urban watersheds, the interval between rainfall and measured stormwater discharges may be only a few minutes. For watersheds of many tens or hundreds of square miles, the lag between these two components of storm response may be hours or even a day.

From a regulatory perspective, stormwater must pass through some sort of engineered conveyance, be it a gutter, a pipe, or a concrete canal. If it simply runs over the ground surface, or soaks into the soil and soon reemerges as seeps into a nearby stream, it may be water generated by the storm but it is not regulated stormwater.

This report emphasizes the first, more hydrologically oriented definition. However, attention is focused mainly on that component of stormwater that emanates from those parts of a landscape that have been affected in some fashion by human activities ("urban stormwater"). Mostly this includes water that flows over the ground surface and is subsequently collected by natural channels or artificial conveyance systems, but it can also include water that has infiltrated into the ground but nonetheless reaches a stream channel relatively rapidly and that contributes to the increased stream discharge that commonly accompanies almost any rainfall event in a human-disturbed watershed.

road density or pavement coverage as a percentage of gross land area, are more likely to determine stormwater runoff-related consequences. An inverse metric, the percentage of mature vegetation or forest across a landscape, expresses the magnitude of related, but not identical, impacts to downstream systems. Alternatively, these measures of land cover can be replaced by measures of land use, wherein the types of human activity (e.g., residential, industrial, commercial) are used as proxies for the suite of hydrologic, chemical, and biological changes imposed on the surrounding landscape.

All of these metrics of urbanization are strongly correlated, although none can directly substitute for another. They also are measured differently, which renders one or another more suitable for a given application. Land use is a common measure in the realm of urban planning, wherein current and future conditions for a city or an entire region are characterized using equivalent categories across parcels, blocks, or broad regions. Road density can be reliably and rapidly measured, either manually or in a Geographic Information System environment, and it commonly displays a very good correlation with other measures of human activity. "Land cover," however, and particularly the percentage of impervious cover, is the metric most commonly used in studying the effects of urban development on stormwater, because it clearly expresses the hydrologic influence and watershed scale of urbanization. Box 1-2 describes the ways in which the percent of impervious cover in a watershed is measured.

There is no universally accepted terminology to describe land-cover or land-use conditions along the rural-to-urban gradient. Pozzi and Small (2005), for example, identified "rural," "suburban," and "urban" land uses on the basis of population density and vegetation cover, but they did not observe abrupt transitions that suggested natural boundaries (see Figure 1-1). In contrast, the Center for Watershed Protection (2005) defined the same terms but used impervious area percentage as the criterion, with such labels as "rural" (0 to 10 percent imperviousness), "suburban" (10 to 25 percent imperviousness), "urban" (25 to 60 percent imperviousness) and "ultra-urban" (greater than 60 percent imperviousness).

Beyond the problems posed by precise yet inconsistent definitions for commonly used words, none of the boundaries specified by these definitions are reflected in either hydrologic or ecosystem responses. Hydrologic response is strongly dependent on both land cover and drainage connectivity (e.g., Leopold, 1968); ecological responses in urbanizing watersheds do not show marked thresholds along an urban gradient (e.g., Figure 1-2) and they are dependent on not only the sheer magnitude of urban development but also the spatial configuration of that development across the watershed (Alberti et al., 2006). This report, therefore, uses such terms as "urban" and "suburban" under their common usage, without implying or advocating for a more precise (but ultimately limited and discipline-specific) definition.

Changing land cover and land use influence the physical, chemical, and biological conditions of downstream waterways. The specific mechanisms by which this influence occurs vary from place to place, and even a cursory review

BOX 1-2
Measures of Impervious Cover

The percentage of impervious surface or cover in a landscape is the most frequently used measure of urbanization. Yet this parameter has its limitations, in part because it has not been consistently used or defined. Most significant is the distinction between ***total*** impervious area (TIA) and ***effective*** impervious area (EIA). TIA is the "intuitive" definition of imperviousness: that fraction of the watershed covered by constructed, non-infiltrating surfaces such as concrete, asphalt, and buildings. Hydrologically, however, this definition is incomplete for two reasons. First, it ignores nominally "pervious" surfaces that are sufficiently compacted or otherwise so low in permeability that the rate of runoff from them is similar or indistinguishable from pavement. For example, Burges and others (1998) found that the impervious unit-area runoff was only 20 percent greater than that from pervious areas—primarily thin sodded lawns over glacial till—in a western Washington residential subdivision. Clearly, this hydrologic contribution cannot be ignored entirely.

The second limitation of TIA is that it includes some paved surfaces that may contribute nothing to the stormwater-runoff response of the downstream channel. A gazebo in the middle of parkland, for example, probably will impose no hydrologic changes into the catchment except for a very localized elevation of soil moisture at the edge of its roof. Less obvious, but still relevant, would be the different downstream consequences of rooftops that drain alternatively into a piped storm-drain system with direct discharge into a natural stream or onto splash blocks that disperse the runoff onto the garden or lawn at each corner of the building. This metric therefore cannot recognize any stormwater mitigation that may result from alternative runoff-management strategies, for example, pervious pavements or rainwater harvesting.

The first of these TIA limitations, the production of significant runoff from nominally pervious surfaces, is typically ignored in the characterization of urban development. The reason for such an approach lies in the difficulty in identifying such areas and estimating their contribution, and because of the credible belief that the degree to which pervious areas shed water as overland flow should be related, albeit imperfectly, with the amount of *impervious* area: where construction and development are more intense and cover progressively greater fractions of the

of the literature demonstrates that many different factors can be important, such as changes to flow regime, physical and chemical constituents in the water column, or the physical form of the stream channel itself (Paul and Meyer, 2001). Not all of these changes are present in any given system—lakes, wetlands, and streams can be altered by human activity in many different ways, each unique to the activity and the setting in which it occurs. Nonetheless, direct influences of land-use change on freshwater systems commonly include the following (Naiman and Turner, 2000):

- Altering the composition and structure of the natural flora and fauna,
- Changing disturbance regimes,
- Fragmenting the land into smaller and more diverse parcels, and
- Changing the juxtaposition between parcel types.

Historically, human-induced alteration was not universally seen as a problem. In particular, dams and other stream-channel "improvements" were a watershed, it is more likely that the intervening green spaces have been stripped and compacted during construction and only imperfectly rehabilitated for their hydrologic functions during subsequent "landscaping."

The second of these TIA limitations, inclusion of non-contributing impervious areas, is formally addressed through the concept of EIA, defined as the impervious surfaces with direct hydraulic connection to the downstream drainage (or stream) system. Thus, any part of the TIA that drains onto pervious (i.e., "green") ground is excluded from the measurement of EIA. This parameter, at least conceptually, captures the hydrologic significance of imperviousness. EIA is the parameter normally used to characterize urban development in hydrologic models.

The direct measurement of EIA is complicated. Studies designed specifically to quantify this parameter must make direct, independent measurements of both TIA and EIA (Alley and Veenhuis, 1983; Laenen, 1983; Prysch and Ebbert, 1986). The results can then be generalized either as a correlation between the two parameters or as a "typical" value for a given land use. Sutherland (1995) developed an equation that describes the relationship between EIA and TIA. Its general form is:

$$\text{EIA} = A\,(\text{TIA})^{B}$$

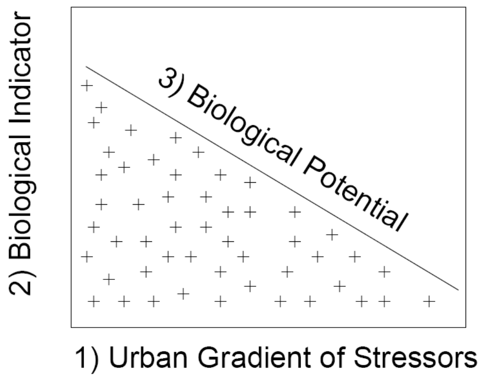
where A and B are a unique combination of numbers that satisfy the following criteria:

TIA = 1 then EIA = 0%
TIA = 100 then EIA = 100%

A commonly used version of this equation ($\text{EIA} = 0.15\ \text{TIA}^{1.41}$) was based on samples from highly urbanized land uses in Denver, Colorado (Alley and Veenhuis, 1983; Gregory et al., 2005). These results, however, are almost certainly region- and even neighborhood-specific, and, although highly relevant to watershed studies, they can be quite laborious to develop.

common activity of municipal and federal engineering works of the mid-20th century (Williams and Wolman, 1984). "Flood control" implied a betterment of conditions, at least for streamside residents (Chang, 1992). And fisheries "enhancements," commonly reflected by massive infrastructure for hatcheries or artificial spawning channels, were once seen as unequivocal benefits for fish populations (White, 1996; Levin et al., 2001).

By almost any currently applied metric, however, the net result of human alteration of the landscape to date has resulted in a degradation of the conditions in downstream watercourses. Many prior researchers, particularly when considering ecological conditions and metrics, have recognized a crude but monotonically declining relationship between human-induced landscape alteration and downstream conditions (e.g., Figure 1-2; Horner et al., 1997; Davies and Jackson, 2006). These include metrics of physical stream-channel conditions (e.g., Bledsoe and Watson, 2001), chemical constituents (e.g., Figure 1-3; House et al., 1993), and biological communities (e.g., Figure 1-4; Steedman, 1988; Wang et al., 1997).



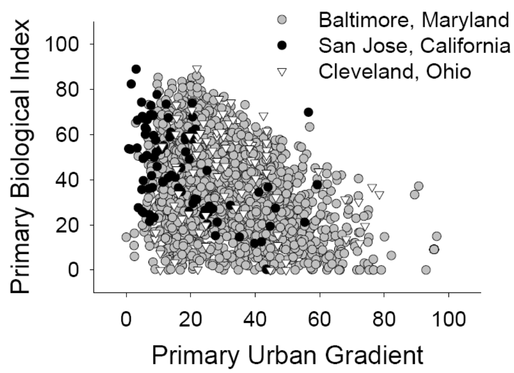


FIGURE 1-2 Conceptual model (top) and actual response (bottom) of a biological system's response to stress. The "Urban Gradient of Stressors" might be a single metric of urbanization, such as percent watershed impervious or road density; the "Biological Indicator" may be single-metric or multi-metric measures of the level of disturbance in an aquatic community. The right-declining line traces the limits of a "factor-ceiling distribution" (Thomson et al., 1986), wherein individual sites (i.e., data points) have a wide range of potential values for a given position along the urban gradient but are not observed above a maximum possible limit of the biological index. The bottom graph illustrates actual biological responses, using a biotic index developed to show responses to urban impacts plotted against a standardized urban gradient comprising urban land use, road density, and population. SOURCE: Top figure reprinted, with permission, from Davies and Jackson (2006). Copyright by the Ecological Society of America. Bottom figure reprinted, with permission, from Barbour et al. (2006). Copyright by the Water Environment Research Foundation.

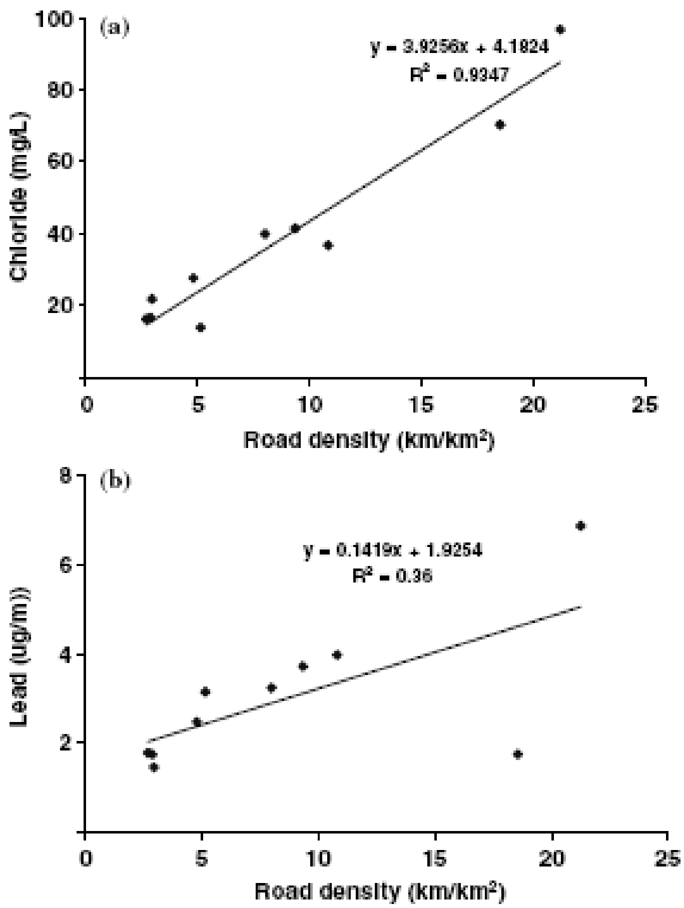


FIGURE 1-3 Example relationships between road density (a surrogate measure of urban development) and common water quality constituents. Direct causality is not necessarily implied by such relationships, but the monotonic increase in concentrations with increasing "urbanization," however measured, is near-universal. SOURCE: Reprinted, with permission, from Chang and Carlson (2005). Copyright 2005 by Springer.

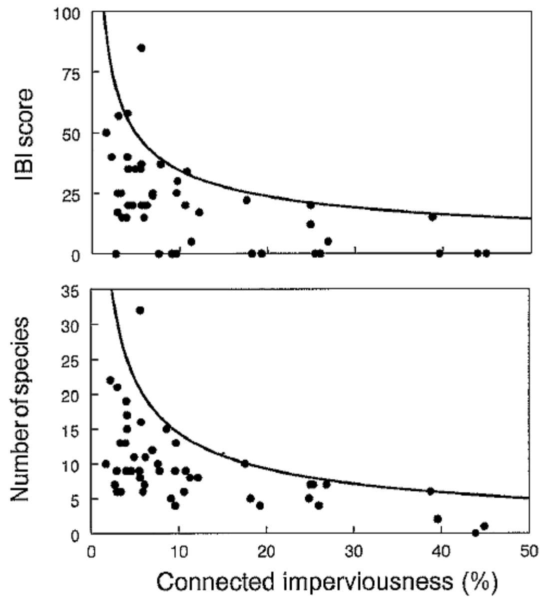


FIGURE 1-4 Plots of Effective Impervious Area (EIA, or "connected imperviousness") against metrics of biologic response in fish populations. SOURCE: Reprinted, with permission, from Wang et al. (2001). Copyright 2001 by Springer.

The association between watercourse degradation and landscape alteration in general, and urban development in particular, seems inexorable. The scientific and regulatory challenge of the last three decades has been to decouple this relationship, in some cases to reverse its trend and in others to manage where these impacts are to occur.

WHAT'S WRONG WITH THE NATION'S WATERS?

Since passage of the Water Quality Act of 1948 and the Clean Water Act (CWA) of 1972, 1977, and 1987, water quality in the United States has measurably improved in the major streams and rivers and in the Great Lakes. However, substantial challenges and problems remain. Major reporting efforts that have examined state and national indicators of condition, such as CWA 305(b) reports (EPA, 2002) and the Heinz State of the Nation's Ecosystem report (Heinz Center, 2002), or environmental monitoring that was designed to provide statistically valid estimates of condition (e.g., National Wadeable Stream Assessment; EPA, 2006), have confirmed widespread impairments related to diffuse sources of pollution and stressors.

The National Water Quality Inventory (derived from Section 305b of the CWA) compiles data in relation to use designations and water quality standards.

As discussed in greater detail in Chapter 2, such standards include both (1) a description of the use that a waterbody is supposed to achieve (such as a source of drinking water or a cold water fishery) and (2) narrative or numeric criteria for physical, chemical, and biological parameters that allow the designated use to be achieved. As of 2002, 45 percent of assessed streams and rivers, 47 percent of assessed lakes, 32 percent of assessed estuarine areas, 17 percent of assessed shoreline miles, 87 percent of near-coastal ocean areas, 51 percent of assessed wetlands, 91 percent of assessed Great Lakes shoreline miles, and 99 percent of assessed Great Lakes open water areas were not meeting water quality standards set by the states (2002 EPA Report to Congress).[1]

The U.S. Environmental Protection Agency (EPA) has also embarked on a five-year statistically valid survey of the nation's waters (http://www.epa.gov/owow/monitoring/guide.pdf). To date, two waterbody types—coastal areas and wadeable streams—have been assessed. The most recent data indicate that 42 percent of wadeable streams are in poor biological condition and 25 percent are in fair condition (EPA, 2006). The overall condition of the nation's estuaries is generally fair, with Puerto Rico and Northeast Coast regions rated poor, the Gulf Coast and West Coast regions rated fair, and the Southeast Coast region rated good to fair (EPA, 2007). These condition ratings for the National Estuary Program are based on a water quality index, a sediment quality index, a benthic index, and a fish tissue contaminants index.

The impairment of waterbodies is manifested in a multitude of ways. Indeed, EPA's primary process for reporting waterbody condition (Section 303(d) of the CWA—see Chapter 2) identifies over 200 distinct types of impairments. As shown in Table 1-1, these have been categorized into 15 broad categories, encompassing about 94 percent of all impairments. 59,515 waterbodies fall into one of the top 15 categories, while the total reported number of waterbodies impaired from all causes is 63,599 (which is an underestimate of the actual total because not all waterbodies are assessed). Mercury, microbial pathogens, sediments, other metals, and nutrients are the major pollutants associated with impaired waterbodies nationwide. These constituents have direct impacts on aquatic ecosystems and public health, which form the basis of the water quality standards set for these compounds. Sediments can harm fish and macroinvertebrate communities by introducing sorbed contaminants, decreasing available light in streams, and smothering fish eggs. Microbial pathogens can cause disease to humans via both ingestion and dermal contact and are frequently cited as the cause of beach closures and other recreational water hazards in lakes and estuaries. Nutrient over-enrichment can promote a cascade of events in waterbodies from algal blooms to decreases in dissolved oxygen and associated fish kills. Metals like mercury, pesticides, and other organic compounds that enter

[1] EPA does not yet have the 2004 assessment findings compiled in a consistent format from all the states. EPA is also working on processing the states 2006 Integrated Reports as the 303(d) portions are approved and the states submit their final assessment findings. Susan Holdsworth, EPA, personal communication, September 2007.

waterways can be taken up by fish species, accumulating in their tissues and presenting a health risk to organisms (including humans) that consume the fish.

However, Table 1-1 can be misleading if it implies that degraded *water quality* is the primary metric of impairment. In fact, many of the nation's streams, lakes, and estuaries also suffer from fundamental changes in their flow regime and energy inputs, alteration of aquatic habitats, and resulting disruption of biotic interactions that are not easily measured via pollutant concentrations. Such waters may not be listed on State 303(d) lists because of the absence of a corresponding water quality standard that would directly indicate such conditions (like a biocriterion). Figure 1-5A, B, and C show examples of such impacted waterbodies.

TABLE 1-1 Top 15 Categories of Impairment Requiring CWA Section 303(d) Action

Cause of Impairment	Number of Waterbodies	Percent of the Total
Mercury	8,555	14%
Pathogens	8,526	14%
Sediment	6,689	11%
Metals (other than mercury)	6,389	11%
Nutrients	5,654	10%
Oxygen depletion	4,568	8%
pH	3,389	6%
Cause unknown - biological integrity	2,866	5%
Temperature	2,854	5%
Habitat alteration	2,220	4%
PCBs	2,081	3%
Turbidity	2,050	3%
Cause unknown	1,356	2%
Pesticides	1,322	2%
Salinity/TDS/chlorides	996	2%

Note: "Waterbodies" refers to individual river segments, lakes, and reservoirs. A single waterbody can have multiple impairments. Because most waters are not assessed, however, there is no estimate of the number of unimpaired waters in the United States. SOURCE: EPA, National Section 303(d) List Fact Sheet (http://iaspub.epa.gov/waters/national_rept.control). The data are based on three-fourths of states reporting from 2004 lists, with the remaining from earlier lists and one state from a 2006 list.

FIGURE 1-5A Headwater tributary in Philadelphia suffering from Urban Stream Syndrome. SOURCE: Courtesy of Chris Crockett, Philadelphia Water Department.

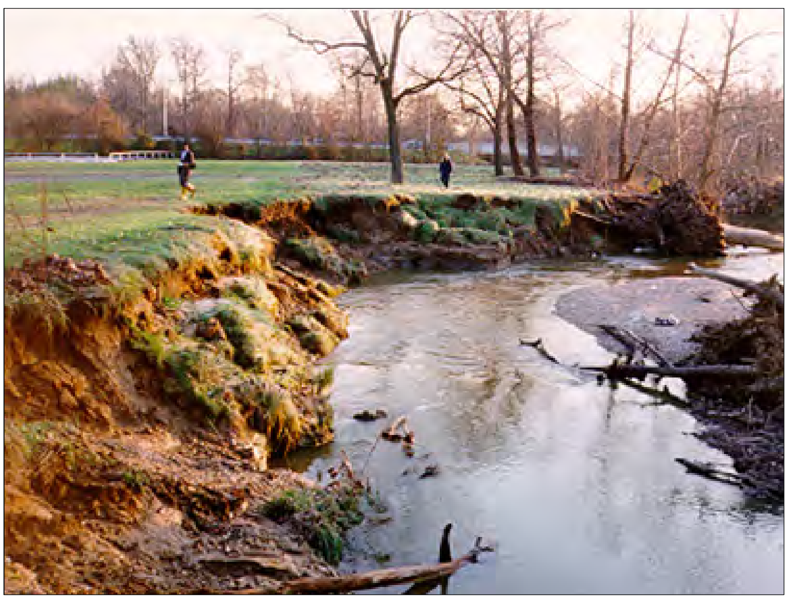


FIGURE 1-5B A destabilized stream in Vermont. SOURCE: Courtesy of Pete LaFlamme, Vermont Department of Environmental Conservation.

FIGURE 1-5C An urban stream, the Lower Oso Creek in Orange County, California, following a storm event. Oso Creek was formerly an ephemeral stream, but heavy development in the contributing watershed has created perennial flow—stormwater flow during wet weather and minor wastewater discharges and authorized non-stormwater discharges such as landscape irrigation runoff during dry weather. Courtesy of Eric Stein, Southern California Coastal Research Water Project.

Over the years, the greatest successes in improving the nation's waters have been in abating the often severe impairments caused by municipal and industrial point source discharges. The pollutant load reductions required of these facilities have been driven by the National Pollutant Discharge Elimination System (NPDES) permit requirements of the CWA (see Chapter 2). Although the majority of these sources are now controlled, further declines in water quality remain likely if the land-use changes that typify more diffuse sources of pollution are not addressed (Palmer and Allan, 2006). These include land-disturbing agricultural, silvicultural, urban, industrial, and construction activities from which hard-to-monitor pollutants emerge during wet-weather events. Pollution from these landscapes has been almost universally acknowledged as the most pressing challenge to the restoration of waterbodies and aquatic ecosystems nationwide. All population and development forecasts indicate a continued worsening of the environmental conditions caused by diffuse sources of pollution under the nation's current growth and land-use trajectories.

Recognition of urban stormwater's role in the degradation of the nation's waters is but the latest stage in the history of this byproduct of the human environment. Runoff conveyance systems have been part of cities for centuries, but they reflected only the desire to remove water from roads and walkways as rapidly and efficiently as possible. In some arid environments, rainwater has always been collected for irrigation or drinking; elsewhere it has been treated as an unmetered, and largely benign, waste product of cities. Minimal (unengineered) ditches or pipes drained developed areas to the nearest natural watercourse. Where more convenient, stormwater shared conveyance with wastewater, eliminating the cost of a separate pipe system but commonly resulting in sewage overflows during rainstorms. Recognition of downstream flooding that commonly resulted from upstream development led to construction of stormwater storage ponds or vaults in many municipalities in the 1960s, but their performance has typically fallen far short of design objectives (Booth and Jackson, 1997; Maxted and Shaver, 1999; Nehrke and Roesner, 2004). Water-quality treatment has been a relatively recent addition to the management of stormwater, and although a significant fraction of pollutants can be removed through such efforts (e.g., Strecker et al., 2004; see http://www.bmpdatabase.org), the constituents remaining even in "treated" stormwater represent a substantial, but largely unappreciated, impact to downstream watercourses.

Of the waterbodies that have been assessed in the United States, impairments from urban runoff are responsible for about 38,114 miles of impaired rivers and streams, 948,420 acres of impaired lakes, 2,742 square miles of impaired bays and estuaries, and 79,582 acres of impaired wetlands (2002 305(b) report). These numbers must be considered an underestimate, since the urban runoff category does not include stormwater discharges from municipal separate storm sewer systems (MS4s) and permitted industries, including construction. Urban stormwater is listed as the "primary" source of impairment for 13 percent of all rivers, 18 percent of all lakes, and 32 percent of all estuaries (2000 305(b) report). Although these numbers may seem low, urban areas cover just 3 percent of the land mass of the United States (Loveland and Auch, 2004), and so their influence is disproportionately large. Indeed, developed and developing areas that are a primary focus of stormwater regulations contain some of the most degraded waters in the country. For example, in Ohio few sites with greater than 27 percent imperviousness can meet interim CWA goals in nearby waterbodies, and biological degradation is observed with much less urban development (Miltner et al., 2004). Numerous authors have found similar patterns (see Meyer et al., 2005).

Although no water quality inventory data have been made available from the EPA since 2002, the dimensions of the stormwater problem can be further gleaned from several past regional and national water quality inventories. Many of these assessments are somewhat dated and are subject to the normal data and assessment limitations of national assessment methods, but they indicate that stormwater runoff has a deleterious impact on nearly all of the nation's waters. For example:

- Harvesting of shellfish is prohibited, restricted, or conditional in nearly 40 percent of all shellfish beds nationally due to high bacterial levels, and urban runoff and failing septic systems are cited as the prime causes. Reopening of shellfish beds due to improved wastewater treatment has been more than offset by bed closures due to rapid coastal development (NOAA, 1992; EPA, 1998).

- In 2006 there were over 15,000 beach closings or swimming advisories due to bacterial levels exceeding health and safety standards, with polluted runoff and stormwater cited as the cause of the impairment 40 percent of the time (NRDC, 2007).

- Pesticides were detected in 97 percent of urban stream water samples across the United States, and exceeded human health and aquatic life benchmarks 6.7 and 83 percent of the time, respectively (USGS, 2006). In 94 percent of fish tissues sampled in urban areas nationwide, organochlorine compounds were detected.

- Urban development was responsible for almost 39 percent of freshwater wetland loss (88,960 acres) nationally between 1998 and 2004 (Dahl, 2006), and the direct impact of stormwater runoff in degrading wetland quality is predicted to affect an even greater acreage (Wright et al., 2006).

- Eastern brook trout are present in intact populations in only 5 percent of more than 12,000 subwatersheds in their historical range in eastern North America, and urbanization is cited as a primary threat in 25 percent of the remaining subwatersheds with reduced populations (Trout Unlimited, 2006).

- Increased flooding is common throughout urban and suburban areas, sometimes as a consequence of improperly sited development (Figure 1-6A) but more commonly as a result of increasing discharges over time resulting from progressive urbanization farther upstream (Figure 1-6B). According to FEMA (undated), property damage from all types of flooding, from flash floods to large river floods, averages $2 billion a year.

- The chemical effects of stormwater runoff are pervasive and severe throughout the nation's urban waterways, and they can extend far downstream of the urban source. Stormwater discharges from urban areas to marine and estuarine waters cause greater water column toxicity than similar discharges from less urban areas (Bay et al., 2003).

- A variety of studies have shown that stormwater runoff is a vector of pathogens with potential human health implications in both freshwater (Calderon et al., 1991) and marine waters (Dwight et al., 2004; Colford et al., 2007).

A

B

FIGURE 1-6 (A) New residential construction in the path of episodic stream discharge (Issaquah, Washington); (B) recent flooding of an 18th-century tavern in Collegeville, Pennsylvania following a storm event in an upstream developing watershed. SOURCES: Top, Derek Booth, Stillwater Sciences, Inc., and bottom, Robert Traver, Villanova University.

WHY IS IT SO HARD TO REDUCE THE IMPACTS OF STORMWATER?

"Urban stormwater" is the runoff from a landscape that has been affected in some fashion by human activities, during and immediately after rain. Most visibly, it is the water flow over the ground surface, which is collected by natural channels and artificial conveyance systems (pipes, gutters, and ditches) and ultimately routed to a stream, river, lake, wetland, or ocean. It also includes water that has percolated into the ground but nonetheless reaches a stream channel relatively rapidly (typically within a day or so of the rainfall), contributing to the high discharge in a stream that commonly accompanies rainfall. The subsurface flow paths that contribute to this stormflow response are typically quite shallow, in the upper layers of the soil, and are sometimes termed “interflow.” They stand in contrast to deeper groundwater paths, where water moves at much lower velocities by longer paths and so reaches the stream slowly, over periods of days, weeks, or months. This deeper flow sustains streamflow during rainless periods and is usually called baseflow, as distinct from “stormwater.” A formal distinction between these types of runoff is sometimes needed for certain computational procedures, but for most purposes a qualitative understanding is sufficient.

These runoff paths can be identified in virtually all modified landscapes, such as agriculture, forestry, and mining. However, this report focuses on those settings with the particular combination of activities that constitute “urbanization,” by which we mean to include the commonly understood conversion (whether incremental or total) of a vegetated landscape to one with roads, houses, and other structures.

Although the role of urban stormwater in degrading the nation’s waters has been recognized for decades (e.g., Klein, 1979), reducing that role has been notoriously difficult. This difficulty arises from three basic attributes of what is commonly termed “stormwater”:

1. It is produced from literally everywhere in a *developed* landscape;
2. Its production and delivery are episodic, and these fluctuations are difficult to attenuate; and
3. It accumulates and transports much of the collective waste of the urban environment.

Wherever grasslands and forest are replaced by urban development in general, and impervious surfaces in particular, the movement of water across the landscape is radically altered (see Figure 1-7). Nearly all of the associated problems result from one underlying cause: loss of the water-retaining function of the soil and vegetation in the urban landscape. In an undeveloped, vegetated landscape, soil structure and hydrologic behavior are strongly influenced by biological activities that increase soil porosity (the ratio of void space to total soil volume) and the number and size of macropores, and thus the storage and conductivity of water as it moves through the soil. Leaf litter on the soil surface dissipates raindrop energy; the soil’s organic content reduces detachment of small soil particles and maintains high surface infiltration rates. As a consequence, rainfall typically infiltrates into the ground surface or is evapotranspired by vegetation, except during particularly intense rainfall events (Dunne and Leopold, 1978).

In the urban landscape, these processes of evapotranspiration and water retention in the soil may be lost for the simple reason that the loose upper layers of the soil and vegetation are gone—stripped away to provide a better foundation for roads and buildings. Even if the soil still exists, it no longer functions if precipitation is denied access because of paving or rooftops. In either case, a stormwater

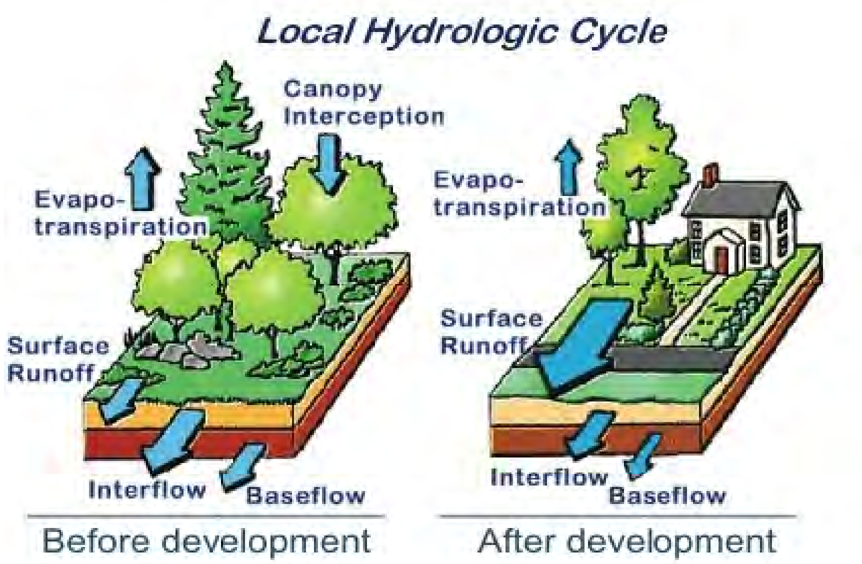


FIGURE 1-7 Schematic of the hydrologic pathways in humid-region watersheds, before and after urban development. The sizes of the arrows suggest relative magnitudes of the different elements of the hydrologic cycle, but conditions can vary greatly between individual catchments and only the increase in surface runoff in the post-development condition is ubiquitous. SOURCE: Adapted from Schueler (1987) and Maryland Department of the Environment; http://www.mde.state.md.us/Programs/WaterPrograms.

runoff reservoir of tremendous volume is removed from the stormwater runoff system; water that may have lingered in this reservoir for a few days or many weeks, or been returned directly to the atmosphere by evaporation or transpiration by plants, now flows rapidly across the land surface and arrives at the stream channel in short, concentrated bursts of high discharge.

This transformation of the hydrologic regime from one where subsurface flow once dominated to one where overland flow now dominates is not simply a readjustment of runoff flow paths, and it does not just result in a modest increase in flow volumes. It is a wholesale reorganization of the processes of runoff generation, and it occurs throughout the developed landscape. As such, it can affect every aspect of that runoff (Leopold, 1968)—not only its rate of production, its volume, and its chemistry, but also what it indirectly affects farther downstream (Walsh et al., 2005a). This includes erosion of mobile channel boundaries, mobilization of once-static channel elements (e.g., large logs), scavenging of contaminants from the surface of the urban landscape, and efficient transfer of heat from warmed surfaces to receiving waterbodies. These changes have commonly inspired human reactions—typically with narrow objectives but carrying additional, far-ranging consequences—such as the piping of once-exposed channels, bank armoring, and construction of large open-water detention ponds (e.g., Lieb and Carline, 2000).

This change in runoff regime is also commonly accompanied by certain land-use activities that have the potential to generate particularly harmful or toxic discharges, notably those commercial activities that are the particular focus of the industrial NPDES permits. These include manufacturing facilities, transport of freight or passengers, salvage yards, and a more generally defined category of "sites where industrial materials, equipment, or activities are exposed to stormwater" (e.g., EPA, 1992).

Other human actions are associated with urban landscapes that do not affect stormwater directly, but which can further amplify the negative consequences of altered flow. These actions include clearing of riparian vegetation around streams and wetlands, introduction of atmospheric pollutants that are subsequently deposited, inadvertent release of exotic chemicals into the environment, and channel crossings by roads and utilities. Each of these additional actions further degrades downstream waterbodies and increases the challenge of finding effective methods to reverse these changes (Boulton, 1999). There is little doubt as to why the problem of urban stormwater has not yet been "solved"—because every functional element of an aquatic ecosystem is affected. Urban stormwater has resulted in such widespread impacts, both physical and biological, in aquatic systems across the world that this phenomenon has been termed the "Urban Stream Syndrome" (see Figure 1-5; Walsh et al., 2005b).

Of the many possible ways to consider these conditions, Karr (1991) has recommended a simple yet comprehensive grouping of the major stressors arising from urbanization that influence aquatic assemblages (Figure 1-8). These include chemical pollutants (water quality and toxicity); changes to flow magnitude, frequency, and seasonality of various discharges; the physical aspects of stream, lake, or wetland habitats; the energy dynamics of food webs, sunlight, and temperature; and biotic interactions between native and exotic species. Stormwater and stormwater-related impacts encompass all of these categories, some directly (e.g., water chemistry) and some indirectly (e.g., habitat, energy dynamics). Because of the wide-ranging effects of stormwater, programs to abate stormwater impacts on aquatic systems must deal with a broad range of impairments far beyond any single altered feature, whether traditional water-chemistry parameters or flow rates and volumes.

The broad spatial scale of where and how these impacts are generated suggests that solutions, if effective, should be executed at an equivalent scale. Although the "problem" of stormwater runoff is manifested most directly as an altered hydrograph or elevated concentrations of pollutants, it is ultimately an expression of land-use change at a landscape scale. Symptomatic solutions, applied only at the end of a stormwater collection pipe, are not likely to prove fully effective because they are not functioning at the scale of the original disturbance (Kloss and Calarusse, 2006).

The landscape-scale generation of stormwater has a number of consequences for any attempt to reduce its effects on receiving waters, as described below.

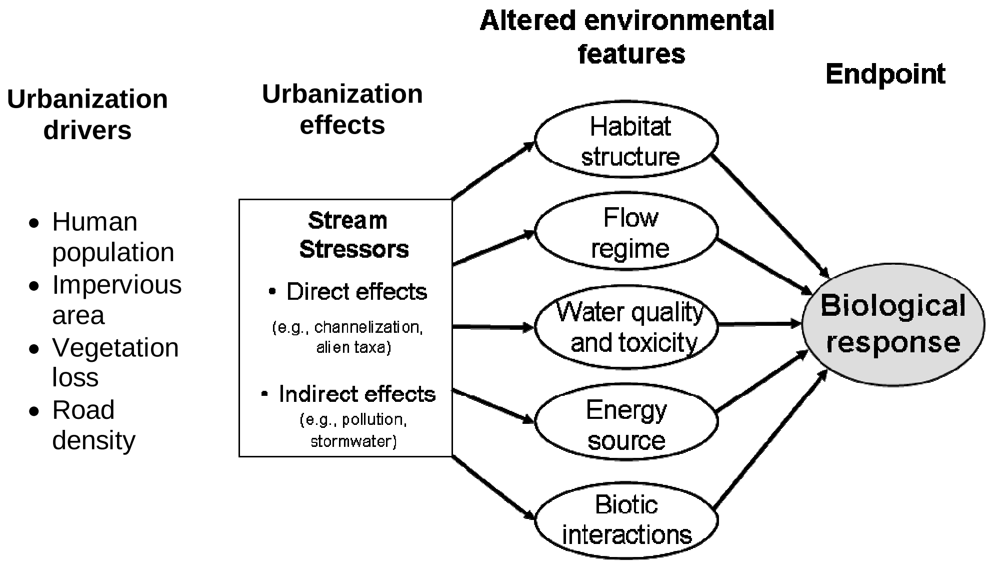


FIGURE 1-8 Five features that are affected by urban development and, in turn, affect biological conditions in urban streams. SOURCES: Modified from Karr (1991), Karr and Yoder (2004), and Booth (2005). Reprinted, with permission, from Karr (1991). Copyright 2001 by Ecological Society of America. Reprinted, with permission, from Karr and Yoder (2004). Copyright 2004 by American Society of Civil Engineers. Reprinted, with permission, from Booth (2005). Copyright 2005 by the North American Benthological Society.

Sources and Volumes

The "source" of stormwater runoff is dispersed, making collection and centralized treatment challenging. To the extent that collection is successful, however, the flip side of this condition—very large volumes—becomes manifest. Either an extensive infrastructure brings stormwater to centralized facilities, whose operation and maintenance may be relatively straightforward (e.g., Anderson et al., 2002) but of modest effectiveness, or stormwater remains dispersed for management, treatment, or both across the landscape (e.g., Konrad and Burges, 2001; Holman-Dodds et al., 2003; Puget Sound Action Team, 2005; Walsh et al., 2005a; Bloom, 2006; van Roon, 2007), better mimicking the natural processes of runoff generation but requiring a potentially unlimited number of "facilities" that may have their own particular needs for space, cost, and maintenance.

Treatment Challenges

Regardless of the scale at which treatment is attempted, technological difficulties are significant because of the variety of "pollutants" that must be addressed. These include physical objects, from large debris to microscopic particles; chemical constituents, both dissolved and immiscible; and less easily categorized properties such as temperature. Wastewater treatment plants manage a similarly broad range of pollutants, but stormwater flows have highly unsteady inflows and, when present, typically much greater volumes to treat.

Industrial sources of stormwater pose a particularly challenging problem because potential generators of polluted or toxic runoff are widespread and are regulated under NPDES permitting by their *activities*, not by the specific category of industrial activity under which they fall. This complicates any systematic effort to identify those entities that should be regulated (Duke et al., 1999). Even for the limited number of regulated generators, pollution prevention measures are of uncertain effectiveness.

Soil erosion from construction sites is another pollution source that has proven difficult to effectively control. Although most bare sites are relatively small and only short-lived, at any given time there can be many sites under construction, each of which can deliver sediment loads to downstream waterbodies at rates that exceed background levels by many orders of magnitude (e.g., Wolman and Schick, 1967). Relatively effective approaches and technologies exist to dramatically reduce the magnitude of these sediment discharges (e.g., Raskin et al., 2005), but they depend on conscientious installation and regular maintenance. Enforcement of such requirements, normally a low-priority activity of local departments of building or public works, is commonly lacking.

Another difference between the stormwater and wastewater streams is that stormwater treatment must address not only "pollutants" but also physically and ecologically deleterious changes in flow rate and total runoff volume. Treating these changes constitutes a particularly difficult task for two reasons. First, there is simply more runoff, as a rule, and so replicating the predevelopment hydrograph is not an option—the increased volume of runoff guarantees that some discharges, some of the time, must be allowed to increase. Second, there is little agreement on what constitutes "adequate" or "effective" treatment for the various attributes of flow. Even the most basic metrics, such as the magnitude of peak flow, can require extensive infrastructure to achieve (e.g., Booth and Jackson, 1997); other flow metrics that correlate more directly with undesired effects on physical and biological systems can require even greater efforts to match. In many cases, the urban-induced transformation of the flow regime makes true "mitigation" virtually impossible.

Widespread Cause and Effects

The spatial scale of stormwater generation and its impacts is wide-ranging. "Generators" are literally landscape-wide, and impacts can occur at every location in the path followed by urban runoff, from source to receiving waterbody (Hamilton et al., 2004). There are few ways to demonstrate causal connections between distributed landscape sources and cumulative downstream effects (Allan, 2004), and so site-specific mitigation typically provides little lasting improvement in the watershed as a whole (Maxted and Shaver, 1997).

Stormwater Measurements

The desired attributes of stormwater runoff are normally expressed through a combination of physical and chemical parameters. These parameters are commonly presumed to have direct correlation to attributes of human or ecological concern, such as the condition of human or fish communities, or the stability of a stream channel, even though these parameters do not directly measure those effects. The most commonly measured physical parameters are hydrologic and simply measure the rate of flow past a specified location. Both the absolute, instantaneous magnitude of that flow rate (i.e., the discharge) and the variations in that rate over multiple time scales (i.e., how rapidly the discharge varies over an hour, a day, a season, etc.) can be captured by analysis of a continuous time series of a flow. Obviously, however, a nearly unlimited number of possible metrics, capturing a multitude of temporal scales, could be defined (Poff et al., 1997, 2006; Cassin et al., 2004; Konrad et al., 2005; Roy et al., 2005; Chang, 2007). Commonly only a single parameter—the peak storm discharge for a given return period (Hollis, 1975)—has been emphasized in the past. Mitigation of urban-induced flow increases have followed this narrow approach, typically by endeavoring to reduce peak discharge by use of detention ponds but leaving the underlying increase in runoff volumes—and the associated augmentation of both frequency and duration of high discharges—untouched. This partly explains why evaluation of downstream conditions commonly document little improvement resulting from traditional flow-mitigation measures (e.g., Maxted and Shaver, 1997; Roesner et al., 2001; May and Horner, 2002).

Other physical parameters, less commonly measured or articulated, can also express the conditions of downstream watercourses. Measures of size or complexity, particularly for stream channels, are particularly responsive to the changes in flow regime and discharge. Booth (1990) suggested that discriminating between *channel expansion*, the proportional increase in channel cross-sectional area with increasing discharge, and *channel incision*, the catastrophic vertical downcutting that sometimes accompanies urban-induced flow increases, captures important end-members of the physical response to hydrologic change. The former (proportional expansion) is more thoroughly documented (Hammer, 1972; Hollis and Luckett, 1976; Morisawa and LaFlure, 1982; Neller, 1988;

Whitlow and Gregory, 1989; Booth and Jackson, 1997; Moscrip and Montgomery, 1997; Booth and Henshaw, 2001); the latter (catastrophic incision) is more difficult to quantify but has been recognized in both urban and agricultural settings (e.g., Simon, 1989). Both types of changes result not only in a larger channel but also in substantial simplification and loss of features normally associated with high-quality habitat for fish and other in-stream biota. The sediment released by these "growing channels" also can be the largest component of the overall sediment load delivered to downstream waterbodies (Trimble, 1997; Nelson and Booth, 2002).

Chemical parameters (or, historically, "water-quality parameters"; see Dinius, 1987; Gergel et al., 2002) cover a host of naturally and anthropogenically occurring constituents in water. In flowing water these are normally expressed as instantaneous measurements of concentration. In waterbodies with long residence times, such as lakes, these may be expressed as either concentrations or as loads (total accumulated amounts, or total amounts integrated over an extended time interval). The CWA defined a list of priority pollutants, of which a subset is regularly measured in many urban streams (e.g., Field and Pitt, 1990). Parameters that are not measured may or may not be present, but without assessment they are rarely recognized for their potential (or actual) contribution to waterbody impairment.

Other attributes of stormwater do not fit as neatly into the categories of water quantity or water quality. Temperature is commonly measured and is normally treated as a water quality parameter, although it is obviously not a chemical property of the water (LeBlanc et al., 1997; Wang et al., 2003). Similarly, direct or indirect measures of suspended matter in the water column (e.g., concentration of total suspended solids, or secchi disk depths in a lake) are primarily physical parameters but are normally included in water quality metrics. Flow velocity is rarely measured in either context, even though it too correlates directly to stream-channel conditions. Even more direct expressions of a flow's ability to transport sediment or other debris, such as shear stress or unit stream power, are rarely reported and virtually never regulated.

***

Urban runoff degrades aquatic systems in multiple ways, which confounds our attempts to define causality or to demonstrate clear linkages between mitigation and ecosystem improvement. It is generally recognized from the conceptual models that seek to describe this system that no single element holds the key to ecosystem condition. All elements must be functional, and yet every element can be affected by urban runoff in different ways. These impacts occur at virtually all spatial scales, from the site-specific to the landscape; this breadth and diversity challenges our efforts to find effective solutions.

This complexity and the continued growth of the built environment also present fundamental social choices and management challenges. Stormwater control measures entail substantial costs for their long-term maintenance, monitoring to determine their performance, and enforcement of their use—all of which must be weighed against their (sometimes unproven) benefits. Furthermore, the overarching importance of impervious surfaces inextricably links stormwater management to land-use decisions and policy. For example, where a reversal of the effects of urbanization cannot be realized, more intensive land-use development in certain areas may be a paradoxically appropriate response to reduce the overall impacts of stormwater. That is, increasing population density and impervious cover in designated urban areas may reduce the creation of impervious surface and the associated ecological impacts in areas that will remain undeveloped as a result. In these highly urban areas (with very high percentages of impervious surface), aquatic conditions in local streams will be irreversibly changed and the Urban Stream Syndrome may be unavoidable to some extent. Where these impacts occur and what effort and cost will be used to avoid these impacts are both fundamental issues confronting the nation as it attempts to address stormwater.

IMPETUS FOR THE STUDY AND REPORT ROADMAP

In 1972 Congress amended the Federal Water Pollution Control Act (subsequently referred to as the Clean Water Act) to require control of discharges of pollutants to waters of the United States from point sources. Initial efforts to improve water quality using NPDES permits focused primarily on reducing pollutants from industrial process wastewater and municipal sewage discharges. These point source discharges were clearly and easily shown to be responsible for poor, often drastically degraded conditions in receiving waterbodies because they tended to emanate from identifiable and easily monitored locations, such as pipe outfalls.

As pollution control measures for industrial process wastewater and municipal sewage were implemented and refined during the 1970s and 1980s, more diffuse sources of water pollution have become the predominant causes of water quality impairment, including stormwater runoff. To address the role of stormwater in causing water quality impairments, Congress included Section 402(p) in the CWA; this section established a comprehensive, two-phase approach to stormwater control using the NPDES program. In 1990 EPA issued the Phase I Stormwater Rule (55 Fed. Reg. 47990; November 16, 1990) requiring NPDES permits for operators of municipal separate storm sewer systems (MS4s) serving populations over 100,000 and for runoff associated with industrial activity, including runoff from construction sites five acres and larger. In 1999 EPA issued the Phase II Stormwater Rule (64 Fed. Reg. 68722; December 8, 1999), which expanded the requirements to small MS4s in urban areas and to construction sites between one and five acres in size.

Since EPA's stormwater program came into being, several problems inherent in its design and implementation have become apparent. As discussed in more detail in Chapter 2, problems stem to a large extent from the diffuse nature of stormwater discharges combined with a regulatory process that was created for point sources (the NPDES permitting approach). These problems are compounded by the shear number of entities requiring oversight. Although exact numbers are not available, EPA estimates that the number of regulated MS4s is about 7,000, including 1,000 Phase I municipalities and 6,000 from Phase II. The number of industrial permittees is thought to be around 100,000. Each year, the construction permit covers around 200,000 permittees each for both Phase I (five acres or greater) and Phase II (one to five acres) projects. Thus, the total number of permittees under the stormwater program at any time numbers greater than half a million. There are fewer than 100,000 non-stormwater (meaning wastewater) permittees covered by the NPDES program, such that stormwater permittees account for approximately 80 percent of NPDES-regulated entities. To manage this large number of permittees, the stormwater program relies heavily on the use of general permits to control industrial, construction, and Phase II MS4 discharges, which are usually statewide, one-size-fits-all permits in which general provisions are stipulated.

An example of the burden felt by a single state is provided by Michigan (David Drullinger, Michigan Department of Environmental Quality Water Bureau, personal communication, September 2007). The Phase I Stormwater regulations that became effective in 1990 regulate 3,400 industrial sites, 765 construction sites per year, and five large cities in Michigan. The Phase II regulations, effective since 1999, have extended the requirements to 7,000 construction sites per year and 550 new jurisdictions, which are comprised of about 350 "primary jurisdictions" (cities, villages, and townships) and 200 "nested jurisdictions" (county drains, road agencies, and public schools). Often, only a handful of state employees are allocated to administer the entire program (see the survey in Appendix C).

In order to comply with the CWA regulations, permittees must fulfill a number of requirements, including the creation and implementation of a stormwater pollution prevention plan, and in some cases, monitoring of stormwater discharges. Stormwater pollution prevention plans document the stormwater control measures (SCMs; sometimes known as best management practices or BMPs) that will be used to prevent or slow stormwater from quickly reaching nearby waterbodies and degrading their quality. These include structural methods such as detention ponds and nonstructural methods such as designing new development to reduce the percentage of impervious surfaces. Unfortunately, data on the degree of pollutant reduction that can be assigned to a particular SCM are only now becoming available (see Chapter 5).

Other sources of variability in EPA's stormwater program are that (1) there are three permit types (municipal, industrial, and construction), (2) some states and local governments have assumed primacy for the program from EPA while others have not, and state effluent limits or benchmarks for stormwater discharges may differ from the federal requirements, and (3) whether there are monitoring requirements varies depending on the regulating entity and the type of activity. For industrial stormwater there are 29 sectors of industrial activity covered by the general permit, each of which is characterized by a different suite of possible contaminants and SCMs.

Because of the industry-, site-, and community-specific nature of stormwater pollution prevention plans, and because of the lack of resources of most NPDES permitting authorities to review these plans and conduct regular compliance inspections, water quality-related accountability in the stormwater program is poor. Monitoring data are minimal for most permittees, despite the fact that they are often the only indicators of whether an adequate stormwater program is being implemented. At the present time, available monitoring data indicate that many industrial facilities routinely exceed "benchmark values" established by EPA or the states, although it is not clear whether these exceedances provide useful indicators of stormwater pollution prevention plan inadequacies or potential water quality problems. These uncertainties have led to mounting and contradictory pressure from permittees to eliminate monitoring requirements entirely as well as from those hoping for greater monitoring requirements to better understand the true nature of stormwater discharges and their impact.

To improve the accountability of it Stormwater Program, EPA requested advice on stormwater issues from the National Research Council's (NRC's) Water Science and Technology Board as the next round of general permits is being prepared. Although the drivers for this study have been in the industrial stormwater arena, this study considered all entities regulated under the NPDES program (municipal, industrial, and construction). The following statement of task guided the work of the committee:

(1) Clarify the mechanisms by which pollutants in stormwater discharges affect ambient water quality criteria and define the elements of a "protocol" to link pollutants in stormwater discharges to ambient water quality criteria.

(2) Consider how useful monitoring is for both determining the potential of a discharge to contribute to a water quality standards violation and for determining the adequacy of stormwater pollution prevention plans. What specific parameters should be monitored and when and where? What effluent limits and benchmarks are needed to ensure that the discharge does not cause or contribute to a water quality standards violation?

(3) Assess and evaluate the relationship between different levels of stormwater pollution prevention plan implementation and in-stream water quality, considering a broad suite of SCMs.

(4) Make recommendations for how to best stipulate provisions in stormwater permits to ensure that discharges will not cause or contribute to exceedances of water quality standards. This should be done in the context of general permits. As a part of this task, the committee will consider currently available information on permit and program compliance.

(5) Assess the design of the stormwater permitting program implemented under the CWA.

The report is intended to inform decision makers within EPA, affected industries, public stormwater utilities, other government agencies and the private sector about potential options for managing stormwater.

EPA requested that the study be limited to those issues that fall under the agency's current regulatory scheme for stormwater, which excludes nonpoint sources of pollution such as agricultural runoff and septic systems. Thus, these sources are not extensively covered in this report. The reader is referred to NRC (2000, 2005) for more detailed information on the contribution of agricultural runoff and septic systems to waterbody impairment and on innovative technologies for treating these sources. Also at the request of EPA, concentrated animal feeding operations and combined sewer overflows were not a primary focus. However, the committee felt that in order to be most useful it should opine on certain critical effects of regulated stormwater beyond the delivery of traditional pollutants. Thus, changes in stream flow, streambank erosion, and habitat alterations caused by stormwater are considered, despite the relative inattention given to them in current regulations.

Chapter 2 presents the regulatory history of stormwater control in the United States, focusing on relevant portions of the CWA and the regulations that have been created to implement the Act. Federal, state, and local programs for or affecting stormwater management are described and critiqued. Chapter 3 deals with the first item in the statement of task. It reviews the scientific aspects of stormwater, including sources of pollutants in stormwater, how stormwater moves across the land surface, and its impacts on receiving waters. It reflects the best of currently available science, and addresses biological endpoints that go far beyond ambient water quality criteria. Methods for monitoring and modeling stormwater (the subject of the second item in the statement of task) are described in Chapter 4. The material evaluates the usefulness of current benchmark and MS4 monitoring requirements, and suggestions for improvement are made. The latter half of the chapter considers the multitude of models available for linking stormwater discharges to ambient water quality. This analysis makes it clear that stormwater pollution cannot yet be treated as a deterministic system (in which the contribution of individual dischargers to a waterbody impairment can be identified) without significantly greater investment in model development. Addressing primarily the third item in the statement of task, Chapter 5 considers the vast suite of both structural and nonstructural measures designed to control stormwater and reduce its pollutant loading to waterbodies. It also takes on relevant larger-scale concepts, such as the benefit of stormwater management within a watershed framework. In Chapter 6, the limitations and possibilities associated with a new regulatory approach are explored, as are those of an enhanced but more traditional scheme. Numerous suggestions for improving the stormwater permitting process for municipalities, industrial sites, and construction are made. Along with Chapter 2, this chapter addresses the final two items in the committee's statement of task.

REFERENCES

Alberti, M., D. B. Booth, K. Hill, B. Coburn, C. Avolio, S. Coe, and D. Spirandelli. 2006. The impact of urban patterns on aquatic ecosystems: an empirical analysis in Puget lowland sub-basins. Landscape Urban Planning, doi:10.1016/j.landurbplan.2006.08.001.

Allan, J. D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics 35:257–284.

Alley, W. A., and J. E. Veenhuis. 1983. Effective impervious area in urban runoff modeling. Journal of Hydrological Engineering ASCE 109(2):313–319.

Anderson, B .C., W. E. Watt, and J. Marsalek. 2002. Critical issues for stormwater ponds: learning from a decade of research. Water Science and Technology 45(9):277–283.

Barbour, M. T., M. J. Paul, D. W. Bressler, A. H. Purcell, V. H. Resh, and E. T. Rankin. 2006. Bioassessment: a tool for managing aquatic life uses for urban streams. Water Environment Research Foundation Research Digest 01-WSM-3.

Bay, S., B. H. Jones, K. Schiff, and L. Washburn. 2003. Water quality impacts of stormwater discharges to Santa Monica Bay . Marine Environmental Research 56:205–223.

Bledsoe, B. P., and C. C. Watson. 2001. Effects of urbanization on channel instability. Journal of the American Water Resources Association 37(2):255–270.

Bloom, M. F. 2006. Low Impact Development approach slows down drainage, reduces pollution. Water and Wastewater International 21(4):59.

Booth, D. B. 1990. Stream channel incision in response following drainage basin urbanization. Water Resources Bulletin 26:407–417.

Booth, D. B. 2005. Challenges and prospects for restoring urban streams: a perspective from the Pacific Northwest of North America. Journal of the North American Benthological Society 24(3):724–737.

Booth, D. B., and C. R. Jackson. 1997. Urbanization of aquatic systems—degradation thresholds, stormwater detention, and the limits of mitigation. Water Resources Bulletin 33:1077–1090.

Booth, D. B., and P. C. Henshaw. 2001. Rates of channel erosion in small urban streams. Pp. 17–38 *In*: Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas. M. Wigmosta and S. Burges (eds.). AGU Monograph Series, Water Science and Application, Volume 2.

Boulton, A. J. 1999. An overview of river health assessment: philosophies, practice, problems and prognosis. Freshwater Biology 41(2):469–479.

Brookings Institute. 2004. Toward a new metropolis: the opportunity to rebuild America. Arthur C. Nelson, Virginia Polytechnic Institute and State University. Discussion paper prepared for The Brookings Institution Metropolitan Policy Program.

Burges, S. J., M. S. Wigmosta, and J. M. Meena. 1998. Hydrological effects of land-use change in a zero-order catchment. Journal of Hydrological Engineering 3:86–97.

Calderon, R., E. Mood, and A. Dufour. 1991. Health effects of swimmers and nonpoint sources of contaminated water. International Journal of Environmental Health Research 1:21–31.

Cassin, J., R. Fuerstenberg, F. Kristanovich, L. Tear, and K. Whiting. 2004. Application of normative flow on small streams in Washington State—hydrologic perspective. Pp. 4281*–4299 In:* Proceedings of the 2004 World Water and Environmental Resources Congress: Critical Transitions in Water and Environmental Resources Management.

Center for Watershed Protection (CWP). 2005. An integrated framework to restore small urban watersheds. Ellicott City, MD: CWP. Available at http://www.cwp.org/Store/usrm.htm. Last accessed September 23, 2008.

Chang, H. 2007. Comparative streamflow characteristics in urbanizing basins in the Portland Metropolitan Area, Oregon, USA. Hydrological Processes 21(2):211–222.

Chang, H., and T. N. Carlson. 2005. Water quality during winter storm events in Spring Creek, Pennsylvania USA. Hydrobiologia 544(1):321–332.

Chang, H. H. 1992. Fluvial Processes in River Engineering. Malabar, FL: Krieger Publishing.

Colford, J. M., Jr, T. J. Wade, K. C. Schiff, C. C. Wright, J. F. Griffith, S. K. Sandhu, S. Burns, J. Hayes, M. Sobsey, G. Lovelace, and S. Weisberg. 2007. Water quality indicators and the risk of illness at non-point source beaches in Mission Bay, California. Epidemiology 18(1):27–35.

Dahl, T. 2006. Status and trends of wetlands in the conterminous United States: 1998–2004. Washington, DC: U.S. Department of the Interior Fish and Wildlife Service.

Davies, S. P., and S. K. Jackson. 2006. The biological condition gradient: a descriptive model for interpreting change in aquatic ecosystems. Ecological Applications 16(4):1251–1266.

Dinius, S. H. 1987. Design of an index of water quality. Water Resources Bulletin 23(5):833–843.

Duke, L. D., K. P. Coleman, and B. Masek. 1999. Widespread failure to comply with U.S. storm water regulations for industry—Part I: Publicly available data to estimate number of potentially regulated facilities. Environmental Engineering Science 16(4):229–247.

Dunne, T., and L. B. Leopold. 1978. Water in Environmental Planning. New York: W. H. Freeman.

Dwight, R. H., D. B. Baker, J. C. Semenza, and B. H. Olson. 2004. Health effects associated with recreational coastal water use: urban vs. rural California. American Journal of Public Health 94(4):565–567.

EPA (U.S. Environmental Protection Agency). 1992. Storm Water Management for Industrial Activities, Developing Pollution Prevention Plans and Best Management Practices. Available at http://www.ntis.gov.

EPA. 1998. EPA Project Beach. Washington, DC: EPA Office of Water.

EPA. 2000. National Water Quality Inventory. 305(b) List. Washington, DC: EPA Office of Water.

EPA. 2002. 2000 National Water Quality Inventory. EPA-841-R-02-001. Washington, DC: EPA Office of Water.

EPA. 2006. Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams. EPA 841-B-06-002. Washington, DC: EPA Office of Water.

EPA. 2007. National Estuary Program Coastal Condition Report. EPA-842-B-06-001. Washington, DC: EPA Office of Water and Office of Research and Development.

FEMA (Federal Emergency Management Agency). No date. Flood. A report of the Subcommittee on Disaster Reduction. Available at http://www.sdr.gov. Last accessed September 23, 3008.

Field, R., and R. E. Pitt. 1990. Urban storm-induced discharge impacts: U.S. Environmental Protection Agency research program review. Water Science and Technology 22(10–11):1–7.

Gergel, S. E., M. G. Turner, J. R. Miller, J. M. Melack, and E. H. Stanley. 2002. Landscape indicators of human impacts to riverine systems. Aquatic Sciences 64(2):118–128.

Gregory, M., J. Aldrich, A. Holtshouse, and K. Dreyfuss-Wells. 2005. Evaluation of imperviousness impacts in large, developing watersheds. Pp. 115–150 *In:* Efficient Modeling for Urban Water Systems, Monograph 14. W. James, E. A. McBean, R. E. Pitt, and S. J. Wright (eds.). Guelph, Ontario, Canada: CHI.

Grübler, A. 1994. Technology. Pp. 287–*328 In:* Changes in Land Use and Land Cover: A Global Perspective. W. B. Meyer and B. L. Turner II (eds.). Cambridge: Cambridge University Press.

Hamilton, P. A., T. L. Miller, and D. N. Myers. 2004. Water Quality in the Nation's Streams and Aquifers—Overview of Selected Findings, 1991–2001. U.S. Geological Survey Circular 1265. Available at http://pubs.usgs.gov/circ/2004/1265/pdf/circular1265.pdf. Last accessed September 23, 2008.

Hammer, T. R. 1972. Stream and channel enlargement due to urbanization. Water Resources Research 8:1530–1540.

Hart, J. F. 1968. Loss and abandonment of cleared farm land in the Eastern United States. Annals of the Association of American Geographers 58(5):417–440.

Heinz Center. 2002. The State of the Nation's Ecosystems. Measuring the Lands, Waters, and Living Resources of the United States. Cambridge: Cambridge University Press.

Hollis, G. E. 1975. The effect of urbanization on floods of different recurrence interval. Water Resources Research 11:431–435.

Hollis, G. E., and J. K. Luckett. 1976. The response of natural river channels to urbanization: two case studies from southeast England. Journal of Hydrology 30:351–363.

Holman-Dodds, J. K., A. A. Bradley, and K. W. Potter. 2003. Evaluation of hydrologic benefits of infiltration based urban storm water management. Journal of the American Water Resources Association 39(1):205–215.

Horner, R. R., D. B. Booth, A. A. Azous, and C. W. May. 1997. Watershed determinants of ecosystem functioning. Pp. 251-274 *In*: Effects of Watershed Development and Management on Aquatic Ecosystems. L. A. Roesner (ed.). Proceedings of the Engineering Foundation Conference, Snowbird, UT, August 4–9, 1996.

House, M. A., J. B. Ellis, E. E. Herricks, T. Hvitved-Jacobsen, J. Seager, L. Lijklema, H. Aalderink, and I. T. Clifforde. 1993. Urban drainage: Impacts on receiving water quality. Water Science and Technology 27(12):117–158.

Karr, J. R. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1:66–84.

Karr, J. R., and C. O. Yoder. 2004. Biological assessment and criteria improve TMDL planning and decision making. Journal of Environmental Engineering 130:594–604.

Klein, R. D. 1979. Urbanization and stream quality impairment. Water Resources Bulletin 15:948–969.

Kloss, C., and C. Calarusse. 2006. Rooftops to rivers—green strategies for controlling stormwater and combined sewer overflows. New York: National Resources Defense Council. Available at http://www.nrdc.org/water/pollution/rooftops/rooftops.pdf. Last accessed September 23, 2008.

Konrad, C. P., and S. J. Burges. 2001. Hydrologic mitigation using on-site residential storm-water detention. Journal of Water Resources Planning and Management 127:99–107.

Konrad, C. P., D. B. Booth, and S. J. Burges. 2005. Effects of urban development in the Puget Lowland, Washington, on interannual streamflow patterns: consequences for channel form and streambed disturbance. Water Resources Research 41(7):1–15.

Laenen, A. 1983. Storm runoff as related to urbanization based on data collected in Salem and Portland, and generalized for the Willamette Valley, Oregon. U.S. Geological Survey Water-Resources Investigations Report 83-4238, 9 pp.

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E. F. Moran, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H. Skånes, W. Steffen, G. D. Stone, U. Svedin, T. A. Veldkamp, C. Vogel, and J. Xu. 2001. The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change 11(4):261–269.

LeBlanc, R. T., R. D. Brown, and J. E. FitzGibbon. 1997. Modeling the effects of land use change on the water temperature in unregulated urban streams. Journal of Environmental Management 49(4):445–469.

Leopold, L. B. 1968. Hydrology for urban land planning: a guidebook on the hydrologic effects of urban land use. U.S. Geological Survey Circular 554. Washington, DC: USGS.

Levin, P. S., R. W. Zabel, and J. G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. Proceedings of the Royal Society—Biological Sciences (Series B) 268(1472):1153–1158.

Lieb, D. A., and R. F. Carline. 2000. Effects of urban runoff from a detention pond on water quality, temperature and caged gammarus minus (say) (amphipoda) in a headwater stream. Hydrobiologia 441:107–116.

Loveland, T., and R. Auch. 2004. The changing landscape of the eastern United States. Washington, DC: U.S. Geological Survey. Available at http://www.usgs.gov/125/articles/eastern_us.html. Last accessed November 25, 2007.

Maxted, J. R., and E. Shaver. 1997. The use of retention basins to mitigate stormwater impacts on aquatic life. Pp. 494-512 *In:* Effects of Watershed Development and Management on Aquatic Ecosystems. L. A. Roesner (Ed.). New York: American Society of Civil Engineers.

Maxted, J. R., and E. Shaver. 1999. The use of detention basins to mitigate stormwater impacts to aquatic life. Pp. 6–*15 In:* National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments, Chicago, February 9–12, 1998. EPA/625/R-99/002. Washington, DC: EPA Office of Research and Development.

May, C. W., and R. R. Horner. 2002. The limitations of mitigation-based stormwater management in the pacific northwest and the potential of a conservation strategy based on low-impact development principles. Pp. 1-16 *In:* Global Solutions for Urban Drainage. Proceedings of the Ninth International Conference on Urban Drainage.

Meyer, J. L., M. J. Paul, and W. K. Taulbee. 2005. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society 24:602–612.

Miltner, R. J., White, D., and C. O. Yoder. 2004. The biotic integrity of streams in urban and suburbanizing landscapes. Landscape and Urban Planning 69:87–100.

Morisawa, M., and E. LaFlure. 1982. Hydraulic geometry, stream equilibrium and urbanization. Pp. 333–350 *In:* Adjustments of the Fluvial System. D. D. Rhodes and G. P. Williams (eds.). London: Allen and Unwin.

Moscrip, A. L., and D. R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Puget Lowland streams. Journal of the American Water Resources Association 33:1289–1297.

Naiman, R. J., and M. G. Turner. 2000. A future perspective on North America's freshwater ecosystems. Ecological Applications 10(4):958–970.

Neller, R. J. 1988. A comparison of channel erosion in small urban and rural catchments, Armidale, New South Wales. Earth Surface Processes and Landforms 13:1–7.

Nelson, E. J., and D. B. Booth. 2002. Sediment budget of a mixed-land use, urbanizing watershed. Journal of Hydrology 264:51–68.

Nehrke, S. M., and L. A. Roesner. 2004. Effects of design practice for flood control and best management practices on the flow-frequency curve. Journal of Water Resources Planning and Management 130(2):131-139.

NOAA (National Oceanic and Atmospheric Administration). 1992. 1990 Shellfish Register of Classified Estuarine Waters. Data supplement. Rockville, MD: National Ocean Service.

NRC (National Research Council). 2000. Watershed Management for Potable Water Supply: Assessing the New York City Strategy. Washington, DC: National Academies Press.

NRC. 2005. Regional Cooperation for Water Quality Improvement in Southwestern Pennsylvania. Washington, DC: National Academies Press.

NRDC (Natural Resources Defense Council). 2007. Testing the Waters: A Guide to Water Quality at Vacation Beaches (17th ed.). New York: NRDC.

Palmer, M. A., and J. D. Allan. 2006. Restoring Rivers. Issues in Science & Technology. Washington, DC: National Academies Press.

Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333–365.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11):769–784.

Poff, N. L., B. P. Bledsoe, and C. O. Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: geomorphic and ecological consequences for stream ecosystems. Geomorphology 79 (3–4):264–285.

Pozzi, F., and C. Small. 2005. Analysis of urban land cover and population density in the United States. Photogrammetric Engineering and Remote Sensing 71(6):719–726.

Prysch, E. A., and J. C. Ebbert. 1986. Quantity and quality of storm runoff from three urban catchments in Bellevue, Washington. USGS Water-Resources Investigations Report 86-4000, 85 pp.

Puget Sound Action Team. 2005. Low Impact Development: Technical Guidance Manual for Puget Sound. Available at http://www.psat.wa.gov/Programs/LID.htm. Last accessed September 23, 2008.

Raskin, L., A. DePaoli, and M. J. Singer. 2005. Erosion control materials used on construction sites in California. Journal of Soil and Water Conservation 60(4):187–192.

Roesner, L. A., B. P. Bledsoe, and R. W. Brashear. 2001. Are best-management-practice criteria really environmentally friendly? Journal of Water Resources Planning and Management 127(3):150-154.

Roy, A. H., M. C. Freeman, B. J. Freeman, S. J. Wenger, W. E. Ensign, and J. L. Meyer. 2005. Investigating hydrological alteration as a mechanism of fish assemblage shifts in urbanizing streams. Journal of the North American Benthological Society 24:656–678.

Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices. Washington, DC: Metropolitan Washington Council of Governments.

Simon, A. 1989. A model of channel response in disturbed alluvial channels. Earth Surface Processes and Landforms 14:11–26.

Steedman, R. J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in Southern Ontario. Canadian Journal of Fisheries and Aquatic Sciences 45:492–501.

Strecker, E. W., M. M. Quigley, B. Urbonas, and J. Jones. 2004. Analyses of the expanded EPA/ASCE International BMP Database and potential implications for BMP design. *In*: Proceedings of the World Water and Environmental Congress 2004, June 27–July 1, 2004, Salt Lake City, UT. G. Sehlke, D. F. Hayes, and D. K. Stevens (eds.). Reston, VA: ASCE.

Sutherland, R. 1995. Methods for estimating the effective impervious area of urban watersheds. Watershed Protection Techniques 2(1):282-284. Ellicott City, MD: Center for Watershed Protection.

Thomson, J. D., G. Weiblen, B. A. Thomson, S. Alfaro, and P. Legendre. 1986. Untangling multiple factors in spatial distributions: lilies, gophers, and rocks. Ecology 77:1698–1715.

Trimble, S. W. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. Science 278:1442–1444.

Trout Unlimited. 2006. Eastern Brook Trout: Status and Threats. Eastern Brook Trout Joint Venture. Arlington, VA: Trout Unlimited.

USGS (U.S. Geological Survey). 2006. The quality of our nation’s waters: pesticides in the nation’s streams and ground water: 1992–2001. National Water Quality Assessment Program. USGS Circular 1291. Reston, VA: USGS.

van Roon, M. 2007. Water localisation and reclamation: steps towards low impact urban design and development. Journal of Environmental Management 83(4):437–447.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science 277(5325):494–499.

Walsh, C. J., T. D. Fletcher, and A. R. Ladson. 2005a. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. Journal of the North American Benthological Society 24:690–705.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. 2005b. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society 24(3):706–723.

Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22(6):6–12.

Wang, L., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28(2):255–266.

Wang, L., J. Lyons, and P. Kanehl. 2003. Impacts of urban land cover on trout streams in Wisconsin and Minnesota. Transactions of the American Fisheries Society 132(5):825–839.

White, R. J. 1996. Growth and development of North American stream habitat management for fish. Canadian Journal of Fisheries and Aquatic Sciences 53(Suppl 1):342–363.

Whitlow, J. R., and K. J. Gregory. 1989. Changes in urban stream channels in Zimbabwe. Regulated Rivers: Research and Management 4:27–42.

Williams, G. P., and M. G. Wolman. 1984. Downstream Effects of Dams on Alluvial Rivers. U.S. Geological Survey Professional Paper 1286.

Wolman, M. G., and Schick, A. 1967. Effects of construction on fluvial sediment, urban and suburban areas of Maryland. Water Resources Research 3:451–464.

Wright, T., J. Tomlinson, T. Schueler, and K. Cappiella. 2006. Direct and indirect impacts of urbanization on wetland quality. Wetlands and Watersheds Article 1. Ellicott City, MD: Center for Watershed Protection.

2
The Challenge of Regulating Stormwater

Although stormwater has long been regarded as a major culprit in urban flooding, only in the past 30 years have policymakers appreciated the significant role stormwater plays in the impairment of urban watersheds. This recent rise to fame has led to a cacophony of federal, state, and local regulations to deal with stormwater, including the federal Clean Water Act (CWA) implemented by the U.S. Environmental Protection Agency (EPA). Perhaps because this longstanding environmental problem is being addressed so late in the development and management of urban watersheds, the laws that mandate better stormwater control are generally incomplete and were often passed for other purposes, like industrial waste control.

This chapter discusses the regulatory programs that govern stormwater, particularly the federal program, explaining how these programs manage stormwater only impartially and often inadequately. While progress has been made in the regulation of urban stormwater—from the initial emphasis on simply moving it away from structures and cities as fast as possible to its role in degrading neighboring waterbodies—a significant number of gaps remain in the existing system. Chapter 6 returns to these gaps and considers the ways that at least some of them may be addressed.

FEDERAL REGULATORY FRAMEWORK FOR STORMWATER

The Clean Water Act

The CWA is a comprehensive piece of U.S. legislation that has a goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. Its long-term goal is the elimination of polluted discharges to surface waters (originally by 1985), although much of its current effort focuses on the interim goal of attaining swimmable and fishable waters. Initially enacted as the Federal Water Pollution Control Act in 1948, it was revised by amendments in 1972 that gave it a stronger regulatory, water chemistry-focused basis to deal with acute industrial and municipal effluents that existed in the 1970s. Amendments in 1987 broadened its focus to deal with more diffuse sources of impairments, including stormwater. Improved monitoring over the past two decades has documented that although discharges have not been eliminated, there has been a widespread lessening of the effects of direct municipal and industrial wastewater discharges.

A timeline of federal regulatory events over the past 125 years relevant to stormwater, which includes regulatory precursors to the 1972 CWA, is shown in Table 2-1. The table reveals that while there was a flourish of regulatory activity related to stormwater during the mid-1980s to 1990s, there has been much less regulatory activity since that time.

TABLE 2-1 Legal and Regulatory Milestones for the Stormwater Program

1886	**Rivers and Harbors Act.** A navigation-oriented statute that was used in the 1960s and 1970s to challenge unpermitted pollutant discharges from industry.
1948 *1952* *1955*	**Federal Water Pollution Control Act.** Provided matching funds for wastewater treatment facilities, grants for state water pollution control programs, and limited federal authority to act against interstate pollution.
1965	**Water Quality Act.** Required states to adopt water quality standards for interstate waters subject to federal approval. It also required states to adopt state implementation plans, although failure to do so would not result in a federally implemented plan. As a result, enforceable requirements against polluting industries, even in interstate waters, was limited.
1972	**Federal Water Pollution Control Act.** First rigorous national law prohibiting the discharge of pollutants into surface waters without a permit. • Goal is to restore and maintain health of U.S. waters • Protection of aquatic life and human contact recreation by 1983 • Eliminate discharge of pollutants by 1985 • Wastewater treatment plant financing
	Clean Water Act Section 303(d) • Contains a water quality-based strategy for waters that remain polluted after the implementation of technology-based standards. • Requires states to identify waters that remain polluted, to determine the total maximum daily loads that would reverse the impairments, and then to allocate loads to sources. If states do not perform these actions, EPA must.
	Clean Water Act Section 208 • Designated and funded the development of regional water quality management plans to assess regional water quality, propose stream standards, identify water quality problem areas, and identify wastewater treatment plan long-term needs. These plans also include policy statements which provide a common consistent basis for decision making.
1977 *1981*	**Clean Water Act Sections 301 and 402** • Control release of toxic pollutants to U.S. waters • Technology treatment standards for conventional pollutants and priority toxic pollutants. • Recognition of technology limitations for some processes.
1977	*NRDC vs. Costle.* Required EPA to include stormwater discharges in the National Pollution Discharge Elimination System (NPDES) program.
1987	**Clean Water Act Amended Sections 301 and 402** • Control toxic pollutants discharged to U.S. waters. • Manage urban stormwater pollution. • Numerical criteria for all toxic pollutants. • Integrated control strategies for impaired waters. • Stormwater permit programs for urban areas and industry. • Stronger enforcement penalties. • Anti-backsliding provisions.

Table continues next page

TABLE 2-1 continued

1990	**EPA's Phase I Stormwater Permit Rules are Promulgated** • Application and permit requirements for large and medium municipalities • Application and permit requirements for light and heavy industrial facilities based on Standard Industrial Classification (SIC) Codes, and construction activity ≥ 5 acres
1999	**EPA's Phase II Stormwater Permit Rules are Promulgated** • Permit requirements for census-defined urbanized areas • Permit requirements for construction sites 1 to 5 acres
1997-2001	**Total Maximum Daily Load (TMDL) Program Litigation** • Courts order EPA to establish TMDLs in a number of states if the states fail to do so. The TMDLs assign Waste Load Allocations for stormwater discharges which must be incorporated as effluent limitations in stormwater permits.
2006-2008	**Section 323 of the Energy Policy Act of 2005** • EPA promulgates rule (2006) to exempt stormwater discharges from oil and gas exploration, production, processing, treatment operations, or transmission facilities from NPDES stormwater permit program. • In 2008, courts order EPA to reverse the rule which exempted certain activities in the oil and gas exploration industry from storm water regulations. In *Natural Resources Defense Council vs. EPA* (9th Cir. 2008), the court held that it was "arbitrary and capricious" to exempt from the Clean Water Act stormwater discharges containing sediment contamination that contribute to a violation of water quality standards.
2007	**Energy Independence and Security Act of 2007** • Requires all federal development and redevelopment projects with a footprint above 5,000 square feet to achieve predevelopment hydrology to the "maximum extent technically feasible."

The Basic NPDES Program: Regulating Pollutant Discharges

The centerpiece of the CWA is its mandate "that all *discharges* into the nation's waters are unlawful, unless specifically authorized by a permit" [42 U.S.C. §1342(a)]. Discharges do not include all types of pollutant flows, however. Instead, "discharges" are defined more narrowly as "point sources" of pollution, which in turn include only sources that flow through a discrete conveyance, like a pipe or ditch, into a lake or stream [33 U.S.C. §§ 1362(12) and (14)]. Much of the focus of the CWA program, then, is on limiting pollutants emanating from these discrete, point sources directly into waters of the United States. Authority to control nonpoint sources of pollution, like agricultural runoff (even when drained via pipes or ditches), is generally left to the states with more limited federal oversight and direction.

All point sources of pollutants are required to obtain a National Pollutant Discharge Elimination System (NPDES) permit and ensure that their pollutant discharges do not exceed specified effluent standards. Congress also commanded that rather than tie effluent standards to the needs of the receiving waterbody—an exercise that was far too scientifically uncertain and time-consuming—the effluent standards should first be based on the best available pollution technology or the equivalent. In response to a very ambitious mandate, EPA has promulgated very specific, quantitative discharge limits for the wastewater produced by over 30 industrial categories of sources based on what the best pollution control technology could accomplish, and it requires at least secondary treatment for the effluent produced by most sewage treatment plants. Under the terms of their permits, these large sources are also required to self-monitor their effluent at regular intervals and submit compliance reports to state or federal regulators.

EPA quickly realized after passage of the CWA in 1972 that if it were required to develop pollution limits for all point sources, it would need to regulate hundreds of thousands and perhaps even millions of small stormwater ditches and thousands of small municipal stormwater outfalls, all of which met the technical definition of "point source". It attempted to exempt all these sources, only to have the D.C. Circuit Court read the CWA to permit no exemptions [*NRDC vs. Costle*, 568 F.2d 1369 (D.C. Cir. 1977)]. In response, EPA developed a "general" permit system (an "umbrella" permit that covers multiple permittees) for smaller outfalls of municipal stormwater and similar sources, but it generally did not require these sources to meet effluent limitations or monitor their effluent.

It should be noted that, while the purpose of the CWA is to ensure protection of the physical, biological, and chemical integrity of the nation's waters, the enforceable reach of the Act extends only to the discharges of "pollutants" into waters of the United States [33 U.S.C. § 1311(a); cf. PUD No. 1 of Jefferson County v. Washington Department of Ecology, 511 U.S. 700 (1994) (providing states with broad authority under section 401 of the CWA to protect designated uses, not simply limit the discharge of pollutants)]. Even though "pollutant" is defined broadly in the Act to include virtually every imaginable substance added to surface waters, including heat, it has not traditionally been read to include water volume [33 U.S.C. § 1362(6)]. Thus, the focus of the CWA with respect to its application to stormwater has traditionally been on the water quality of stormwater and not on its quantity, timing, or other hydrologic properties. Nonetheless, because the statutory definition of "pollutant" includes "industrial, municipal, and agricultural waste discharged into water," using transient and substantial increases in flow in urban watersheds as a proxy for pollutant loading seems a reasonable interpretation of the statute. EPA Regions 1 and 3 have considered flow control as a particularly effective way to track sediment loading, and they have used flow in TMDLs as a surrogate for pollutant loading (EPA Region 3, 2003). State trial courts have thus far ruled that municipal separate storm sewer system (MS4) permits issued under delegated federal authority can impose restrictions on flow where changes in flow impair the beneficial uses of surface waters (Beckman, 2007). EPA should consider more formally clarifying that significant, transient increases in flow in urban watersheds serve as a legally valid proxy for the loading of pollutants. This clarification will allow regulators to address the problems of stormwater in more diverse ways that include attention to water volume as well as to the concentration of individual pollutants.

Stormwater Discharge Program

By 1987, Congress became concerned about the significant role that stormwater played in contributing to water pollution, and it commanded EPA to regulate a number of enumerated stormwater discharges more rigorously. Specifically, Section 402(p), introduced in the 1987 Amendments to the CWA, directs EPA to regulate some of the largest stormwater discharges—those that occur at industrial facilities and municipal storm sewers from larger cities and other significant sources (like large construction sites)—by requiring permits and promulgating discharge standards that require the equivalent of the best available technology [42 U.S.C. § 1342(p)(3)]. Effectively, then, Congress grafted larger stormwater discharges onto the existing NPDES program that was governing discharges from manufacturing and sewage treatment plants.

Upon passage of Section 402(p), EPA divided the promulgation of its stormwater program into two phases that encompass increasingly smaller discharges. The first phase, finalized in 1990, regulates stormwater discharges from ten types of industrial operations (this includes the entire manufacturing sector), construction occurring on five or more acres, and medium or large storm sewers in areas that serve 100,000 or more people [40 C.F.R. § 122.26(a)(3) (1990); 40 C.F.R. § 122.26 (b)(14) (1990)]. The second phase, finalized in 1995, includes smaller municipal storm sewer systems and smaller construction sites (down to one acre) [60 Fed. Reg. 40,230 (Aug. 7, 1995) (codified at 40 C.F.R. Parts 122, 124 (1995)]. If these covered sources fail to apply for a permit, they are in violation of the CWA.

Because stormwater is more variable and site specific with regard to its quality and quantity than wastewater, EPA found it necessary to diverge in two important ways from the existing NPDES program governing discharges from industries and sewage treatment plants. First, stormwater discharge limits are not federally specified in advance as they are with discharges from manufacturing plants. Even though Congress directed EPA to require stormwater sources to install the equivalent of the best available technology or “best management practices,” EPA concluded that the choice of these best management practices (referred to in this report as stormwater control measures or SCMs) would need to be source specific. As a result, although EPA provides constraints on the choices available, it generally leaves stormwater sources with responsibility for developing a stormwater pollution prevention plan and the state with the authority to approve, amend, or reject these plans (EPA, 2006, p. 15).

Second, because of the great variability in the nature of stormwater flow, some sources are not required to monitor the pollutants in their stormwater discharges. Even when monitoring is required, there is generally a great deal of flexibility for regulated parties to self-monitor as compared with the monitoring requirements applied to industrial waste effluent (not stormwater from industries). More specifically, for a small subset of stormwater sources such as Phase I MS4s, some monitoring of effluent during a select number of storms at a select number of outfalls is required (EPA, 1996a, p. VIII-1). A slightly larger number of identified stormwater dischargers, primarily industrial, are only required to collect grab samples four times during the year and visually sample and report on them (so-called benchmark monitoring). The remaining stormwater sources are not required to monitor their effluent at all (EPA, 1996a). States and localities may still demand more stringent controls and rigorous stormwater monitoring, particularly in areas undergoing a Total Maximum Daily Load (TMDL) assessment, as discussed below. Yet, even for degraded waters subject to TMDLs, any added monitoring that might be required will be limited only to the pollutants that cause the degraded condition [40 C.F.R. §§ 420.32-420.36 (2004)].

Water Quality Management

Since technology-based regulatory requirements imposed on both stormwater and more traditional types of discharges are not tied to the conditions of the receiving water—that is, they require sources only to do their technological best to eliminate pollution—basic federal effluent limits are not always adequate to protect water quality. In response to this gap in protection, Congress has developed a number of programs to ensure that waters are not degraded below minimal federal and state goals [e.g., 33 U.S.C. §§ 1288, 1313(e), 1329, 1314(l)]. Among these, the TMDL program involves the most rigorous effort to control both point and nonpoint sources to ensure that water quality goals are met [33 U.S.C. § 1313(d)].

Under the TMDL program, states are required to list waterbodies not meeting water quality standards and to determine, for each degraded waterbody, the "total maximum daily load" of the problematic pollutant that can be allowed without violating the applicable water quality standard. The state then determines what types of additional pollutant loading reductions are needed, considering not only point sources but also nonpoint sources. It then promulgates controls on these sources to ensure further reductions to achieve applicable water quality goals.

The TMDL process has four separate components. The first two components are already required of the states through other sections of the CWA: (1) identify beneficial uses for all waters in the state and (2) set water quality standards that correlate with these various uses. The TMDL program adds two components by requiring that states then (3) identify segments where water quality goals have not been met for one or more pollutants and (4) develop a plan that will ensure added reductions are made by point and/or nonpoint sources to meet water quality goals in the future. Each of these is discussed below.

Beneficial Uses. States are required to conduct the equivalent of "zoning" by identifying, for each water segment in the state, a beneficial use, which consists of ensuring that the waters are fit for either recreation, drinking water, aquatic life, or agricultural, industrial, and other purposes [33 U.S.C. § 1313(c)(2)(A)]. All states have derived "narrative definitions" to define the beneficial uses of waterbodies that are components of all water quality standard programs. Many of these narrative criteria are conceptual in nature and tend to define general aspects of the beneficial uses. For categories such as *aquatic life uses*, most states have a single metric for differentiating uses by type of stream (e.g., coldwater vs. warmwater fisheries). In general, the desired biological characteristics of the waterbody are not well defined in the description of the beneficial use. Some states, such as Ohio, have added important details to their beneficial uses by developing tiered aquatic life uses that recognize a strong gradient of anthropogenic background disturbance that controls whether a waterbody can attain a certain water quality and biological functioning (see Box 2-1; Yoder and Rankin, 1998). Any aquatic life use tier less stringent than the CWA interim goal of "swimmable–fishable" requires a Use Attainability Analysis to support a finding that restoration is not currently feasible and recovery is not likely in a reasonable period of time. This analysis and proposed designation must undergo public comment and review and are always considered temporary in nature. More importantly, typically one or more tiers above the operative interim goal of "swimmable–fishable" are provided. This method typically will protect the highest attainable uses in a state more effectively than having only single uses.

The concept of tiered beneficial uses and use attainability is especially important with regard to urban stormwater because of the potential irreversibility of anthropogenic development and the substantial costs that might be incurred in attempting to repair degraded urban watersheds to "swimmable–fishable" or higher status. Indeed, it is important to consider what public benefits and costs might occur for different designated uses. For example, large public benefits (in terms of aesthetics and safety) might be gained from initial improvements in an urban stream (e.g., restoring base flow) that achieve modest aquatic use and protect secondary human contact. However, achieving designated uses associated with primary human contact or exceptional aquatic habitat may be much more costly, such that the perceived incremental public gains may be much lower than the costs that must be expended to achieve that more ambitious designation.

BOX 2-1
Ohio's Tiered Aquatic Life Uses

"Designated" or "beneficial" uses for waterbodies are an important aspect of the CWA because they are the explicit water quality goals or endpoints set for each water or class of waters. Ohio was one of the first states to implement tiered aquatic life uses (TALUs) in 1978 as part of its water quality standards (WQS). Most states have a single aquatic life use for a class of waters based on narrative biological criteria (e.g., warmwater or cold-water fisheries) although many states now collect data that would allow identification of multiple tiers of condition. EPA has recognized the management advantages inherent to tiered aquatic life uses and has developed a technical document on how to develop the scientific basis that would allow States to implement tiered uses (EPA, 2005a; Davies and Jackson, 2006).

Ohio's TALUs reflect the mosaic of natural features across Ohio and over 200 years of human changes to the natural landscape. Widespread information on Ohio's natural history (e.g., Trautman's 1957 *Fishes of Ohio*) provided strong evidence that the potential fauna of streams was not uniform, but varied geographically. Based on this knowledge, Ohio developed a more protective aquatic life use tier to protect streams of high biological diversity that harbored unique assemblages of rare or sensitive aquatic species (e.g., fish, mussels, invertebrates). In its WQS in 1978, Ohio established a narrative Exceptional Warmwater Habitat (EWH) aquatic life use to supplement its more widespread general or "Warmwater Habitat" aquatic life use (WWH) (Yoder and Rankin, 1995).

The CWA permits states to assign aquatic life uses that do not meet the baseline swimmable-fishable goals of the CWA under specific circumstances after conducting a Use Attainability Analysis (UAA), which documents that higher CWA aquatic life use goals (e.g., WWH and EWH in Ohio) are not feasibly attainable. These alternate aquatic life uses are always considered temporary in case land use changes or technology changes to make restoration feasible. The accrual of more than ten years of biological assessment data by the late 1980s and extensive habitat and stressor data provided a key link between the stressors that limited attainment of a higher aquatic life use in certain areas and reaches of Ohio streams. This assessment formed the basis for several "modified" (physical) warm-water uses for Ohio waters and a "limited" use (limited resource water, LRW) for mostly small ephemeral or highly artificial waters (Yoder and Rankin, 1995). Table 2-2 summarizes the biological and physical characteristics of Ohio TALUs and the management consequences of these uses. Channelization typically maintained by county or municipal drainage and flood control efforts, particularly where such changes have been extensive, are the predominant cause of Modified and Limited aquatic life uses. Extensive channel modification in urban watersheds has led to some modified warmwater habitat (MWH) and LRW uses in urban areas. There has been discussion of developing specific "urban" aquatic life uses; however the complexity of multiple stressors and the need to find a clear link between the sources limiting aquatic life and feasible remediation is just now being addressed in urban settings (Barbour et al., 2006).

The TALUs in Ohio (EWH→LRW) reflect a gradient of landscape and direct physical changes, largely related to changes to instream habitat and associated hydrological features. Aquatic life uses and the classification strata based on ecoregion and stream size (headwater, wadeable, and boatable streams) provide the template for the biocriteria expectations for Ohio streams (see Box 2-2). Identification of the appropriate tiers for streams and UAA are a routine part of watershed monitoring in Ohio and are based on biological, habitat, and other supporting data. Any recommendations for changes in aquatic life uses are subject to public comment when the Ohio WQS are changed.

Ohio's water quality standards contain specific listings by stream or stream reach with notations about the appropriate aquatic life use as well as other applicable uses (e.g., recreation). Much of the impact of tiered uses on regulated entities or watershed management

TABLE 2-2 Key features associated with tiered aquatic life uses in the Ohio WQS. SOURCE: EPA (2005a), Appendix B.

Aquatic Life Use	Key Attributes	Why a Waterbody Would Be Designated	Practical Impacts (compared to a baseline of WWH)
Warmwater Habitat (WWH)	Balanced assemblages of fish/invertebrates comparable to least impacted *regional* reference condition	Either supports biota consistent with numeric biocriteria for that ecoregion **or** exhibits the habitat potential to support recovery of the aquatic fauna	Baseline regulatory requirements consistent with the CWA "fishable" and "protection & propagation" goals; criteria consistent with U.S. EPA guidance with State/regional modifications as appropriate
Exceptional Warmwater Habitat (EWH)	Unique and/or diverse assemblages; comparable to upper quartile of *statewide* reference condition	Attainment of the EWH biocriteria demonstrated by both organism groups	More stringent criteria for D.O., temperature, ammonia, and nutrient targets; more stringent restrictions on dissolved metals translators; restrictions on nationwide dredge & fill permits; may result in more stringent wastewater treatment requirements
Coldwater Habitat (CWH)	Sustained presence of Salmonid or non-salmonid coldwater aquatic organisms; bonafide trout fishery	Bioassessment reveals coldwater species as defined by Ohio EPA (1987); put-and-take trout fishery managed by Ohio DNR	Same as above except that common metals criteria are more stringent; may result in more stringent wastewater treatment requirements
Modified Warmwater Habitat (MWH)	Warmwater assemblage dominated by species tolerant of low D.O., excessive nutrients, siltation, and/or habitat modifications	Impairment of the WWH biocriteria; existence and/or maintenance of hydrological modifications that cannot be reversed or abated to attain the WWH biocriteria; a use attainability analysis is required	Less stringent criteria for D.O., ammonia, and nutrient targets; less restrictive applications of dissolved metals translators; Nationwide permits apply without restrictions or exception; may result in less restrictive wastewater treatment requirements
Limited Resource Waters (LRW)	Highly degraded assemblages dominated exclusively by tolerant species; *should not* reflect acutely toxic conditions	Extensive physical and hydrological modifications that cannot be reversed and which preclude attainment of higher uses; a use attainability analysis is required	Chemical criteria are based on the prevention of acutely lethal conditions; may result in less restrictive wastewater treatment requirements

efforts arises from the tiered chemical and stressor criteria associated with each TALU. Criteria for compounds such as ammonia and dissolved oxygen vary with aquatic life use (see Table 2-2). Furthermore, application of management actions in Ohio, ranging from assigning antidegradation tiers, awarding funding for wastewater infrastructure and other projects, to issuing CWA Section 401/404 permits, are influence by the TALU and the biological assemblages present.

Ohio has been expanding its use of tiered uses by proposing tiered uses for wetlands (*http://www.epa.state.oh.us/dsw/rules/draft_1-53_feb06.pdf*) and developing new aquatic life uses for very small (primary headwater, PHW) streams. Both of these water types have a strong intersection with urban construction and stormwater practices. In Ohio this is especially so because the proposed mitigation standards for steams and wetlands are linked to TALUs (Ohio EPA, 2007).

Davies and Jackson (2006) present a good summary of the Maine rationale for TALUs: "(1) identifying and preserving the highest quality resources, (2) more accurately depicting existing conditions, (3) setting realistic and attainable management goals, (4) preserving incremental improvements, and (5) triggering management action when conditions decline" (Davies et al., 1999). Appendices A and B of EPA (2005a) provide more detailed information about the TALUs in Maine and Ohio, respectively.

Water Quality Criteria. Once a state has created a list of beneficial uses for its waters, water quality criteria are then determined that correspond with these uses. These criteria can target chemical, biological, or physical parameters, and they can be either numeric or narrative.

In response to the acute chemical water pollution that existed when the CWA was written, the primary focus of water quality criteria was the control of toxic and conventional pollutants from wastewater treatment plants. EPA developed water quality criteria for a wide range of conventional pollutants and began working on criteria for a list of priority pollutants. These were generally in the form of numeric criteria that are then used by states to set their standards for the range of waterbody types that exist in that state. While states do not have to adopt EPA water quality criteria, they must have a scientific basis for setting their own criteria. In practice, however, states have promulgated numerical water quality standards that can vary by as much as 1,000-fold for the same contaminant but are still considered justified by the available science [e.g., the water quality criteria for dioxin—*Natural Resources Defense Council, Inc. vs. EPA*, 16 F.3d 1395, 1398, 1403-05 (4^{th} Cir. 1993)].

The gradual abatement of point source impairments and increased focus on ambient monitoring and nonpoint source pollutants has led to a gradual, albeit inconsistent, shift by states toward (1) biological and intensive watershed monitoring and (2) consideration of stressors that are not typical point source pollutants including nutrients, bedded sediments, and habitat loss. For these parameters, many states have developed narrative criteria (e.g., "nutrients levels that will not result in noxious algal populations"), but these can be subjective and hard to enforce.

The use of biological criteria (biocriteria) has gained in popularity because traditional water quality monitoring is now perceived as insufficient to answer questions about the wide range of impairments caused by activities other than wastewater point sources, including stormwater (GAO, 2000). As described in Box 2-2, Ohio has defined biocriteria in its water quality standards based on multimetric indices from reference sites that quantify the baseline expectations for each tier of aquatic life use.

Antidegradation. The antidegradation provision of the water quality standards deals with waters that already achieve or exceed baseline water quality criteria for a given designated use. Antidegradation provisions must be considered before any regulated activity can be authorized that may result in a lowering of water quality which includes biological criteria. These provisions protect the existing beneficial uses of a water and only allow a lowering of water quality (but never lower than the baseline criteria associated with the beneficial use) where necessary to support important social and economic development. It essentially asks the question: is the discharge or activity necessary? States with refined designated uses and biological criteria have used these programs to their advantage to craft scientifically sound, protective, yet flexible antidegradation rules (see Ohio and Maine). Antidegradation is not a replacement for tiered

BOX 2-2
Ohio's Biocriteria

After it implemented tiered aquatic life uses in 1978, Ohio developed numeric biocriteria in 1990 (Ohio WQS; Ohio Administrative Code 3745-1) as part of its WQS. Since designated uses were formulated and described in ecological terms, Ohio felt that it was natural that the criteria should be assessed on an ecological basis (Yoder, 1978). Subsequent to the establishment of the EWH tier in its WQS, Ohio expanded its biological monitoring efforts to include both macroinvertebrates and fish (Yoder and Rankin, 1995) and established consistent and robust monitoring methodologies that have been maintained to the present. This core of consistently collected data has allowed the application of analytical tools, including multimetric indices such as the Index of Biotic Integrity (IBI), the Invertebrate Community Index (ICI), and other multivariate tools. The development of aquatic ecoregions (Omernik, 1987, 1995; Gallant et al., 1989), a practical definition of biological integrity (Karr and Dudley, 1981), multimetric assessment tools (Karr, 1981; Karr et al., 1986), and reference site concepts (Hughes et al., 1986) provided the basis for developing Ohio's ecoregion-based numeric criteria.

Successful application of biocriteria in Ohio was dependent on the ability to accurately classify aquatic ecosystem changes based on primarily natural abiotic features of the environment. Ohio's reference sites, on which the biocriteria are based, reflect spatial differences that were partially explained by aquatic ecoregions and stream size. Biological indices were calibrated and stratified on this basis to arrive at biological criteria that present minimally acceptable baseline ecological index scores (e.g., IBI, ICI). Ohio biocriteria stratified by ecoregion aquatic life use and stream size are depicted in Figure 2-1.

Huron Erie Lake Plain (HELP)

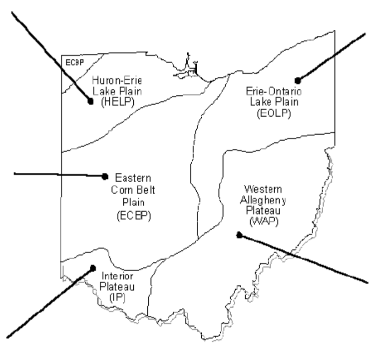
Use	Size	IBI	MIwb	ICI
WWH	H	28	NA	34
	W	32	7.3	34
	B	34	8.6	34
MWH-C	H	20	NA	22
	W	22	5.6	22
	B	20	5.7	22
MWH-I	B	30	5.7	NA

Eastern Corn Belt Plains (ECBP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	36
	W	40	8.3	36
	B	42	8.5	36
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA

Interior Plateau (IP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	30
	W	40	8.1	30
	B	38	8.7	30
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA



Erie Ontario Lake Plain (EOLP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	34
	W	38	7.9	34
	B	40	8.7	34
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA

Western Allegheny Plateau (WAP)

Use	Size	IBI	MIwb	ICI
WWH	H	44	NA	34
	W	44	8.4	34
	B	40	8.6	34
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-A	H	24	NA	30
	W	24	5.5	30
	B	24	5.5	30
MWH-I	B	30	6.6	NA

Statewide Exceptional Criteria

Use	.Size	IBI	MIwb	ICI
EWH	H	50	NA	46
	W	50	9.4	46
	B	48	9.6	46

FIGURE 2-1 Numeric biological criteria adopted by Ohio EPA in 1990, using three biological indices [IBI, ICI, and the Modified Index of well-being (MIwb), which is used to assessed fish assemblages] and showing stratification by stream size, ecoregion, and designated use (warmwater habitat, WWH; modified warmwater habitat-channelized, MWH-C; modified warmwater habitat-impounded, MWH-I; and exceptional warmwater habitat, EWH). SOURCE: EPA (2006, Appendix B). The basis for the Ohio biocriteria and sampling methods is found in Ohio EPA (1987, 1989a,b), DeShon (1995), and Yoder and Rankin (1995).

uses, which provide a permanent floor against lowering water quality protection. Tiered beneficial uses and refined antidegradation rules can have substantial influence on stormwater programs because they influence the goals and levels of protection assigned to each waterbody.

Monitoring Programs to Identify Degraded Segments. Monitoring strategies by the states generally follow the regulatory efforts of EPA and seek to identify those waterbodies where water quality standards are not being met. Much of the initial ambient monitoring (i.e., monitoring of receiving waterbodies) was chemical based and focused on documenting changes in pollutant concentrations and exceedances of water quality criteria. Biological monitoring techniques have a long history of use as indicators of water quality impacts. However, it was not until such tools became more widespread—initially in states like Maine, North Carolina, and Ohio—that the extent of stormwater and other stressor effects on waterbodies became better understood. The biological response to common nonpoint stressors has driven the consideration of new water quality criteria (e.g., for nutrients, bedded sediments) that were not major considerations under an effluent-dominated paradigm of water management.

In parallel with the increase in biocriteria has been the development of biological monitoring to measure beneficial use attainment. Integrated biological surveys have revealed impairments of waterbodies that go beyond those caused by typical point sources (EPA, 1996b; Barbour et al., 1999a). The substantial increase in biological assemblage monitoring during the 1980s was enhanced by the development of more standard methods (Davis, 1995; Barbour et al., 1999a,b; Klemm et al., 2003) along with conceptual advances in the development of assessment tools (Karr, 1981; Karr and Chu, 1999). Development of improved classification tools (e.g., ecoregions, stream types), the reference site concept (Stoddard et al., 2006), and analytical approaches including multivariate (e.g., discriminant analysis) and multimetric indices such as IBI and ICI (see Box 2-3; Karr et al., 1986; DeShon, 1995) resulted in biological criteria being developed for several states. Biological monitoring approaches are becoming a widespread tool for assessing attainment of aquatic life use designation goals inherent to state water quality standards. Development of biocriteria represents a maturation of the use of biological data and provides institutional advantages for states in addressing pollutants without numeric criteria (e.g., nutrients) and non-chemical stressors such as habitat (Yoder and Rankin, 1998).

Setting Loads and Restricting Loading. Section 303d of the CWA requires that states compare existing water quality data with water quality standards set by the states, territories, and tribes. For those waters found to be in violation of their water quality standards, Section 303d requires that the state develop a TMDL. Currently, approximately 20,000 of monitored U.S. waters are in non-attainment of water quality standards, as evidenced by not meeting at least one specific narrative or numeric physical, chemical, or biological criterion, and thus require the development of a TMDL.

BOX 2-3
Commonly Used Biological Assessment Indices

Much of the initial work using biological data to assess the effects of pollution on inland streams and rivers was a response to Chicago's routing of sewage effluents into the Illinois River in the late 1800s. Early research focused on the use of indicator species, singly or in aggregate, and how they changed along gradients of effluent concentrations (Davis, 1990, 1995). In the 1950s Ruth Patrick used biological data to assess rivers by observing longitudinal changes in taxonomic groups, and later in the 1950s and 1960s "diversity indices" (e.g., Shannon-Wiener index, Shannon and Weaver, 1949) were used to assess aquatic communities (Washington, 1984; Davis 1990, 1995). These indices were various mathematical constructs that measured attributes such as richness and evenness of species abundance in samples and are still widely used today in ecological studies. Similarity indices are another approach that is used to compare biological assemblages between sites. There are a wide multitude of such indices (e.g., Bray-Curtis, Jaccard) and all use various mathematical constructs to examine species in common and absent between samples.

Biotic indices are generally of more recent origin (1970s to the present). Hilsenhoff (1987, 1988) assigned organic pollution tolerances to macroinvertebrate taxa and then combined these ratings in a biotic index that is still widely used for macroinvertebrates. Karr (1981) developed the Index of Biotic Integrity (IBI), a "multimetric" index that is composed of a series of 12 metrics of a Midwest stream fish community. This approach has been widely adopted and adapted to many types of waterbodies (streams, lakes, rivers, estuaries, wetlands, the Great Lakes, etc.) and organism groups and is probably the most widely used biotic index approach in the United States. Examples include the periphyton IBI (PIBI; Hill et al., 2000) for algal communities, the Invertebrate Community Index (ICI; DeShon, 1995) and benthic IBI (B-IBI, Kerans and Karr, 1994) for macroinvertebrates, a benthic IBI for estuaries (B-IBI; Weisberg et al., 1997), and a vegetative IBI for wetlands (VIBI-E; Mack, 2007).

Various multivariate statistical approaches have also been used to assess aquatic assemblages, often concurrently with multimetric indices. Maine, for example, uses a discriminant analysis that assesses stream stations by comparison to reference sites (Davies and Tsomides, 1997). Predictive modeling approaches, incorporating both biotic and environmental variables, have been widely used in Great Britain and Europe (River Invertebrate Prediction and Classification System, RIVPACS; Wright et al., 1993), Australia (AUS-RIVAS; Simpson and Norris, 2000), and more recently in the United States by Hawkins et al. (2000).

All of these approaches now have a wide scientific literature supporting their use and application. EPA (2002a) reports that most states have a biomonitoring program with at least one organism group to assess key waters in their states, although the level of implementation and sophistication varies by state. For example, only four states have numeric biocriteria in their state water quality standards, although 11 more are developing such biocriteria based on one or more of the above monitoring approaches (EPA, 2002a). The key to implementation of any of these approaches is to set appropriate goals for waters that can be accurately measured and then to use this type of information to identify limiting stressors (e.g., EPA Stressor Identification Process; EPA, 2000a).

The TMDL process includes an enforceable pollution control plan for degraded waters based on a quantification of the loading of pollutants and an understanding of problem sources within the watershed [33 U.S.C. § 1313(d)(1)(C)]. Both point and nonpoint sources of the problematic pollutants, including runoff from agriculture, are typically considered and their contributions to the problem are assessed. A plan is then developed that may require these sources to reduce their loading to a level (the TMDL) that ensures that the water will ultimately meet its designated use. Most of the TMDL requirements have been developed through regulation. Additional effluent limits for point sources discharging into segments subject to TMDLs are incorporated into the NPDES permit.

Total Maximum Daily Load Program and Stormwater

The new emphasis on TMDLs and the revelation that impacts are primarily from diffuse sources has increased the attention given to stormwater. If a TMDL assigns waste load allocations to stormwater discharges, these must be incorporated as effluent limitations into stormwater permits. In addition, the TMDL program provides a new opportunity for states to regulate stormwater sources more vigorously. In degraded waterbodies, effluent reductions for point sources are not limited by what is economically feasible but instead include requirements that will ensure that the continued degradation of the receiving water is abated. If a permitted stormwater source is contributing pollutants to a degraded waterbody and the state believes that further reductions in pollution from that source are needed, then more stringent discharge limitations are required. For example, in *City of Arcadia vs. State Water Resources Control Board* [135 Cal. App. 4th 1392 (Ca. Ct. App. 2006)], the court held in part that California's zero trash requirements for municipal storm drains, resulting from state TMDLs, were not inconsistent with TMDL requirements or the CWA. Thus, the maximum-extent-practicable standard for MS4s, as well as other technology-based requirements for other stormwater permittees, are a floor, not a ceiling, for permit requirements when receiving waters are impaired (Beckman, 2007). Finally, since the TMDL program expects the states to regulate any source—point or nonpoint—that it considers problematic, any source of stormwater is fair game, regardless of whether it is listed in Section 402p, and regardless of whether it is a "point source." Nonpoint source runoff from agricultural and silvicultural operations is in fact a common target for TMDL-driven restrictions [see, e.g., *Pronsolino vs. Nastri*, 291 F.3d 1123, 1130 (9th Cir. 2002), upholding restrictions on nonpoint sources, such as logging, compelled by State's TMDLs)].

Despite the potential for positive interaction between stormwater regulation and the TMDL program, there appears to be little activity occurring at the stormwater–TMDL interface. This is partly because the TMDL program itself has been slow in developing. In 2000, the National Wildlife Federation applied 36 criteria to the 50 states' water quality programs and concluded that 75 percent of the states had failed to develop meaningful TMDL programs (National Wildlife Federation, 2000, pp. 1–2). The General Accounting Office (GAO, 1989) identified the lack of implementation of TMDLs as a major impediment to attaining the goals of the CWA, which led to a spate of lawsuits filed by environmental groups to reverse this pattern. The result was numerous settlements with ambitious deadlines for issuing TMDLs.

Commentators blame the delays in these TMDL programs on inadequate ambient monitoring data and on the technical and political challenges of causally linking individual sources to problems of impairment. In a 2001 report, for example, the National Research Council (NRC) noted that unjustified and poorly supported water quality standards, a lack of monitoring, uncertainty in the relevant models, and a failure to use biocriteria to assess beneficial uses directly all contributed to the delays in states' abilities to bring their waters into attainment through the TMDL program (NRC, 2001). Each of these facets is not only technically complicated but also expensive. The cost of undertaking a rigorous TMDL program in a single state has been estimated to be about $4 billion per state, assuming that each state has 100 watersheds in need of TMDLs (Houck, 1999, p. 10476).

As a result, the technical demands of the TMDL program make for a particularly bad fit with the technical impediments already present in monitoring and managing stormwater. As mentioned earlier, the pollutant loadings in stormwater effluent vary dramatically over time and stormwater is notoriously difficult to monitor for pollutants. It is thus difficult to understand how much of a pollutant a stormwater point source contributes to a degraded waterbody, much less determine how best to reduce that loading so that the waterbody will meet its TMDL. As long as the focus in these TMDLs remains on pollutants rather than flow (a point raised earlier that will be considered again), the technical challenges of incorporating stormwater sources in a water quality-based regulatory program are substantial. Without considerable resources for modeling and monitoring, the regulator has insufficient tools to link stormwater contributions to water quality impairments.

These substantial challenges in linking stormwater sources back to TMDLs are reflected by the limited number of reports and guidance documents on the subject. In one recent report, for example, EPA provides 17 case studies in which states and EPA regions incorporated stormwater control measures into TMDL plans, but it is not at all clear from this report that these efforts are widespread or indicative of greater statewide activity (EPA, 2007a). Indeed, it almost appears that these case studies represent the universe of efforts to link TMDLs and stormwater management together. The committee's statement of task also appears to underscore, albeit implicitly, EPA's difficulty in making scientific connections between the TMDL and stormwater programs. This challenge is returned to in Chapter 6, which suggests some ways that the two can be joined together more creatively.

Other Statutory Authorities that Control Stormwater

Although the CWA is by far the most direct statutory authority regulating stormwater discharges, there are other federal regulatory authorities that could lead to added regulation of at least some stormwater sources of pollution.

Critical Resources

If there is evidence that stormwater flows or pollutants are adversely impacting either endangered species habitat or sensitive drinking water sources, federal law may impose more stringent regulatory restrictions on these activities. Under the Endangered Species Act, stormwater that jeopardizes the continued existence of endangered species may need to be reduced to the point that it no longer threatens the endangered or threatened populations in measurable ways, especially if the stormwater discharge results from the activity of a federal agency [16 U.S.C. §§ 1536(a), 1538(a)].

Under the Safe Drinking Water Act, a surface water supply of drinking water must conduct periodic "sanitary surveys" to ensure the quality of the supply (see 40 C.F.R. § 142.16). During the course of these surveys, significant stormwater contributions to pollution may be discovered that are out of compliance or not regulated under the Clean Water Act because they are outside of an MS4 area. Such a discovery could lead to more rigorous regulation of stormwater discharges. For a groundwater source that supplies 50 percent or more of the drinking water for an area and for which there is no reasonably available alternative source, the aquifer can be designated as a "Sole Source Aquifer" and receive greater protection under the Safe Drinking Water Act [42 U.S.C. § 300(h)-3(e)]. Stormwater sources that result from federally funded projects are also more closely monitored to ensure they do not cause significant contamination to these sole source aquifers.

Some particularly sensitive water supplies are covered by both programs. The Edwards Aquifer underlying parts of Austin and San Antonio, Texas, for example, is identified as a "Sole Source Aquifer." There are also several endangered species of fish and salamander in that same area. As a result, both the Safe Drinking Water Act and the Endangered Species Act demand more rigorous stormwater management programs to protect this delicate watershed.

Stormwater is also regulated indirectly by floodplain control requirements promulgated by the Federal Emergency Management Agency (FEMA). In order for a community to participate in the FEMA National Flood Insurance Program, it must fulfill a number of requirements, including ensuring that projects will not increase flood heights, including flood levels adjacent to the project site [see, e.g., 44 C.F.R. § 60.3(d)].

Contaminated Sites

Continuous discharges of contaminated stormwater and other urban pollutants (particularly through combined sewer overflows) have led to highly contaminated submerged sediments in many urban bays and rivers throughout the United States. In several cases where the sediment contamination was perceived as presenting a risk to human health or has led to substantial natural resource damages, claims have been filed under the federal hazardous waste cleanup statute commonly known as Superfund (42 U.S.C. § 9601 et seq.). This liability under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) technically applies to any area—whether submerged or not—as long as there is a "release or a threat of release of a hazardous substance" and the hazardous substances have accumulated in such a way as to lead to the "incurrence of response [cleanup] costs" or to "natural resource damages" [42 U.S.C. §9607(a)]. Although only a few municipalities and sewer systems have been sued, Superfund liability is theoretically of concern for possibly a much larger number of cities or even industries whose stormwater contains hazardous substances and when at least some of the discharges were either in violation of a permit or unpermitted. The National Oceanic and Atmospheric Administration brought suit against the City of Seattle and the Municipality of Metropolitan Seattle alleging natural resource damages to Elliott Bay resulting from pollution in stormwater and combined sewer overflows; the case was settled in 1991 (*United States vs. City of Seattle*, No. C90-395WD, *http://www.gc.noaa.gov/natural-office1.html*). While some of the elements for liability remain unresolved by the courts, such as whether some or all of the discharges are exempted under the "federally permitted release" defense of CERCLA [42 U.S.C. § 9601(10)(H)], which exempts surface water discharges that are covered by a general or NPDES permit from liability, the prospect of potential liability is still present.

Diversion of Stormwater Underground or into Wetlands

In some areas, stormwater is eliminated by discharging it into wetlands. If done through pipes or other types of point sources, these activities require a permit under the CWA. Localities or other sources that attempt to dispense with their stormwater discharges in this fashion must thus first acquire an NPDES permit.

Even without a direct discharge into wetlands, stormwater can indirectly enter wetland systems and substantially impair their functioning. In a review of more than 50 studies, the Center for Watershed Protection found that increased urbanization and development increased the amount of stormwater to wetlands, which in turn "led to increased ponding, greater water level fluctuation and/or hydrologic drought in urban wetlands" (Wright et al., 2006). They found that, in some cases, the ability of the wetlands to naturally remove pollutants became overwhelmed by pollutant loadings from stormwater.

An even more common method of controlling stormwater is to discharge it underground. Technically, these subsurface discharges of stormwater, including dry wells, bored wells, and infiltration galleries, are considered by EPA to be infiltration or "Class V" wells, which require a permit under the CWA as long as they are in proximity to an underground source of drinking water (40 C.F.R. Parts 144, 146). While EPA's definition excludes surface impoundments and excavated trenches lined with stone (provided they do not include subsurface fluid distribution systems or amount to "improved sinkholes" that involve the man-made modification of a naturally occurring karst depression for the purpose of stormwater control), most other types of subsurface drainage systems are covered regardless of the volume discharged (40 C.F.R. § 144.81(4)).

Given EPA's recent description of SCMs considered to be Class V injection wells (EPA, 2008), most SCMs that rely on infiltration are exempted. For example, if an infiltration trench is wider than it is deep, it is exempted from the Class V well regulations. Residential septic systems are also exempted [see 40 C.F.R. §§ 144.1(g)(1)(ii) and (2)(iii)]. However, those that involve deeper dry wells or infiltration galleries appear to require Class V well permits under the Safe Drinking Water Act. Because the use of these SCMs is likely to involve expensive compliance requirements, dischargers may steer away from them.

Air Contaminants

Air pollutants from vehicular exhaust and industrial sources that precipitate on roads and parking lots can also be collected in stormwater and increase pollutant loading (see Chapter 3 discussion of atmospheric deposition). While the Clean Air Act regulates these sources of air contamination, it does not eliminate them. Stormwater that is contaminated with air pollutants may consist of both "legal" releases of air pollutants, as well as "illegal" releases emitted in violation of a permit, although the distinction between the two groups of pollutants is effectively impossible to make in practice.

Pesticides and Other Chemical Products Applied to Land and Road Surfaces

EPA regulates the licensing of pesticides as well as chemicals and chemical mixtures, although its actual authority to take action, such as restricting product use or requiring labeling, varies according to the statute and whether the product is new or existing. Although EPA technically is allowed to consider the extent to which a chemical is accumulating in stormwater in determining whether additional restrictions of the chemical are needed, EPA is not aware of any instances in its Toxic Substances Control Act (TSCA) chemical regulatory decision-making in which it actually used this authority to advance water quality protection (Jenny Molloy, EPA, personal communication, March 13, 2008).

In its pesticide registration program, EPA does routinely consider a pesticide's potential for adverse aquatic effects from stormwater runoff in determining whether the pesticide constitutes an unreasonable risk (Bill Jordan, EPA, personal communication, March 14, 2008). EPA has imposed use restrictions on a number of individual pesticides, such as prohibiting aerial applications, requiring buffer strips, or reducing application amounts. Presumably states and localities are tasked with primary enforcement responsibility for most of these use restrictions. EPA has also required a surface water monitoring program as a condition of the re-registration for atrazine and continues to evaluate available surface water and groundwater data to assess pesticide risks (Bill Jordan, EPA, personal communication, March 14, 2008).

EPA STORMWATER PROGRAM

Stormwater is defined in federal regulations as "storm water runoff, snow melt runoff, and surface runoff and drainage" [40 CFR §122.26(b)(13)]. EPA intended that the term describe runoff from precipitation-related events and not include any type of non-stormwater discharge (55 Fed. Reg. 47995). A brief discussion of the evolution of the EPA's stormwater program is followed by an explanation of the permitting mechanisms and the various ways in which the program has been implemented by the states. As shown in Figure 2-2, the entire NPDES program has grown by almost an order of magnitude over the past 35 years in terms of the number of regulated entities, which explains the reliance of the program on general rather than individual permits. Both phases of the stormwater program have brought a large number of new entities under regulation.

Historical Background

States like Florida, Washington, Maryland, Wisconsin, and Vermont and some local municipalities such as Austin, Texas, Portland, Oregon, and Bellevue, Washington, preceded the EPA in implementing programs to mitigate the adverse impacts of stormwater quality and quantity on surface waters. The State of Florida, after a period of experimentation in the late 1970s, adopted a rule that required a state permit for all new stormwater discharges and for modifications to existing discharges if flows or pollutants increased (Florida Administrative Code, Chapter 17-25, 1982). The City of Bellevue, WA, established a municipal utility in 1974 to manage stormwater for water quality, hydrologic balance, and flood management purposes using an interconnected system of natural areas and existing drainage features.

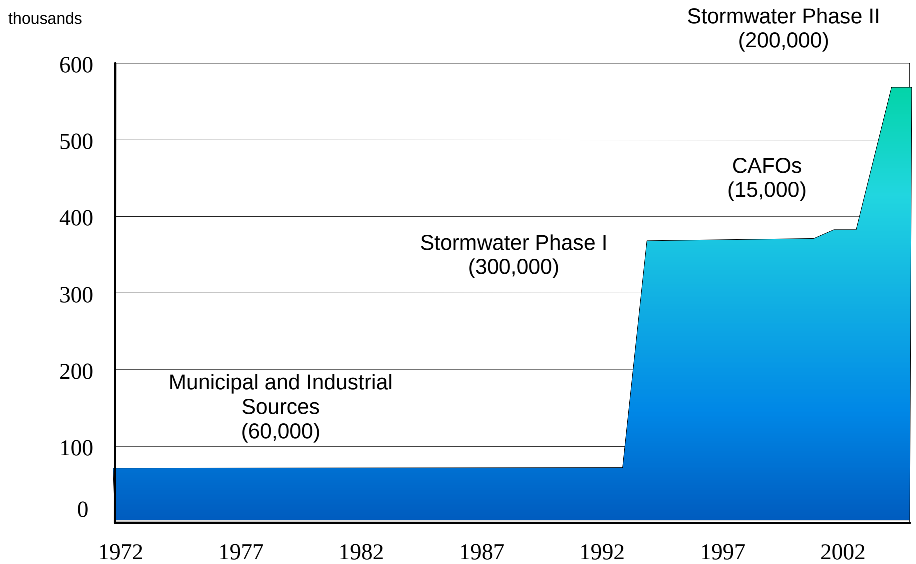


FIGURE 2-2 The number of permittees under the NPDES program of the Clean Water Act from 1972 to the present. Note that concentrated Animal Feeding Operations (CAFOs) are not considered in this report. SOURCE: Courtesy of Linda Boornazian, EPA.

EPA first considered regulating stormwater in 1973. At that time, it exempted from NPDES permit coverage conveyances carrying stormwater runoff not contaminated by industrial or commercial activity, unless the discharge was determined by the Administrator to be a significant contributor of pollutants to surface waters (38 Fed. Reg. 13530, May 22, 1973). EPA reasoned that while these stormwater conveyances were point sources, they were not suitable for end-of-pipe, technology-based controls because of the intermittent, variable, and less predictable nature of stormwater discharges. Stormwater pollution would be better managed at the local agency level through nonpoint source controls such as practices that prevent pollutants from entering the runoff. Further, EPA justified its decision by noting that the enormous numbers of individual permits that the Agency would have to issue would be administratively burdensome and divert resources from addressing industrial process wastewater and municipal sewage discharges, which presented more identifiable problems.

The Natural Resources Defense Council (NRDC) successfully challenged the EPA's selective exemption of stormwater point sources from the NPDES regulatory permitting scheme in federal court [*NRDC vs. Train*, 396 F.Supp. 1393 (D.D.C. 1975), *aff'd NRDC vs. Costle* 568 F.2d. 1369 (D.C. Cir. 1977)]. The court ruled that EPA did not have the authority to exempt point source discharges from the NPDES permit program, but recognized the Agency's discretion to use reasonable procedures to manage the administrative burden and to define what constitutes a stormwater point source. Consequently, EPA issued a rule establishing a comprehensive permit program for all stormwater discharges (except rural runoff) including municipal separate storm sewer systems (MS4s), which were to be issued "general" or area permits after a period of study (41 Fed. Reg. 11307, March 18, 1976). Individual permits were required for stormwater discharges from industrial or commercial activity, or where the stormwater discharge was designated by the permitting authority to be a significant contributor of pollutants. Comprehensive revisions to the NPDES regulations were published next, retaining the broad definition of stormwater discharges subject to the NPDES permit program and requiring permit application requirements similar to those for industrial wastewater discharges, including testing for an extended list of pollutants (44 Fed. Reg. 32854, June 7, 1979; 45 Fed. Reg. 33290, May 19, 1980).

The new NPDES regulations resulted in lawsuits filed in federal courts by a number of major trade associations, member companies, and environmental groups challenging several aspects of the NPDES program, including the stormwater provisions. The cases were consolidated in the D.C. Circuit Court of Appeals, and EPA reached a settlement with the industry petitioners on July 7, 1982, agreeing to propose changes to the stormwater regulations to balance environmental concerns with the practical limitations of issuing individual NPDES permits and limited resources. The Agency significantly narrowed the definition of stormwater point sources to conveyances contaminated by process wastes, raw materials, toxics, hazardous pollutants, or oil and grease, and it reduced application requirements by dividing stormwater discharges into two groups based on their potential for significant pollution problems (47 Fed. Reg. 52073, November 18, 1982). EPA issued a final rule retaining the broad coverage of stormwater point sources, and a two-tiered classification to administratively regulate these stormwater discharges (49 Fed. Reg. 37998, September 26, 1984).

The rule generated considerably controversy; trade associations and industry contended that application deadlines would be impossible to meet and that the sampling requirements were excessive, while the environmental community expressed a concern that additional changes or delays would exacerbate the Agency's failure to regulate sources of stormwater pollution. On the basis of the post-promulgation comments received, EPA determined that it was necessary to obtain additional data on stormwater discharges to assess their significance, and it conducted meetings with industry groups, who indicated an interest in providing representative data on the quality of stormwater discharges of their membership. The Agency determined that the submission of representative data was the most practical and efficient means of determining appropriate permit terms and conditions, as well as priorities for the multitude of stormwater point source discharges that needed to be permitted (50 Fed. Reg. 32548, August 12, 1985).

In the mean time, the U.S. House of Representatives and the Senate both passed bills to amend the CWA in mid-1985. The separate bills were reconciled in Conference Committee, and on February 4, 1987, Congress passed the Water

Quality Act (WQA), which specifically addressed stormwater discharges. The WQA added Section 402(p) to the CWA, which requires stormwater permits to be issued prior to October 1992 for (i) municipal stormwater discharges from large and medium municipalities based on the 1990 census; (ii) discharges associated with industrial activity; and (iii) a stormwater discharge that the Administrator determines contributes to the violation of a water quality standard or is a significant contributor of pollutants to waters of the United States. MS4s were required to reduce pollutants in stormwater discharges to the "maximum extent practicable" (MEP). Industrial and construction stormwater discharges must meet the best conventional technology (BCT) standard for conventional pollutants and the best available technology economically achievable (BAT) standard for toxic pollutants. EPA and the NPDES-delegated states were given the flexibility to issue municipal stormwater permits on a system-wide or jurisdiction-wide basis. In addition, the WQA amended Section 402(l)(2) of the CWA to not require a permit for stormwater discharges from mining and oil and gas operations if the stormwater discharge is not contaminated by contact, and it amended Section 502(14) of the CWA to exclude agricultural stormwater discharges from the definition of point source.

These regulations had been informed by the National Urban Runoff Program, conducted from 1978 to 1983 to characterize the water quality of stormwater runoff from light industrial, commercial, and residential areas (Athayde et al., 1983). The majority of samples collected were analyzed for eight conventional pollutants and three heavy metals, and a subset was analyzed for 120 priority pollutants. The study indicated that on an annual loading basis, some of the conventional pollutants were greater than the pollutant loadings resulting from municipal wastewater treatment plants. In addition, the study found that a significant number of samples exceeded EPA's water quality criteria for freshwater.

The Federal Highway Administration conducted studies over a ten-year period ending in 1990 to characterize the water quality of stormwater runoff from roadways (Driscoll et al., 1990). A total of 993 individual stormwater events at 31 highway sites in 11 states were monitored for eight conventional pollutants and three heavy metals. In addition, a subset of samples was analyzed for certain other conventional pollutant parameters. The studies found that urban highways had significantly higher pollutant concentrations and loads than non-urban highway sites. Also, sites in relatively dry semi-arid regions had higher concentrations of many pollutants than sites in humid regions.

Final Stormwater Regulations

EPA issued final regulations in 1990 establishing a process for stormwater permit application, the required components of municipal stormwater management plans, and a permitting strategy for stormwater discharges associated with industrial activities (55 Fed. Reg. 222, 47992, November 16, 1990). Stormwater discharges associated with industrial activity that discharge to MS4s were required to obtain separate individual or general NPDES permits. Nevertheless, EPA recognized that medium and large MS4s had a significant role to play in source identification and the development of pollution controls for industry, and thus municipalities were obligated to require the implementation of controls under local government authority for stormwater discharges associated with industrial activity in their stormwater management program. The final regulations also established minimum sampling requirements during permit application for medium and large MS4s (serving a population based on the 1990 census of 100,000 to 250,000, and 250,000 or more, respectively). MS4s were required to submit a two-part application over two years with the first part describing the existing program and resources and the second part providing representative stormwater quality discharge data and a description of a proposed stormwater management program, after which individual MS4 NPDES permits would be issued for medium and large MS4s.

In addition, the regulations identified ten industry groups and construction activity disturbing land area five acres or greater as being subject to stormwater NPDES permits. These industries were classified as either heavy industry or light industry where industrial activities are exposed to stormwater, based on the Office of Management and Budget Standard Industrial Classifications (SIC). The main industrial sectors subject to the stormwater program are shown in Table 2-3 and include 11 regulatory categories: (i) facilities with effluent limitations, (ii) manufacturing, (iii) mineral, metal, oil and gas, (iv) hazardous waste treatment, storage, or disposal facilities, (v) landfills, (vi) recycling facilities, (vii) steam electric plants, (viii) transportation facilities, (ix) treatment works, (x) construction activity, and (xi) light industrial activity.

The second phase of final stormwater regulations promulgated on December 8, 1999 (64 Fed. Reg. 68722) required small MS4s to obtain permit coverage for stormwater discharges no later than March 10, 2003. A small MS4 is defined as an MS4 not already covered by an MS4 permit as a medium or large MS4, or is located in “urbanized areas” as defined by the Bureau of the Census (unless waived by the NPDES permitting authority), or is designated by the NPDES permitting authority on a case-by-case basis if situated outside of urbanized areas. Further, the regulations lowered the construction activities regulatory threshold for permit coverage for stormwater discharges from five acres to one acre.

To give an idea of the administrative burden associated with the stormwater program and the different types of permits, Table 2-4 shows the number of regulated entities in the Los Angeles region that fall under either individual or general permit categories. Industrial and construction greatly outweigh municipal permittees, and stormwater permittees are vastly more numerous that traditional wastewater permittees.

TABLE 2-3 Sectors of Industrial Activity Covered by the EPA Stormwater Program

Category (see page 69)	**Sector**	**SIC Major Group**	**Activity Represented**
(i)	A	24	Timber products
(ii)	B	26	Paper and allied products
(ii)	C	28 and 39	Chemical and allied products
(i), (ii)	D	29	Asphalt paving and roofing materials and lubricants
(i) (ii)	E	32	Glass, clay, cement, concrete, and gypsum products
(i) (iii)	F	33	Primary metals
(i), (iii)	G	10	Metal mining (ore mining and dressing)
(i), (iii)	H	12	Coal mines and coal mining-related facilities
(i), (iii)	I	13	Oil and gas refining
(i), (iii)	J	14	Mineral mining and dressing
(iv)	K	HZ	Hazardous waste, treatment, storage, and disposal
(v)	L	LF	Landfills, land application sites, and open dumps
(vi)	M	50	Automobile salvage yards
(vii)	N	50	Scrap recycling facilities
(vii)	O	SE	Steam electric generating facilities
(viii)	P	40, 41, 42, 43, 51	Land transportation and warehousing
(viii)	Q	44	Water transportation
(viii)	R	37	Ship and boat building or repairing yards
(viii)	S	45	Air transportation
(ix)	T	TW	Treatment works
(xi)	U	20, 21	Food and kindred products
(xi)	V	22, 23, 31	Textile mills, apparel, and other fabric product manufacturing, leather and leather products
(xi)	W	24, 25	Furniture and fixtures
(xi)	X	27	Printing and publishing
(xi)	Y	30, 39, 34	Rubber, miscellaneous plastic products, and miscellaneous manufacturing industries
(xi)	AB	35, 37	Transportation equipment, industrial or commercial machinery
(xi)	AC	35, 36, 38	Electronic, electrical, photographic, and optical goods
(x)			Construction activity
	AD		Non-classified facilities designated by Administrator under 40 CFR §122.26(g)(1)(l)

SOURCE: 65 Fed. Reg. 64804, October 30, 2000.

TABLE 2-4 Number of NPDES Wastewater and Stormwater Entities Regulated by the CalEPA, Los Angeles Regional Water Board, as of May 2007

Waste Type	**Individual Permittees**	**General Permittees**
Wastewater and Non-stormwater Industry	103	574
Combined Wastewater and Stormwater	23	0
Stormwater (pre-1990)	45	0
Industrial Stormwater (post-1990)	0	2990
Construction Stormwater (post-1990)	0	2551
Municipal Stormwater (post-1990)	100	0
Total	271	6215

Municipal Permits

States with delegated NPDES permit authority (all except Alaska, Arizona, Idaho, Massachusetts, New Hampshire, and New Mexico) issued the first large and medium MS4 permits beginning in 1990, some of which are presently in their fourth permit term. These MS4 permits require large and medium municipalities to implement programmatic control measures (the six minimum measures) in the areas of (1) public education and outreach, (2) public participation and involvement, (3) illicit discharge detection and elimination, (4) construction site runoff control, (5) post-construction runoff control, and (6) pollution prevention and good housekeeping—all to reduce the discharge of pollutants in stormwater to the *maximum extent practicable*. Efforts to meet the six minimum measures are documented in a stormwater management plan. Non-stormwater discharges to the MS4 are prohibited unless separately permitted under the NPDES, except for certain authorized non-stormwater discharges, such as landscape irrigation runoff, which are deemed innocuous nuisance flows and not a source of pollutants. MS4 permits generally require analytic monitoring of pollutants in stormwater discharges for all Phase I medium and large MS4s from a subset of their outfalls that are 36 inches or greater in diameter or drain 50 acres or more. These data, at the discretion of the permitting authority, may be compared with water quality standards and considered (by default) to be effluent limitations, which refer to any restriction, including schedules of compliance, established by a state or the Administrator pursuant to CWA Section 304(b) on quantities, rates, and concentrations of chemical, physical, biological, and other constituents discharged from point sources into navigable waters, the waters of the contiguous zone, or the ocean (40 CFR §401.11). A future exceedance of an effluent limitation constitutes a permit violation. However, permitting authorities have so far not taken this approach to interpreting MS4 stormwater discharge data.

The Phase I stormwater regulations require medium and large MS4s to inspect "high-risk" industrial facilities and construction sites within their jurisdictions. Certain industrial facilities and construction sites of a minimum acreage are also subject to separate EPA/state permitting under the industrial and construction general permits (see below). While EPA envisioned a partnership with municipalities on these inspections in its Phase I Rule Making, it provided no federal funding to build these partnerships. Both industry and municipalities have argued that the dual inspection responsibilities are duplicative and redundant. Municipalities have further contended that the inspection of Phase I industrial facilities and construction sites are solely an EPA/state obligation, although state and federal courts have ruled otherwise. In the committee's experience, many MS4s do not oversee or regulate industries within their boundaries.

As part of the Phase II program, small MS4s are covered under general permits and are required to implement a stormwater management program to meet the six minimum measures mentioned above. Unlike with Phase I, Phase II MS4 stormwater discharge monitoring was made discretionary, and inspection of industrial facilities within the boundary of a Phase II MS4 is not required.

Industrial Permits

EPA issued the first nationwide multi-sector industrial stormwater general permit (MSGP) on September 29, 1995 (60 Fed. Reg. 50804), which was reissued on October 30, 2000 (65 Fed. Reg. 64746). A proposed new MSGP was released for public comment in 2005 (EPA, 2005b). The proposed MSGP requires that industrial facility operators prepare a stormwater pollution prevention plan (similar to an MS4's stormwater management plan) that documents the SCMs that will be implemented to reduce pollutants in stormwater discharges. They must achieve technology-based requirements using BAT or BCT or water quality-based effluent limits, which is the same requirement as for process wastewater permits.

All industrial sectors covered under the MSGP must conduct visual monitoring four times a year. The visual monitoring is performed by collecting a grab sample within the first hour of stormwater discharge and observing its characteristics qualitatively. A subset of MSGP industrial categories is required to perform analytical monitoring for benchmark pollutant parameters four times in Year 2 of permit coverage and again in Year 4 if benchmarks were exceeded in Year 2. The benchmark pollutant parameters, listed in Table 2-5, were selected based on the sampling data included with group permit applications submitted after the EPA issued its stormwater regulations in 1990. To comply with the benchmark monitoring requirements, a grab sample must be collected within the first hour of stormwater discharge after a rainfall event of 0.1 inch or greater and with an interceding dry period of at least 72 hours. A benchmark exceedance is not a permit violation, but rather is meant to trigger the facility operator to investigate SCMs and make necessary improvements.

TABLE 2-5 Industry Sectors and Sub-Sectors Subject to Benchmark Monitoring

MSGP Sector	Industry Sub-sector	Required Parameters for Benchmark Monitoring
C	Industry organic chemicals Plastics, synthetic resins, etc. Soaps, detergents, cosmetics, perfumes Agricultural chemicals	Al, Fe, nitrate and nitrite N Zn Zn, nitrate and nitrite N Pb, Fe, Zn, P, nitrate and nitrite N
D	Asphalt paving and roofing materials	TSS
E	Clay products Concrete products	Al TSS and Fe
F	Steel works, blast furnaces, rolling and finishing mills Iron and steel foundries Non-ferrous rolling and drawing Non-ferrous foundries (casting)	Al, Zn Al, Cu, Fe, Zn, TSS Cu, Zn Cu, Zn
G	Copper ore mining and dressing	COD, TSS, nitrate and nitrite N
H	Coal mines and coal mining related facilities	TSS
J	Dimension stone, crushed stone, and non-metallic minerals (except fuels) Sand and gravel mining	TSS, Al, Fe Nitrate and nitrite N, TSS
K	Hazardous waste treatment, storage, or disposal	NH_3, Mg, COD, Ar, Cd, CN, Pb, Hg, Se, Ag
L	Landfills, land application sites, and open dumps	Fe, TSS
M	Automobile salvage yards	TSS, Al, Fe, Pb
N	Scrap recycling	Cu, Al, Fe, Pb, Zn, TSS, COD
O	Steam electric generating facilities	Fe
Q	Water transportation facilities	Al, Fe, Pb, Zn
S	Airports with deicing activities	BOD, COD, NH_3, pH
U	Grain mill products Fats and oils	TSS BOD, COD, nitrate and nitrite N, TSS
Y	Rubber products	Zn
AA	Fabricated metal products except coating Fabricated metal coating and engraving	Fe, Al, Zn, nitrate and nitrite N Zn, nitrate and nitrite N

NOTE: BOD, biological oxygen demand; COD, chemical oxygen demand; TSS, total suspended solids.
SOURCE: 65 Fed. Reg. 64817, October 30, 2000.

EPA had already established technology-based effluent limitations for stormwater discharges for eight subcategories of industrial discharges prior to 1987, namely, for cement manufacturing, feedlots, fertilizer manufacturing, petroleum refining, phosphate manufacturing, steam electric, coal mining, and ore mining and dressing (see Table 2-6). Most of these facilities were covered under individual permits prior to 1987 and are generally required to stay covered under individual stormwater permits. Facilities in these sub-categories that had not been issued a stormwater discharge permit prior to 1992 are allowed to be covered under the MSGP, but they still have analytical monitoring requirements that must be compared to effluent limitation guidelines. An exceedance of the effluent limitation constitutes a permit violation.

TABLE 2-6 Select Stormwater Effluent Limitation Guidelines for Illustrative Purposes

Discharges	**Design Storm**	**Pollutant Parameters**	**Effluent Limitations (max per day)**
Phosphate Fertilizer Manufacturing Runoff (40 C.F.R. 418)	Not specified	Total P Fluoride	105 mg/L 75 mg/L
Petroleum Refining (40 C.F.R. 419)	Not specified	O&G TOC BOD5 COD Phenols Cr Hex Cr pH	15 mg/L 110 mg/L 48 kg/1000 m^3 flow 360 mg/1000 m^3 flow 0.35 mg/1000 m^3 flow 0.73 mg/1000 m^3 flow 0.062 mg/1000 m^3 flow 6–9
Asphalt Paving and Roofing Emulsion Products Runoff (40 C.F.R. 443)	Not specified	TSS O&G pH	0.023 kg/m^3 0.015 kg/m^3 6.0–9.0
Cement Manufacturing Material Storage Piles Runoff (40 C.F.R. 411)	10 yr, 24 hour	TSS pH	50 mg/L 6.0–9.0
Coal Mining (40 C.F.R. 434 Subpart B)	1 yr, 24 hour	Fe Mn TSS pH	7.0 mg/L 4 mg/L 70 mg/L 6.0–9.0
Steam Electric Power Generating (40 C.F.R. 423)	10 yr, 24 hour	TSS pH PCBs	50 mg/L 6.0–9.0 No discharge

NOTE: BOD5, biological oxygen demand; COD, chemical oxygen demand; O&G, oil and grease; PCBs, polychlorinated biphenyls; TOC, total organic carbon; TSS, total suspended solids. SOURCE: 40 C.F.R.

At the issuance of the Final Storm Water Rule in 1990, EPA envisioned the use of a mix of general permits and individual permits to better manage the administrative burden associated with permitting thousands of industrial stormwater point sources. In its original permitting strategy for industrial stormwater discharges, EPA articulated a four-tier strategy with the nationwide general permits: Tier 1 was baseline permitting, Tier 2 would incorporate watershed permits, Tier 3 would be industry category-specific permitting, and Tier 4 would encompass facility-specific individual permits. In reality, individual permits, which would allow for the crafting of permit conditions to be better structured to the specific industrial facility based on its higher potential risk to water quality, and could include adequate monitoring for purposes of compliance and enforcement, have been sparsely used. Similarly, neither the watershed permitting strategy nor the industry category-specific permitting strategy has found favor in the absence of better federal guidance and funding.

Industrial stormwater general permits are issued by the State NPDES Permitting Authority in NPDES-delegated states, and may be in the form a single statewide permit covering thousands of industrial permittees or sector-specific stormwater general permits covering less than a hundred facilities. EPA Regions issue the MSGP in states without NPDES-delegated authority and for facilities on Native Indian and Tribal Lands. EPA's nationwide 2000 MSGP presently covers 4,102 facilities.

Construction Permits

EPA issued the first nationwide construction stormwater general permit (CGP) in February 1998 (63 Fed. Reg. 7858). The permits are valid for five-year terms. The most recent CGP was issued in 2005 (68 Fed. Reg. 39087), and the EPA in 2008 administratively continued the CGP until the end of 2009, when it is expected to have developed effluent guidelines for construction activity (73 Fed. Reg. 40338). The EPA is presently under court order to develop effluent limitation guidelines for stormwater discharges from the construction and land development industry. The construction general permit requires the implementation of stormwater pollution prevention plans to prevent erosion, control sediment in stormwater discharges, and manage construction waste materials. Operators of the construction activity are required to perform visual inspections regularly, but no sampling of stormwater discharge during rainfall events is required. As with the industrial and municipal permittees, an exceedance of an effluent limitation incorporated in a permit would be a violation of the CWA and is subject to penalties.

EPA's CGP covers construction activity in areas where EPA is the permitting authority, including Indian lands, Puerto Rico, the District of Columbia, Massachusetts, New Hampshire, New Mexico, Idaho, Arizona, and Alaska. All other states have been delegated the authority to issue NPDES permits, and these states issue CGPs based on the EPA model but with subtle variations. For example the California and Georgia CGPs include monitoring requirements for construction sites discharging to sediment-impaired waterbodies. Wisconsin requires weekly inspections and an inspection within 24 hours of a rain event of 0.5 inches or greater. Georgia imposes discharge limits of an increase of no more than 10 Nephelometric Turbidity Units (NTU) above background in trout streams and no more than 25 NTU above background in other types of streams.

Permit Creation, Administration, and Requirements

For individual permits, the entity seeking coverage submits an application and one permit is issued. The conditions of the permit are based on an analysis of information provided in a rather lengthy permit application by the facility operator about the facility and the discharge. Generally, it takes six to 18 months for the permittee to compile the application information and for the permitting authority to finalize the permit. Individual permits are common for medium and large MS4s (Phase I), small MS4s in a few states (Phase II), and a few industrial activities.

General permits, on the other hand, are issued by the permitting authority, and interested parties then submit an Notice of Intent (NOI) to be covered. This mechanism is used where large numbers of dischargers require permit coverage, such as construction activities, most industrial activities, and most small MS4s (Phase II). The permit must identify the area of coverage, the sources covered, and the process for obtaining coverage. Once the permit is issued, a permittee may submit a NOI and receive coverage either immediately or within a very short time frame (e.g., 30 days).

All permits contain "effluent limitations" or "effluent guidelines," adherence to which is required of the permittee. However, the terms (which are synonymous) are agonizingly broad and encompass (1) meeting numeric pollutant limits in the discharge, (2) using certain SCMs, and (3) meeting certain design or performance standards. Effluent limitations may be expressed as SCMs when numeric limits are infeasible or for stormwater discharges where monitoring data are insufficient to carry out the purposes and intent of the CWA [122.44(k)]. If EPA has promulgated numerical "effluent guidelines" for existing and new stormwater sources under CWA Sections 301, 304, or 306, then the permits must incorporate the "effluent guidelines" as permit limits.

Effluent limitations can be either technology-based or water quality-based requirements. Technology-based requirements establish pollutant limits for discharges on what the best pollution control technology installed for that industry would normally accomplish. Water-quality based requirements, by contrast, look to the receiving waters to determine the level of pollution reduction needed for individual sources. There are national technology-based standards available for many categories of point sources, including many industrial sectors and municipal wastewater treatment plants. In the absence of national standards, technology-based requirements are developed on a case-by-case basis using best professional judgment. In general, BAT is the standard for toxic and non-conventional pollutants, while BCT is the standard for conventional pollutants. Water quality-based effluent limitations are required where technology-based limits are found to be insufficient to achieve applicable water quality standards, including restoring impaired waters, preventing impairments, and protecting high-quality waters. Limitations must control all pollutants or pollutant parameters that are or may be discharged at a level which will *cause, have reasonable potential to cause, or contribute to* an excursion above any applicable water quality standard. To distinguish between technology-based and water quality-based effluent limits, consider that a permittee is required to meet a numeric pollutant limit in their stormwater discharge. A technology-based limit would be based on studies of effluent concentrations coming from that technology, while a water quality-based limit would be based on some assessment of the impact of the discharge on a nearby receiving water (with the applicable water quality standard being the most conservative choice).

EPA is presently writing stormwater "effluent guidelines" for airport deicing operations and construction/development activity, with an estimated final action date of December 2009.

Permits Prior to 1990

A limited number of individual stormwater permits (perhaps in the low thousands) were first issued prior to 1990, the period before EPA promulgated regulations specific to stormwater discharges, and before EPA first received the authority to issue general NPDES permits. These individual NPDES permits for industrial stormwater discharges, like traditional individual wastewater NPDES permits, incorporate numerical effluent limits and they impose discharge monitoring requirements to demonstrate compliance. These facilities were selected for permitting before 1990, presumably because of the risk they presented to causing or contributing to the exceedance of water quality standards.

Do Permittees Have to Meet Water Quality Standards in their Effluent?

It is unclear as to whether municipal, industrial, and construction stormwater discharges must meet water quality standards. Furthermore, even if such discharges were required to meet water quality standards, the absence of monitoring found within the permits means that enforcement of the requirement would be difficult at best. Nonetheless, some sources suggest that, with the exception of Phase II MS4 discharges, EPA's intent is that stormwater discharges comply with water quality standards, especially where a TMDL is in place.

First, the EPA Office of General Counsel issued a memorandum in 1991 stating that municipal stormwater permits must require that MS4s reduce stormwater pollutant discharges to the maximum extent practicable and must also comply with water quality standards. Recognizing the complexity of stormwater, EPA's 1996 Interim Permitting Approach for Water Quality-Based Effluent Limitations in Storm Water Permits (61 Fed. Reg. 43761) stated that stormwater permits should use SCMs in first-term stormwater permits and expanded or better-tailored SCMs in subsequent term permits to provide for the attainment of water quality standards. However, where adequate information existed to develop more specific conditions or limitations to meet water quality standards, these conditions or limitations are to be incorporated into stormwater permits as necessary and appropriate.

As permitting authorities began to develop TMDL waste load allocations to address impaired receiving waters, and waste load allocations were assigned to stormwater discharges, EPA issued a TMDL Stormwater Policy. It stated that stormwater permits must include permit conditions consistent with the assumptions and requirements of available waste load allocations (EPA, 2002b). Since waste load allocations derive directly from water quality standards, this could be interpreted as saying that stormwater discharges must meet water quality standards. However, EPA expected that most water quality-based effluent limitations for NPDES-regulated stormwater discharges that implement TMDL waste load allocations would be expressed as SCMs, and that numeric limits would be used only in rare instances. This is understandable, given that storm events are dynamic and variable and it would be expensive to monitor all storm events and discharge points, particularly for MS4s, to demonstrate compliance with a waste load allocation expressed as a numeric effluent limitation. Effluent limitations expressed as SCMs appear to be the best interim approach to demonstrate compliance with TMDLs, provided that these SCMs are reasonably expected to satisfy the waste load allocation in the TMDL. As part of the TMDL, the NPDES permit must also specify the monitoring necessary to determine compliance with effluent limitations. Where effluent limits are specified as SCMs, the permit should specify the monitoring necessary to assess if the load reductions expected from SCM implementation are achieved (e.g., SCM performance data).

Implementation of the Stormwater Program by States and Municipalities

NPDES-delegated states and Indian Tribes generally utilize the CGP and the MSGP as model templates for adopting their respective general permits to regulate stormwater discharges associated with industrial activity, including construction, within their jurisdictions. Nevertheless, some variations exist. For example, the California CGP requires sampling of stormwater at construction sites that discharge to surface waters that are listed as being impaired for sediment. Connecticut's MSGP regulates stormwater discharges associated with commercial activity, in addition to industrial activity. With respect to the municipal permits, the variability with which the stormwater program is implemented reflects the flexibility inherent in the MEP standard. In the absence of a definite description of MEP or nationwide effluent guidelines issued by EPA, states and municipalities have not been very rigorous in determining what constitutes an adequate level of compliance. This self-defined compliance threshold has been translated into a wide range of efforts at program implementation.

A number of MS4 programs have been leaders in some areas of program implementation. For example, Prince George's County, Maryland, was a pioneer in implementing low impact development (LID) techniques. Notable efforts have been made by states and municipalities in the Pacific Northwest, such as Oregon and Washington. California and Florida also are in the forefront of implementing comprehensive and progressive stormwater programs.

Greater implementation is evident in states that had state stormwater regulations in place prior to the advent of the national stormwater program (GAO, 2007). Some states issued early MS4 permits (e.g., California, Florida, Washington, and Wisconsin) prior to the promulgation of the national stormwater program, while a number of MS4s (e.g., Austin, Texas,; Santa Monica, California; and Bellevue, Washington) were already implementing comprehensive stormwater management programs. In addition, some MS4s conducted individual stormwater management activities, such as street-sweeping, household hazardous waste collection, construction site plan review, and inspections, prior to the national stormwater program. These areas are more likely than areas without a stormwater program that predated the EPA program to be successfully meeting the requirements of the current program.

One of the obvious differences is the level of interest and effort exercised by coastal communities or communities in close proximity to a water resource that have immediate access to the beneficial uses of those resources but also have an immediate view of the impacts of polluted runoff. That interest may contrast with the less active posture of upstream or further inland communities that may not be as sensitive and willing to implement more stringent stormwater programs. A recent report has found that programs with more specific permit requirements generally result in more comprehensive and progressive stormwater management programs (TetraTech, 2006a). The report concluded that permittees should be required to develop measurable goals based on the desired outcomes of the stormwater program. Furthermore, additional stormwater permit requirements can be expected as more TMDLs are developed and wasteload allocations must be translated into permit conditions.

GAO Report on Current Status of Implementation

In 2007, the GAO issued a report to determine the impact of EPA's Stormwater Program on communities (GAO, 2007). Some of the relevant findings are that urban stormwater runoff continues to be a major contributor to the nation's degraded waters and that stormwater program implementation has been slow for both Phase I and Phase II communities, with almost 11 percent of all communities not yet permitted as of fall 2006. Litigation, among other reasons, delayed the issuance of some permits for years after the application deadlines. As a result, almost all Phase II and some Phase I communities are still in the early stages of program implementation although deadlines for permit applications were years ago—16 years for Phase I and six years for Phase II. EPA has acknowledged that it does not currently have a system in place to measure the success of the Phase I program on a national scale (EPA, 2000b). Therefore, it is reasonable to conclude that the level of implementation of the stormwater program ranges widely, from municipalities having completed a third-term permit (such as Los Angeles County MS4 permit) to municipalities not yet covered by a Phase II MS4 permit.

The GAO report also indicates that communities' inconsistent reporting of activities makes it difficult to evaluate program implementation nationwide. Based on the report's findings it seems that little auditing activity has been performed to gauge the status of implementation and effectiveness in achieving water quality improvements. Most often cited is the effort by EPA's Region 9 and the State of California auditors that recently discovered, among other things, that some MS4s (1) had not developed stormwater management plans, (2) were not properly performing an adequate number of inspections to enforce their stormwater ordinances, and (3) were lax in implementing SCMs at publicly owned construction sites. They also found that some MS4s were not adequately controlling stormwater runoff at municipally owned and operated facilities, such as maintenance yards. In response to these findings, EPA issued in January 2007 an MS4 Program Evaluation Guidance document (EPA, 2007b).

In the absence of a nationwide perspective of the implementation of the stormwater program, it is hard to make a determination about the program's success. There are communities and states that seem to have made great strides in implementing progressive stormwater programs, but it also seems that overall many programs are still in the early stages of implementation, while a number of communities are still waiting to obtain coverage under the MS4 permits. In addition, it appears that there is no national uniform system of tracking success or cost data. All these unknowns make it very difficult to formulate any definite statements about how successful the implementation of the program is on a national perspective.

Committee Survey

In order to get a better understanding of how the stormwater program is implemented by the states, during 2007 the committee conducted two surveys asking states about their monitoring requirements, compliance determination, and other facts for each program (municipal, industrial, and construction). For the larger survey, 18 states representing all ten EPA regions responded to the survey. Both surveys and all responses are found in Appendix C.

As expected, the responding states reported that Phase I MS4s are required to sample their stormwater discharges for pollutants, although the frequency of sampling and the number of pollutants being sampled tended to vary. No state reported requiring Phase II MS4s to sample stormwater discharges. Monitoring requirements for industrial stormwater varied by state from none in Minnesota, Nebraska, and Maine to benchmark monitoring required under the MSGP in Virginia, New York, and Wyoming. California, Connecticut, and Washington require all industrial facilities to monitor for select chemical pollutants. Connecticut, additionally, requires sampling for aquatic toxicity. Most of the responding states do not require construction sites to do much more than visual monitoring periodically and after rain events. Georgia and Washington require construction sites to monitor for parameters such as turbidity and pH. California and Oregon require sampling when the discharge is to a waterbody impaired by sediment.

As mentioned previously, Phase I MS4s (but not Phase II MS4s) are required to address industrial dischargers within their boundaries. There was considerable variability regarding the survey questions of whether MS4s can conduct inspections of industrial facilities and what industries are considered high risk. In all of the responding states except Virginia, the responders think that MS4s have the authority to inspect industries within their boundaries, although the extent to which this is done is not clear and, in the committee's experience, is quite rare. Many of the responding states have not identified "high-risk" facilities and targeted them for compliance scrutiny, although certain categories were felt to be problematic by the state employee responding to the survey, such as metal foundries, auto salvage yards, metal recyclers, cement plants, and saw mills. In California and Washington, however, some of the Phase I MS4 permits have identified high-risk facilities for the municipal permittee to inspect.

Georgia, Maine, Minnesota, Nevada, New York, Vermont, and Washington have State Guidance Manuals for MS4 implementation, while in California a coalition of municipalities and the California Department of Transportation have developed MS4 guidance manuals. The rest of the responding states rely on general guidance provided by the EPA. State guidance manuals for the implementation of the industrial stormwater program were less common than guidance manuals for construction activity, with only California and Washington having such guidance manuals. In contrast, except for Nebraska and Oklahoma, statewide guidance manuals for erosion and sediment control were available. This may have resulted from the fact that many states had laws in place that required erosion and sediment control practices during land development, timber harvesting, and agricultural farming that predated the EPA stormwater regulations.

In an attempt to determine the level of oversight that a state provides for industrial and construction operations, the survey asked whether and to whom stormwater pollution prevention plans (SWPPPs) are submitted. Most of the responding states require the stormwater pollution prevention plans that industrial facilities prepare to be retained at the facility and produced when requested by the state. Only Oregon, Vermont, Washington, and Hawaii required industrial SWPPPs to be submitted to the state when seeking coverage under the MSGP. The practice for the submittal of construction SWPPPs was similar, except that some states required that SWPPPs for large construction projects be submitted to the state.

Compliance with the MS4 permit in the responding States is mainly determined through the evaluation of annual reports and program audits, although no indication was given of the frequency of audits. Regulators in Maine have monthly meetings with municipalities. The responding states evaluate compliance with the MSGP by reviewing annual monitoring reports and conducting inspections of industrial facilities. Connecticut characterized its industrial inspections as “regular,” Maine inspects industrial facilities twice per five-year permit cycle, while Vermont performs visual inspections four times a year. No other responding states specified the frequency of inspections. Inspections and reviews of the SWPPPs constitute the main ways for responding states to determine the compliance of sites and facilities covered under the CGP.

With respect to the extent of actual compliance, few states have such information, partly because it has not routinely been collected and analyzed. West Virginia has found that, of the 871 permitted industrial facilities in the state, 576 were delinquent in submitting the results of their benchmark monitoring. Several case studies of compliance rates for municipal, industrial, and construction sites in Southern California are presented in Box 2-4. The data suggest that compliance in all three groups is poor, particularly for industrial sites. This may be partly explained by the preponderance of small businesses covered by the MSGP, whose operators may have financial difficulty in committing funds to SCMs, or lack a recognition and knowledge of the stormwater program and its requirements.

Another aspect of compliance is the extent to which industrial facilities have identified themselves and applied for coverage under the state MSGP. Six states responded to the committee’s survey about that topic; only two of the six (California and Vermont) have made efforts to determine the numbers of non-filers of an NOI to be covered by the MSGP. In both cases, the efforts, which involved mailings, telephone calls, and file review, found that the number of non-filing facilities that should be subject to the MSGP was substantial (see Box 2-5 for California’s data). Duke and Augustenborg (2006) studied this level of compliance (whether industries are filing an NOI for permit coverage) and found incomplete compliance that is variable among states and urbanized areas. Texas and Oklahoma had higher levels of permit coverage than California or Florida.

BOX 2-4
Compliance with Stormwater Permits in Southern California

Construction General Permits

In order to determine the compliance of construction sites with the general stormwater permit, data were collected and analyzed from three sources: (1) an audit performed in June 2004 of the development construction program of five cities that are permittees in the Los Angeles County MS4 permit (about 44 sites), (2) an audit performed in February 2002 of the development construction program (among others) of five Ventura County MS4 permittees (about 32 sites), and (3) a review and inspection of 24 large construction sites (50 acres or greater of disturbed land). These sites accounted for about 5 percent of all construction sites in the region at the time, and they represent both small and large construction sites. The most common violations on construction sites were paper violations, such as incomplete SWPPPs and a lack of record keeping. Forty (40) percent of the sites had some type of paper deficiency. A close second is the absence of erosion and/or sediment control, observed on 30 percent of the sites. SOURCE: TetraTech (2002, 2006b,c).

Industrial Multi-Sector General Permit

For industrial sites, information was obtained from the following sources: (1) a review of SCM inspections performed in February 2005 which consisted of 38 sites in the transportation sector; (2) a review of inspections and non-filer identification information in the plastics sector performed in 2007, which consisted of about 100 permitted sites among a large number of non-filer sites; and (3) a review of 13 area airport inspections and 55 port tenant inspections at the ports of Los Angeles and Long Beach. The sites are about 6 percent of the total number of permittees covered by California's MSGP and represent some of the major regulated industrial sectors. The most common violations observed at industrial sites were the lack of implementation of SCMs such as overhead cover, secondary containment and/or spill control. Sixty (60) percent of the sites had poor housekeeping problems. This was followed by incomplete stormwater pollution prevention plans (40 percent). (SOURCE: E. Solomon, California EPA, Los Angeles Regional Water Board, personal communication, 2008).

In another study, the California Water Boards with the assistance of an EPA contractor conducted inspections of 1,848 industrial stormwater permittees (21 percent of permitted facilities) between 2001 and 2005 (TetraTech, 2006d). Seventy-one (71) percent of the industrial facilities inspected were not in compliance with the MSGP and 18 percent were identified as a threat to water quality. Fifty-six (56) percent of facilities that collected one or more water quality samples reported an exceedance of a benchmark. Facility follow-up inspections indicated that field presence of the California Water Boards inspectors improved facility compliance with the MSGP.

Municipal Permits

An audit similar to the TetraTech study described above was conducted for 84 Phase I and Phase II MS4s in California during the same period (TetraTech, 2006e). The audits found that municipal maintenance facilities were often deficient in implementing SCMs, MS4 permittees did not obtain adequate legal authority to implement the program, they were not inspecting industrial facilities and construction sites or were inspecting them inadequately, and they were unable to evaluate program effectiveness in improving water quality. Overall, the audits found that programs with more specific permit requirements

continues next page

BOX 2-4 Continued

generally resulted in more comprehensive and progressive stormwater management programs. For example, the Los Angeles or San Diego MS4 permits enumerate in detail the permit tasks such as the frequency of inspection, the types of facilities, and the SCMs to be inspected that permittees must perform in implementing their stormwater program. The auditors concluded that the specificity of the provisions enabled the permitting authorities to enforce the MS4 permits and improve the quality of MS4 discharges.

Compliance with Industrial Permits within MS4s

The EPA and the California EPA Los Angeles Regional Water Board conducted a limited audit of the inspection program requirements of the Los Angeles County MS4 Permit and the City of Long Beach MS4 Permit in conjunction with industrial facilities covered under the MSGP within the Ports of Los Angeles and Long Beach (EPA, 2007c). The Port of Long Beach is covered under a single NOI for its 53 tenant facilities that discharge stormwater associated with industrial activity, while 137 industrial facilities within the Port of Los Angeles file independent NOIs. At the Port of Los Angeles, of the 23 facilities that were inspected, 30 percent were judged to pose a significant threat to water quality, 43 percent were determined to have some violations with regard to implementation of SCMs or paperwork requirements, and 26 percent appeared to be in compliance with the MSGP. At the Port of Long Beach, of the 21 tenant facilities that were inspected, 14 percent were judged to pose a significant threat to water quality, 52 percent were determined to have some deficiencies with regard to implementation of SCMs or paperwork requirements, and 33 percent appeared to be in full compliance with general permit requirements. The Port of Long Beach had a more comprehensive stormwater monitoring program which indicated that several pollutant parameters were above EPA benchmark values. Communication between the MS4 departments and the ports in both programs appeared deficient. The EPA issued 20 compliance orders for violations of the MSGP, but it did not pursue any action against the MS4s overseeing the industries because it was outside the scope of the EPA audit.

LOCAL CODES AND ORDINANCES THAT AFFECT STORMWATER MANAGEMENT

Zoning and building standards, codes, and ordinances have been the basis for city building in the United States for almost a century. They define how to build to protect the health, safety, and welfare of the public, and to establish a predictable, although often lengthy and cumbersome, process for ensuring that built improvements become a well-integrated part of the larger urban environment. Review processes can be as simple as a walk-through in a local building department for a minor house remodeling project. In other cases, extended rezoning processes for larger projects can require several years of planning; multiple public meetings; multiple reviews by city, state, and federal agencies; and specialized studies to determine impacts on the natural environment and water, sewer, and transportation systems.

BOX 2-5
Searching for Non-Filers Under the Industrial MSGP in Southern California

The California Water Boards conducted an industrial non-filer identification study between 1995 and 1998 (CA SWB, 1999). The study had three components: (1) to develop a mechanism to identify facilities subject to the industrial stormwater general permit that had not filed an NOI, which involved a comparison of commercially available and agency databases with that maintained by the California Water Boards; (2) to communicate with operators of these facilities to inform them of their responsibility to comply, which was done using post-mail, telephone calls, and filed verification; and (3) to refer responses to the communication efforts to the Water Boards for any appropriate follow-up.

About 9 percent of the potential non-filers submitted an NOI after the initial mail contact. About 52 percent of facilities indicated that they were exempt. About 37 percent failed to respond and 16 percent of mailed packages were returned unopened. A follow-up on facilities that claimed they were exempt indicated that 16 percent of them indeed needed to comply. Similarly 33 percent of facilities that failed to respond were determined as needing to file NOIs. The study suggested that only half of facilities considered heavy industrial had filed NOIs through the first five years of the program (Duke and Shaver, 1999).

The California EPA Los Angeles Regional Water Board and the City of Los Angeles conducted a study in the City of Los Angeles between January 1998 and June 2000 to identify non-filers and evaluate compliance by door-to-door visits in industrially zoned areas of the city (Swamikannu et al., 2001). The field investigations covered industrial zones totaling about 4.2 square miles, or about 22 percent of the area in the City of Los Angeles zoned for industrial land use. A total of 1,103 of suspected non-filer facilities were subject to detailed on-site facility investigation. Ninety-three (93) were determined to have already have submitted NOIs, and 436 were determined not to be subject to the industrial stormwater general permit. The site visits identified 223 potential non-filers, or industrial facilities where site-visit evidence suggested the facilities probably needed to comply with relevant regulations but that had not filed NOIs or recognized their duty to comply at the time of the visit. Of the facilities identified as potential non-filers, 202 were identified during detailed on-site investigations, or 18 percent of facilities inspected with that methodology; and 21 were identified during the less-detailed non-filer assessment visits, or 6 percent of the 379 facilities inspected with that methodology. In total, 295 of the 1,103 facilities visited under the project (about 27 percent) were known or suspected to be required to file NOIs under the permit, including 93 facilities that had previously filed NOIs and 202 facilities identified as probably required to file NOIs based on visual evidence of industrial activities exposed to stormwater. Thus, prior to the project, only 31 percent of all facilities in the project area needing to comply had submitted an NOI.

There is an overlapping and conflicting maze of codes, regulations, ordinances, and standards that have a profound influence on the ability to implement stormwater control measures, although they can be loosely categorized into three areas. Land-use zoning is the first type of control. Zoning, which was developed in response to unsanitary and unhealthy living conditions in 19th-century cities, prescribes permitted land uses, building heights, setbacks, and the arrangement of different types of land uses on a given site. Zoning often requires improvements that enhance the aesthetic and functional qualities of communities. For example, ordinances prescribing landscaping, minimum parking requirements, paving types, and related requirements have been developed to improve the livability of cities. These ordinances have a significant impact on both how stormwater affects waterbodies and on attempts to mitigate its impacts.

The second category involves the design and construction of buildings. National and international building codes and standards, such as the International Building Code, and Uniform Plumbing, Electrical, and Fire Codes, for example, allow local governments to establish minimum requirements for building construction. Because these controls primarily affect building construction, they have less effect on stormwater discharges than zoning.

The third category includes engineering and infrastructure standards and practices that govern the design and maintenance of the public realm—streets, roads, utilities rights-of-way, and urban waterways. Roadway design standards and emergency access requirements have resulted in contemporary cities that are 30 percent or more pavement, just to accommodate the movement and storage of vehicles in the public right-of-way. The standards for the construction of deep utilities—water and sewer lines that are typically located underneath streets—are often the reason that streets are wider than necessary to safely carry traffic.

Over time, these codes, standards, and practices have become more complex, and they may no longer support the latest innovations in planning practices. The past 10 to 20 years have seen a number of innovations in zoning and related building standards. Mixed-use, mixed-density communities that incorporate traditional patterns of community development (often described as "New Urbanism"), low impact development (LID), and transit-oriented development are examples of building patterns that challenge traditional zoning and city design standards. With the exception of LID, proposed new patterns of development and regulations connected with their implementation rarely incorporate specific guidelines for innovations in stormwater management, other than to have general references to environmental responsibility, ecological restoration, and natural area protection.

The following sections describe in more detail the codes, ordinances, and standards that affect stormwater and our ability to control it, and alternative approaches to developing new standards and practices that support and encourage effective stormwater management.

Zoning

The primary, traditional purpose of zoning has been to segregate land uses thought to be incompatible. In practice, zoning is used as a permitting system to prevent new development from harming existing residents or businesses. Zoning is commonly controlled by local governments such as counties or cities, though the specifics of the zoning regime are determined primarily by state planning laws (see Box 2-6 for a discussion of land use acts in Oregon and Washington).

BOX 2-6
Growth Management in the Pacific Northwest

In Oregon, the 1973 Legislative Assembly enacted the Oregon Land Use Act, which recognized that the uncoordinated use of lands threatens orderly development of the environment, the health, safety, order, convenience, prosperity and welfare of the people of Oregon. The state required all of Oregon's 214 cities and 36 counties to adopt comprehensive plans and land-use regulations. It specified planning concerns that had to be addressed, set statewide standards that local plans and ordinances had to meet, and established a review process to ensure that those standards were met. Aims of the program are to conserve farm land, forest land, coastal resources, and other important natural resources; encourage-efficient development; coordinate the planning activities of local governments and state and federal agencies; enhance the state's economy; and reduce the public costs that result from poorly planned development. Setting urban growth boundaries is a major mechanism for implementing the act.

The Washington State Legislature followed in 1990 with the Growth Management Act (GMA), adopted on grounds similar to Oregon's act. The GMA requires state and local governments to manage Washington's growth by identifying and protecting critical areas and natural resource lands, designating urban growth areas, preparing comprehensive plans, and implementing them through capital investments and development regulations. Similar again to Oregon, rather than centralize planning and decision-making at the state level, the GMA established state goals, set deadlines for compliance, offered direction on how to prepare local comprehensive plans and regulations, and set forth requirements for early and continuous public participation. Urban growth areas (UGAs) are those areas, designated by counties pursuant to the GMA, "within which urban growth shall be encouraged and outside of which growth can occur only if it is not urban in nature." Within these UGAs, growth is encouraged and supported with adequate facilities. Areas outside of the UGAs are reserved for primarily rural and resource uses. Urban growth areas are to be based on population forecasts made by counties, which are required to have a 20-year supply of land for future residential development inside the boundary—a time frame also pertaining in the Oregon system. In both states urban growth boundaries are reconsidered and sometimes adjusted to meet this criterion.

It is important to note that the growth management efforts in the two states have no direct relationship to stormwater management. Rather, the laws control development density, which has implications for how stormwater should be managed (see discussion in Chapter 5). The local jurisdictions in Washington have reacted in different ways to link growth management and stormwater management. For example, the King County, Washington, stormwater code requires drainage review to evaluate and deal with stormwater impacts for development that adds 2,000 square feet or more of impervious surface or clears more than 7,000 square feet. For rural residential lots outside the UGA, the impervious threshold is reduced to 500 square feet.

Sources:
http://bluebook.state.or.us/state/executive/Land_Conservation/land_conservation_history.htm
http://www.oregonmetro.gov/index.cfm/go/by.web/id=277
http://www.gmhb.wa.gov/gma/ and *http://www.mrsc.org/Subjects/Planning/compfaqs.aspx*

Zoning involves regulation of the kinds of activities that will be acceptable on particular lots (such as open space, residential, agricultural, commercial or industrial), the densities at which those activities can be performed (from low-density housing such as single-family homes to high-density housing such as high-rise apartment buildings), the height of buildings, the amount of space structures may occupy, the location of a building on the lot (setbacks), the proportions of the types of space on a lot (for example, how much landscaped space and how much paved space), and how much parking must be provided. Thus, zoning can have a significant impact on the amount of impervious area in a development and on what constitutes allowable stormwater management.

As an example, local parking ordinances are often found within zoning that govern the size, number, and surface material of parking spaces, as well as the overall geometry of the parking lot as a whole. The parking demand requirements are tied to particular land uses and zoning categories, and can create needless impervious cover. Most local parking codes are overly generous and have few, if any, provisions to treat stormwater at the source (Wells, 1995). For example, in a co-housing project under construction in Fresno, California, current city codes require 27-foot-long parking spaces. The developer, in an effort to reduce construction costs, requested that the length of spaces be reduced to 24 feet. The city agreed to the smaller spaces if the developer would sign an indemnity clause guaranteeing that the local government would not be sued in case of an accident (Wenz, 2008).

Similarly, landscaping ordinances apply to certain commercial and institutional zoning categories and specify that a fixed percentage of site area be devoted to landscaping, screening, or similar setbacks. These codes may require as much as 5 to 10 percent of the site area to be landscaped, but seldom reference opportunities to capture and store runoff at the source, despite the fact that the area devoted to landscaping is often large enough to meet some or all of their stormwater treatment needs.

Zoning codes have evolved over the years as urban planning theory has changed, legal constraints have fluctuated, and political priorities have shifted. The various approaches to zoning can be divided into four broad categories: Euclidean, performance, planned unit development, and form-based.

Euclidean Zoning

Named for the type of zoning code adopted in the town of Euclid, Ohio, Euclidean zoning codes are by far the most prevalent in the United States, used extensively in small towns and large cities alike. Euclidean zoning is characterized by the segregation of land uses into specified geographic districts and dimensional standards stipulating limitations on the magnitude of development activity that is allowed to take place on lots within each type of district. Typical land-use districts in Euclidean zoning are residential (single- or multi-family), commercial, and industrial. Uses within each district are usually heavily prescribed to exclude other types of uses (for example, residential districts typically disallow commercial or industrial uses). Some “accessory” or “conditional” uses may be allowed in order to accommodate the needs of the primary uses. Dimensional standards apply to any structures built on lots within each zoning district and typically take the form of setbacks, height limits, minimum lot sizes, lot coverage limits, and other limitations on the building envelope.

Although traditional Euclidean zoning does not include any significant requirements for stormwater drainage, there is no reason that it could not. Modern Euclidean ordinances include a broad list of "development standards" that address topics like signage, lighting, steep slopes, and other topics, and that list could be expanded to included stormwater standards for private development.

Euclidean zoning is used almost universally across the country (with rare exceptions) because of its relative effectiveness, ease of implementation (one set of explicit, prescriptive rules), long-established legal precedent, and familiarity to planners and design professionals. However, Euclidean zoning has received heavy criticism for its unnecessary separation of land uses, its lack of flexibility, and its institutionalization of now-outdated planning theory. . In response, variances and other methods have been used to modify Euclidean zoning so that it is better adapted to localized conditions and existing patterns of development. The sections below briefly describe a range of innovations in local zoning regulations that have potential for incorporating stormwater controls into existing regulations.

Incentive Zoning. Incentive zoning systems are typically an add-on to Euclidean zoning systems. First implemented in Chicago and New York City in 1961, incentive zoning is intended to provide a reward-based system to encourage development that meets established urban development goals. Typically, a base level of prescriptive limitations on development will be established and an extensive list of incentive criteria with an associated reward scale will be established for developers to adopt at their discretion. Common examples include floor-area-ratio bonuses for affordable housing provided on-site and height-limit bonuses for the inclusion of public amenities on-site.

With incentive zoning, developers are awarded additional development capacity in exchange for a public benefit, such as a provision for low- or moderate-income housing, or an amenity, such as additional open space. Incentive zoning is often used in more highly urbanized areas. Consideration for water quality treatment and innovative SCMs fits well within the incentive zoning model. For example, redevelopment sites in urbanized areas are often required to incorporate stormwater control measures into developments to minimize impacts on aging, undersized stormwater systems in that area, and to meet new water quality requirements. An incentive could be to allow greater building height, and therefore higher density, than under existing zoning, freeing up land area for SCMs that could also serve as a passive park area. Another example would be to allow a higher density on the site and to require not an on-site system but a cash payment to the governing entity to provide for consolidated stormwater management and treatment. Off-site consolidated systems, discussed more extensively in Chapter 5, may require creation of a localized maintenance district or an increase in stormwater maintenance fees to offset long-term maintenance costs.

Incentive zoning could be used to preserve natural areas or stream corridors as part of a watershed enhancement strategy. For example, transferrable development rights (TDR) could be used in the context of the urban or semi-urban interface with rural lands. Many of the formal TDR programs in Colorado (such as Fruita/Mesa County and Aspen/Pitkin) involve cities or counties seeking to preserve sensitive areas in the county, or outlying areas of the city, including the floodplain, in exchange for urban-level density on a more appropriate site (David D. Smith, Garfield & Hecht P.C., personal communication, 2008).

Incentive zoning allows for a high degree of flexibility, but it can be complex to administer. The more a proposed development takes advantage of incentive criteria, the more closely it has to be reviewed on a discretionary basis. The initial creation of the incentive structure can also be challenging and often requires extensive ongoing revision to maintain balance between incentive magnitude and value given to developers.

Performance Zoning

Performance zoning uses performance-based or goal-oriented criteria to establish review parameters for proposed development projects in any area of a municipality. At its heart, performance zoning deemphasizes the specific land uses, minimum setbacks, and maximum heights applicable to a development site and instead requires that the development meet certain performance standards (usually related to noise, glare, traffic generation, or visibility). Performance zoning sometimes utilizes a "points-based" system whereby a property developer can apply credits toward meeting established zoning goals through selecting from a menu of compliance options (some examples include mitigation of environmental impacts, providing public amenities, and building affordable housing units). Additional discretionary criteria may also be established as part of the review process.

The appeal of performance zoning lies in its high level of flexibility, rationality, transparency, and accountability. Because performance zoning is grounded in specific and in many cases quantifiable goals, it better accommodates market principles and private property rights with environmental protection. However, performance zoning can be extremely difficult to implement and can require a high level of discretionary activity on the part of the supervising authority. City staff must often be trained to use specialized equipment to measure the performance of the development, and sometimes those impacts cannot be measured until the building is completed and the activity operating, by which time it may be difficult and expensive to modify a building that turns out not to meet the required performance standards. Because stormwater performance is measurable (especially the amounts of water retained/detained and rates and amounts of water discharge), stormwater regulations could be integrated into a performance zoning system. As with other topics, however, it might be time-consuming or require special equipment to measure compliance (particularly before the building is built).

Planned Unit Development (Including Cluster Development and Conservation Design)

A planned unit development (PUD) is generally a large area of land under unified control that is planned and developed as a whole through a single development operation or series of development phases, in accord with a master plan. In California, these are known as Specific Plans. More specialized forms of PUDs include clustered subdivisions where density limitations apply to the development site as a whole but provide flexibility in the lot size, setback, and other standards that apply to individual house lots. These PUDs provide considerable flexibility in locating building sites and associated roads and utilities, allowing them to be concentrated in parts of the site, with the remaining land use for agriculture, recreation, preservation of sensitive areas, or other open-space purposes.

PUDs are typically, although not exclusively, found in new development areas and have significant open space and park areas that are often 25 percent or more of the total land area. This large amount of open space provides considerable opportunity for the use of consolidated, multifunctional stormwater controls.

Form-Based Zoning

Form-based zoning relies on rules applied to development sites according to both prescriptive and potentially discretionary criteria. These criteria are typically dependent on lot size, location, proximity, and other various site- and use-specific characteristics. Form-based codes offer considerably more flexibility in building uses than do Euclidean codes, but, as they are comparatively new, may be more challenging to create. When form-based codes do not contain appropriate illustrations and diagrams, they are criticized as being difficult to interpret.

One example of a recently adopted code with form-based features is the Land Development Code adopted by Louisville, Kentucky, in 2003. This zoning code creates “form districts” for Louisville Metro. Each form district intends to recognize that some areas of the city are more suburban in nature, while others are more urban. Building setbacks, heights, and design features vary according to the form district. As an example, in a “traditional neighborhood” form district, a maximum setback might be 15 feet from the property line, while in a suburban “neighborhood” there may be no maximum setback. Narrower setbacks allow increased density, requiring less land area for the same number of housing units and resulting in a smaller development footprint.

In rural and suburban areas, form-based codes can often reinforce the "open" character of development by preserving open site areas, which could be used for on-site stormwater management. In denser, urban areas, however, some form-based ordinances favor shorter, more pedestrian-scale buildings that cover more of the site than taller buildings of the same square footage, on the basis that keeping activity closer to the ground and enclosing street frontages results in a better pedestrian environment and urban form. One result of this preference is that there may be less of the site left potentially available for on-site stormwater detention or infiltration. Integrating stormwater management considerations into form-based codes may require a cash payment system where the developer contributes to financing of a district or regional stormwater treatment facility because on-site solutions are not available.

Building Codes

Building codes define minimum standards for the construction of virtually all types and scales of structures. With a few exceptions, building codes have limited direct impact on stormwater management. The main example is where structural and geotechnical design standards, which stem from the need to protect buildings and infrastructure from water damage, discourage or prohibit the potential infiltration of water adjacent to building foundations. Such standards can make it difficult to use landscape-based SCMs, such as porous pavement, bioinfiltration, and extended detention. There is a need to examine and redefine structural and geotechnical "standards of care" that ensure the structural integrity of buildings and other infrastructure like buried utilities, in order for landscaped areas adjacent to structures to be utilized more effectively for SCMs. For example, a developer building a mixed-use, medium-density infill development in Denver intended to incorporate innovative approaches to stormwater management by infiltrating stormwater in a number of areas around the site. The standard of care for the geotechnical design of building foundations typically requires that positive drainage be maintained a minimum of 5 feet from the building edge. The geotechnical engineer required, when informed that water might be infiltrated in the area of the building and without further study, that the minimum distance to an infiltration area must be at least to 20 feet from the building, greatly limiting the potential for using the building landscape areas as SCMs. The City of Los Angeles is in the process of updating its Building Code, but it is not clear if it will be sufficiently comprehensive to address the use of some LID practices, such as on-site infiltration. The 2002 Building Code now in effect is written to require the builder to convey water away from the building using concrete or some other "non-erosive device."

Engineering and Infrastructure Standards and Practices

Engineering standards and practices for public rights-of-way complement building and zoning codes which control development on private property. Engineering standards and practices typically describe requirements for public utilities such as stormwater and wastewater, roadways, and related basic services. For example, there are standards for parking and roadway design that typically describe the specific type of roadway and parking surfacing requirements. Regulations and standards often require minimum gradients for surface drainage, site grading, and drainage pipe size, all of which play an important role in how stormwater is transported. There are also often landscape planting requirements, including the requirement to mound landscape areas to screen cars, which can preclude the opportunity to incorporate SCMs into landscape areas.

Unless right-of-way improvements are constructed as part of the subdivision process by private developers, improvements in the right-of-way are typically provided for by city government and public agencies. Because engineering standards are often based on decades of refinement and have evolved regionally and nationally, they are difficult to change. For example, street widths are determined more by the ability to maneuver emergency equipment and to accommodate water and sewer easements than the need for adequate lane widths for vehicles. Street lane-width requirements might be as narrow as 11 feet for each travel lane, resulting in a street width of 22 to 24 feet. This could accommodate emergency vehicle access, which typically can require a minimum of 20 feet of unobstructed street. However, because most streets also include potable water distribution lines and easement requirements for the lines, which are a minimum of 30 feet in width, this results in a minimum roadway width of 30 feet.

Local drainage codes govern the disposal of stormwater and essentially dictate the nature and capacity of the stormwater infrastructure from the roof to the floodplain. Like many codes, they were developed over time to address problems such as basement flooding, nuisance drainage problems, maintenance of floodplain boundaries, and protection of infrastructure such as bridges and sewers from storm damage. Local drainage codes, many of which predate the EPA's stormwater program, often involve peak discharge control requirements for a series of design storm events ranging from the 2-year storm up to the 100-year event. Traditional drainage codes can often conflict with effective approaches to reducing runoff volume or removing pollutants from stormwater. Examples of such codes include requirements for positive drainage, directly connected roof leaders, curbs and gutters, lined channels, storm-drain inlets, and large-diameter storm-drain pipes discharging to a downstream detention or flood control basins.

Often, standards have been tested through legal precedent, and case law has developed around certain standards of care, which can further deter innovation. Changes in design standards could result in unknown legal exposure and liability. Specific types of equipment, maintenance protocols and procedures, and extensive training further discourage changes in established standards and procedures.

Innovations in Codes and Regulations to Promote Better Stormwater Management

A number of innovations have been developed in the previously described zoning, building codes, and infrastructure and engineering standards that make them more amenable to stormwater management. These are described in detail below.

Separate Ordinances for New and Infill Development

Redevelopment of existing urban areas is almost universally more difficult and expensive than Greenfield development because of the deconstruction costs of the former, higher costs of designing around existing infrastructure, upgrading existing infrastructure, and higher costs and risks associated with assuming liability of pre-existing problems (contamination, etc). Redevelopment often occurs in areas of medium to high levels of impervious surface (e.g., downtown areas). Such severely space-limited areas with high land costs drive up stormwater management costs. Consequently, holding developers of such areas to the same stormwater standard as for Greenfield developments creates a financial disincentive for redevelopment. Without careful application, stormwater requirements may discourage needed redevelopment in existing urban areas. This would be unfortunate because redevelopment can take pressure off of the development of lands at the urban fringe, it can accommodate growth without introducing new impervious surfaces, and it can bring improvements in stormwater management to areas that had previously had none.

Stormwater planning can include the development of separate ordinances for infill and new developments. Wisconsin has administrative rules that establish specific requirements for stormwater management based on whether the site is new development, redevelopment, or infill. Requirements for new development include reducing total suspended solids (TSS) by 80 percent, maintaining the pre-development peak discharge for the 2-year, 24-hour storm, infiltrating 90 percent of the pre-development infiltration volume for residential areas, and infiltrating 60 percent of the pre-development infiltration volume for non-residential areas. Redevelopment varies from new development only in that the TSS requirement is less at 40 percent reduction. Requirements for existing developed areas in incorporated cities, villages, and towns do not include peak flow reduction or infiltration performance standards, but the municipalities must achieve a 40 percent reduction in their TSS load by 2013. Other requirements unique to developed areas include public education activities, proper application of nutrients on municipality property, and elimination of illicit discharges (*www.dnr.state.wi.us/org/water/wm/nps/stormwater/post-constr/*). Chapter 5 makes recommendations for the specific types of SCMs that should be used for new, low-density residential development as opposed to redevelopment of existing urban and industrial areas.

Integrated Stormwater Management and Growth Policies

In the city of San Jose, California, an approach was taken to link water quality and development policies that emphasized higher density in-fill development and performance-based approaches to achieving water quality goals. The city's approach encourages stormwater practices such as minimizing impervious surface and incorporating swales as the preferred means of conveyance and treatment. In urbanized areas, the policy then goes on to define criteria to determine the practicability of meeting numeric sizing requirements for stormwater control measures, and identifies Equivalent Alternative Compliance Measures for cases where on-site controls are impractical. Equivalent Measures can include regional stormwater treatment and other specific projects that "count" as SCMs, including certain affordable and senior housing projects, significant redevelopment within the urban core, and Brownfield projects. This is similar to in lieu fee programs that are sometimes implemented by municipalities to provide additional regulated parties with compliance options (see discussion in Chapter 6).

This approach is a breakthrough in terms of measuring environmental performance, which is now focused only on what happens within the boundaries of a site for a project. This myopic view tends to allow many environmentally unfriendly projects that encourage sprawl and expand the city's boundaries to qualify as "low impact," while more intense projects on a small footprint appear to have a much higher impact because they cover so much of the site. San Jose brought several other layers of review, including location in the watershed (close to other uses or not) as a means of estimating performance. A PowerPoint presentation describing their approach in greater detail is linked here (*http://www.cmcgc.com/media/handouts/260126/THR-PDF/040-Ketchum.PDF*, Lisa Nisenson, Nisenson Consulting, LLC, personal communication, May 8, 2007).

Unified Development Codes

A unified development code (UDC) consolidates development-related regulations into a single code that represents a more consistent, logical, integrated, and efficient means of controlling development. UDCs integrate zoning and subdivision regulations, simplifying development controls that are often conflicting, confusing, and that require multiple layers of review and administration. UDC development standards may include circulation standards that address how vehicles and pedestrians move, including provision for adequate emergency access. Utility standards are described for water distribution and sewage collection, and necessary utility easements are prescribed. Because of the integrated nature of the code, efficiencies in requirements for right-of-way can reduce street widths or the reduction in setbacks, for example, resulting in more compact development.

Design Review Incentives to Speed Permitting

A number of incentives have been put in place to promote innovative stormwater control measures in cities such as Portland and Chicago, where environmental concerns have been identified as a key goal for development and redevelopment. Practices such as the waiver or reduction of development fees, preferential treatment and review and approval of innovative plans, reduction in stormwater fees, and related incentives encourage the use of innovative stormwater practices. In Chicago, the Green Permit Program initiated in April 2005 has proven attractive to many developers as it speeds up the permitting process. Under the Green Permit Program, a green building adviser reviews design plans under an aggressive schedule long before a permit application is submitted. There is one point of contact with intimate knowledge about the project to help speed up the permit process. Projects going through the Green Permit Program receive benefits based on their "level of green." Tier I commercial projects are designed to be Leadership in Energy and Environmental Design (LEED) certified (see Box 2-7). Tier II projects must obtain LEED silver rating. At this level, outside consultant review fees, which range from $5,000 to $50,000, are waived. Tier III projects must earn LEED gold. The goal for a Tier III project is to issue a permit in three weeks for a small project such as a 12-unit condo building. Thus, there is both time and money saved. Private developers are interested in the time savings because they can pay less interest on their construction loans by completing the building faster. By the end of 2005, 19 green permits were issued. The program's director estimated that about 50 would be issued in 2006, which exceeds the city's goal of 40.

In Portland, Oregon, the city's Green Building Program is considering instituting a new High-Performance Green Building Policy. Along with goals for reducing global warming pollution, it proposes (1) waiving development fees if goals are exceeded by specified percentages and (2) eligibility for cash rewards and qualification for state and federal financial incentives and tax credits if even higher goals are achieved. Developers can earn credits by incorporating enhanced stormwater management and water conservation features into their projects, including the use of green roofs (Wenz, 2008).

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BOX 2-7
Innovative Building Codes

An increased interest in energy conservation and more environmentally friendly building practices in general has led to various methods by which buildings can be evaluated for environmentally friendly construction, in addition to conventional code compliance. The most popular system in the United States is the Leadership in Energy and Environmental Design (LEED) system developed in 2000.

The LEED Green Building Rating System is a voluntary, consensus-based national rating system for developing high-performance, sustainable buildings. LEED addresses all building types and emphasizes state-of-the-art strategies in five areas: sustainable site development, water savings, energy efficiency, materials and resources selection, and indoor environmental quality. The U.S. Green Building Council is a 501(c)(3) nonprofit organization that certifies sustainable businesses, homes, hospitals, schools, and neighborhoods.

The LEED system encourages progressive stormwater management practices as part of its rating system. The LEED system has identified specific criteria, with points assigned to each of the criteria, to assess the success of stormwater strategies. Generally, the criteria are based on LID principles and practices and relate directly to the *Better Site Design Handbook* of the Center for Watershed Protection (CWP, 1998). The system identifies eight categories by which building sites and site-planning practices are evaluated. Of the 69 points possible to achieve the highest LEED rating, 16 points are directly related to innovative site design and stormwater management practices. Six of the eight criteria describing sound site-planning practices relate directly to good stormwater practices, including the following:

- Erosion and sediment control;
- Site selection to protect farmland, wetlands, and watercourses;
- Site design to encourage denser infill development to protect Greenfield sites;
- Limitations on site disturbance;
- Specific requirements for the management of stormwater rate and quantity; and
- Specific requirements for the treatment of stormwater for TSS and phosphorous removal.

The LEED rating system has been criticized because it focuses on individual buildings in building sites. A new category, LEED neighborhood development, was developed in response to consider the interrelationship of buildings and building sites and connections to existing urban infrastructure. The category is currently in pilot testing. Evaluation criteria related directly to stormwater include:

- All requirements of the original site design criteria,
- A reduced requirement for parking based on access to transit and reduced auto use, and
- Site planning that emphasizes compact development.

There are parallel challenges in the realm of community development and city building that tend to discourage innovative stormwater management policies and practices. Building codes and zoning have evolved to reflect the complex relationship of legal, political, and social processes and frequently do not promote or allow the most innovative stormwater management. Engineering standards and practices that guide the development of roads and utilities present equal and possibly greater challenges, in that legal and technical precedents and large investments in public equipment and infrastructure present even more intractable reasons to resist change.

The difficulty of implementing stormwater control measures cannot be attributed to an individual code, standard, or regulation. It is important to unravel the complexities of codes, regulations, ordinances, and standards and practices that discourage innovative stormwater management and target the particular element (or multiple elements) that is a barrier to innovation. Elements that are barriers might not have been considered previously. For example, roadway design is controlled more by access for emergency equipment and utilities rights-of-way than by the need for wide travel lanes; it is the fire marshal and the water department that should be the focus of attention, rather than the transportation engineer.

LIMITATIONS OF THE FEDERAL STORMWATER PROGRAM

The regulation of stormwater discharges seems an inevitable next step to the CWA's objective of "restoring the nation's waters," and EPA's stormwater program is still evolving. Yet, in its current configuration EPA's approach seems inadequate to overcome the unique challenges of stormwater and therefore runs the risk of only being partly effective in meeting its goals. A number of regulatory, institutional, and societal obstacles continue to hamper stormwater management in the United States, as described below.

The Poor Fit Between the Clean Water Act's Regulatory Approach and the Realities of Stormwater Management

Controlling stormwater discharges with the CWA introduces a number of obstacles to effective stormwater regulation. Unlike traditional industrial effluent, stormwater introduces not only contaminants but also surges in volume that degrade receiving waterbodies; yet the statute appears focused primarily on the "discharge" of "pollutants." Moreover, unlike traditional effluent streams from manufacturing processes, the pollutant loadings in stormwater vary substantially over time, making effluent monitoring and the development of enforceable control requirements considerably more challenging. Traditional use of end-of-pipe control technologies and automated effluent monitors used for industrial effluent do not work for the episodic and variable loading of pollutants in stormwater unless they account for these eccentricities by adjustments such as flow-weighted measurements. Finally, at the root of the stormwater problem is increasingly intensive land use. Yet the CWA contains little authority for regulators to directly limit land development, even though the discharges that result from these developments increase stormwater loading at a predictably rapid pace. The CWA thus expects regulators to reduce stormwater loadings, but gives them incomplete tools for effectuating this goal.

A more straightforward way to regulate stormwater contributions to waterbody impairment would be to use flow or a surrogate, like impervious cover, as a measure of stormwater loading (such as in the Barberry Creek TMDL [Maine DEP, 2003, pp. 16–20] or the Eagle Brook TMDL [Connecticut DEP, 2007, pp. 8–10]). Flow from individual stormwater sources is easier to monitor, model, and even approximate as compared to calculating the loadings of individual contaminants in stormwater effluent. Efforts to reduce stormwater flow will automatically achieve reductions in pollutant loading. Moreover, flow is itself responsible for additional erosion and sedimentation that adversely impacts surface water quality. Flow provides an inexpensive, convenient, and realistic means of tracking stormwater contributions to surface waters. Congress itself recently underscored the usefulness of flow as a measure for aquatic impairments by requiring that all future developments involving a federal facility with a footprint larger than 5,000 square feet ensure that the development achieves predevelopment hydrology to the maximum extent technically feasible "with regard to the temperature, rate, volume, and duration of flow" (Energy Independence and Security Act of 2007, § 438). Several EPA regions have also used flow in modeling stormwater inputs for TMDL purposes (EPA, 2007a, Potash Brook TMDL, pp. 12–13).

Permitting and Enforcement

For industrial wastewater discharged directly from industrial operations (rather than indirectly through stormwater), the CWA requirements are relatively straightforward. In these traditional cases, EPA essentially identifies an average manufacturer within a category of industry, like iron and steel manufacturers engaged in coke-making, and then quantifies the pollutant concentrations that would result in the effluent if the industry installed the best available pollution control technology. EPA promulgates these effluent standards as national, mandatory limits (e.g., see Table 2-7).

TABLE 2-7 Effluent Limits for Best Available Technology Requirements for By-product Coke-making in Iron and Steel Manufacturing

Regulated Parameter	**Maximum Daily**[1]	**Maximum Monthly Average**[1]
Ammonia-N	0.00293	0.00202
Benzo(a)pyrene	0.0000110	0.00000612
Cyanide	0.00297	0.00208
Naphthalene	0.0000111	0.00000616
Phenols (4AAP)	0.0000381	0.000238

[1]pounds per thousand pound of product.
SOURCE: 40 C.F.R. § 420.13(a).

By contrast, the uncertainties and variability surrounding both the nature of the stormwater discharges and the capabilities of various pollution controls for any given industrial site, construction site, or municipal storm sewer make it much more difficult to set precise numeric limits in advance for stormwater sources. The quantity and quality of stormwater are quite variable over time and vary substantially from one property to another. Natural causes of variation in the pollutant loads in stormwater runoff include the topography of a site, the soil conditions, and of course, the nature of storm flows in intensity, frequency, and volume. In addition, the manner in which the facility stores and uses materials, the amount of impervious cover, and sometimes even what materials the facility uses can vary and affect pollutant loads in runoff from one site to another. Together, these sources of variability, particularly the natural features, make it much more difficult to identify or predict a meaningful "average" pollutant load of stormwater runoff from a facility. As a result, EPA generally leaves it to the regulated facilities, with limited oversight from regulators, to identify the appropriate SCMs for a site. Unfortunately, this deferential approach makes the permit requirements vulnerable to significant ambiguities and difficult to enforce, as discussed below for each permit type.

Municipal Stormwater Permits. MS4 permits are difficult to enforce because the permit requirements have not yet been translated into standardized procedures to establish end-of-pipe numerical effluent limits for MS4 stormwater discharges. CWA Section 402(p) requires that pollutants in stormwater discharges from the MS4 be reduced to the maximum extent practicable and comply with water quality standards (when so required by the permitting authority). However, neither EPA nor NPDES-delegated states have yet expressed these criteria for compliance in numerical form.

The EPA has not yet defined MEP in an objective manner that could lead to convergence of MS4 programs to reduce stormwater pollution. Thus, at present MS4 permittees have no more guidance on the level of effort expected other than what is stated in the CWA:

> [S]hall require controls to reduce the discharge of pollutants to the maximum extent practicable, including management practice, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants. [CWA Section 402(p)(3)(B)(iii)]

A legal opinion issued by the California Water Board's Office of Chief Counsel in 1993 stated that MEP would be met if MS4 permittees implemented technically feasible SCMs, considering costs, public acceptance, effectiveness, and regulatory compliance (Memorandum from Elizabeth Miller Jennings, Office of Chief Counsel, to Archie Matthews, Division of Water Quality, California Water Board, February 11, 1993). In its promulgation of the Phase II Rule in 1999, the EPA described MEP as a flexible site-specific standard, stating that:

> The pollutant reductions that represent MEP may be different for each [MS4 Permittee] given the unique local hydrological and geological concerns that may exist and the differing possible pollutant control strategies. (64 Fed. Reg. 68722, 68754)

As matters stand today, MS4 programs are free to choose from the EPA's menu of SCMs, with MEP being left to the discretionary judgment of the implementing municipality. Similarly, there are no clear criteria to be met for industrial facilities that discharge to MS4s in order for the MS4s to comply with MEP. The lack of federal guidance for MS4s is understandable. A stormwater expert panel convened by the California EPA State Water Board in 2006 (CA SWB, 2006) concluded that it was not yet feasible to establish strictly enforceable end-of-pipe numeric effluent limits for MS4 discharges. The principal reasons cited were (1) the lack of a design storm (because in any year there are few storms sufficiently large in volume and/or intensity to exceed the design volume capacity or flow rates of most treatment SCMs) and (2) the high variability of stormwater quality influenced by factors such as antecedent dry periods, extent of connected impervious area, geographic location, and land use.

Industrial and Construction Stormwater Permits. The industrial and construction stormwater programs suffer from the same kind of deficiencies as the municipal stormwater program. These stormwater discharges are not bound by the MEP criterion, but they are required to comply with either technology-based or, less often, water quality-based effluent limitations. In selecting SCMs to comply with these limitations, the industrial discharger or construction operator similarly selects from a menu of options devised by the EPA or, in some cases, the states or localities for their particular facility (EPA, 2006, p. 15). For example, the regulated party will generally identify structural SCMs, such as fences and impoundments that minimize runoff, and describe how they will be installed. The SWPPP must also include nonstructural SCMs, like good housekeeping practices, that require the discharger to minimize the opportunity for pollutants to be exposed to stormwater. The SWPPP and the accompanying SCMs constitute the compliance requirements for the stormwater discharger and are essentially analogous to the numeric effluent limits listed for industrial effluents in the Code of Federal Regulations.

This set of requirements leaves considerable discretion to regulated parties in several important ways. First, the regulations require the discharger to evaluate the site for problematic pollutants; but where the regulated party does not have specific knowledge or data, they need only offer "estimates" and "predictions" of the types of pollutants that might be present at the site (EPA, 1996a, pp. IV-3, V-3). With the exception of visible features, the deferential site investigation requirements allow regulated parties to describe site conditions in ways that may effectively escape accountability unless there is a vigorous regulatory presence.

Second, dischargers enjoy considerable discretion in drafting the SWPPP (EPA, 1996a, p. IV-3). Despite EPA's instructions to consider a laundry list of considerations that will help the facility settle on the most effective plan (EPA, 2006, p. 20), rational operators may take advantage of the wiggle room and develop ambiguous requirements that leave them with considerable discretion in determining whether they are in compliance (EPA, 2006, pp. 15, 20, 132). Indeed, the federal regulations do little to prevent regulated parties from devising requirements that maximize their discretion. Instead, EPA describes many of the permit requirements in general terms. For example, in its industrial stormwater permit program the EPA commands the regulated party to "implement any additional SCMs that are economically reasonable and appropriate in light of current industry practice, and are necessary to eliminate or reduce pollutants in . . . stormwater discharges" (EPA, 2006, p. 23).

EPA's program provides few rewards or incentives for dischargers to go beyond the federal minimum and embrace rigorous or innovative SCMs. In fact, if the regulated party invests resources to measure pollutant loads on their property, they are creating a paper trail that puts them at risk of greater regulation. Under the EPA's regulations, a regulated party "must provide a summary of existing stormwater discharge sampling data previously taken at [its] facility," but if there are no data or sampling efforts, then the facility is off the hook (EPA, 2006, p. 20). Quantitative measures can thus be incriminating, particularly in a regulatory setting where the regulator is willing to settle for estimates.

Dilemma of Self-Monitoring

Unlike the wastewater program where there are relatively rigid self-monitoring requirements for the end-of-pipe effluent, self-monitoring is much more difficult to prescribe for stormwater discharges, which are variable over time and space. [For example, *compare* 33 U.S.C. § 1342(a)(2)-(b)(2) (2000) (outlining requirements for compliance under NPDES) *with* EPA, 2006, p. 26 (outlining requirements for self-compliance under EPA regulations.)] EPA's middle ground, in response to these challenges, requires self-monitoring of select chemicals in stormwater for only a subset of regulated parties—Phase I MS4 permittees and a limited number of industrial facilities (see Table 2-8, EPA, 2006, pp. 93-94). Yet even for these more rigid monitoring requirements, the discharger enjoys some discretion in sampling. The EPA's sampling guidelines do prescribe regular intervals for sampling but ultimately must defer to the discharger insofar as requiring only that the samples should be taken within 30 minutes after the storm begins, and only if it is the first storm in three days (EPA, 2006, p. 33).

TABLE 2-8 Effluent Monitoring Requirements for Various Dischargers of Stormwater

Source Category	**Type of Effluent Monitoring Required by EPA**
Phase I MS4	Municipality must develop a monitoring plan that provides for representative data collection. This requires the municipality, at the very least, to select at least 5 to 10 of its most representative outfalls for regular sampling and sample for selected conventional pollutants and heavy metals in its effluent.
Phase II MS4	None
Small subset of highest risk industries, like hazardous waste landfills	Must conduct compliance monitoring as specified in effluent guidelines and ensure compliance with these effluent limits. Must also conduct visual monitoring and benchmark monitoring.
Larger subset of higher risk industrial dischargers	Benchmark monitoring: Must conduct analytic monitoring to determine whether effluent exceeds numeric benchmark values; compliance with the numeric values is not required, however. Must also conduct visual monitoring.
Remaining set of industry except construction	Visual monitoring: Must take four grab samples of stormwater effluent each year during first 30 minutes of a storm event and inspect the sample visually for contamination.
Construction (larger than 5 acres)	Visual monitoring: Must take four grab samples of stormwater effluent each year during first 30 minutes of a storm event and inspect the sample visually for contamination.
Construction (between 1 and 5 acres)	Visual monitoring: Must take four grab samples of stormwater effluent each year during first 30 minutes of a storm event and inspect the sample visually for contamination.

Note: State regulators can and sometimes do require more—see Appendix C.

Moreover, while the monitoring itself is mandatory, the legal consequences of an exceedance of a numerical limit vary and may be quite limited. For a small number of identified industries, exceedances of effluent limits established by EPA are considered permit violations (65 Fed. Reg. 64766). For the other high-risk industries subject to benchmark monitoring requirements (see Table 2-5), the analytical limits do not lead to violations per se, but only serve to "flag" the discharger that it should consider amending its SWPPP to address the problematic pollutant (EPA, 2006, pp. 10, 30, 34). Although municipalities are required to do more extensive sampling of stormwater runoff and enjoy less sampling discretion, even municipalities are allowed to select what they believe are their most representative outfalls for purposes of monitoring pollutant loads (EPA, 1996a. p. VIII-1).

A large subset of dischargers—the remaining industrial dischargers and construction sites—are subject to much more limited monitoring requirements. They are not required to sample contaminant levels, but instead are required only to conduct a visual inspection of a grab sample of their stormwater runoff on a quarterly basis and describe the visual appearance of the sample in a document that is kept on file at the site (EPA, 2006, p. 28). Certainly a visual sample is better than nothing, but the requirement allows the discharger not only some discretion in determining how and when to take the sample (explained below), but also discretion in how to describe the sample.

A final set of regulated parties, the Phase II MS4s, are not required to perform any quantitative monitoring of runoff to test the effectiveness of SCMs (EPA, 1996a, p. 3).

Making matters worse, in some states there appear to be limited regulatory resources to verify compliance with many of these permit requirements. Thus, even though monitoring plans are subject to review and approval by permitting agencies, there may be insufficient resources to support this level of oversight. As shown in Appendix C, the total number of staff associated with state stormwater programs is usually just a handful, except in cases of larger states (California and Georgia) or those where there is a longer history of stormwater management (Washington and Minnesota). In its survey of state stormwater programs, the committee asked states how they tracked sources' compliance with the stormwater permits. For the 18 states responding to the questionnaire, review of (1) monitoring data, (2) annual reports, and (3) SWPPP as well as onsite inspections were the primary mechanisms. However, several states indicated that they conduct an inspection only after receiving complaints. West Virginia tracked whether industrial facilities submitted their required samples and followed up with a letter if they failed to comply, but in 2006 it found that over 65 percent of the dischargers were delinquent in their sampling. Although the states were not asked in the survey to estimate the overall compliance rate, Ohio admitted that at least for construction, "the general sense is that no site is 100 percent in compliance with the Construction General Permit" (see Appendix C).

Even where considerable regulatory resources are dedicated to ensuring that dischargers are in compliance, it is not clear how well regulators can independently assess compliance with the permit requirements. For example, some of the permits will require "good housekeeping" practices that should take place daily at the facility. Whether or how well these practices are followed cannot be assessed during a single inspection. While a particularly non-compliant facility might be apparent from a brief visual inspection, a facility that is mildly sloppy, or at least has periods during which it is not careful, can escape detection on one of these pre-announced audits. Facilities also know best the pollutants they generate and how or whether those pollutants might make contact with stormwater. Inspectors might be able to notice some of these problems, but because they do not have the same level of information about the operations of the facility, they can be expected to miss some problems.

Identifying Potentially Regulatable Parties

Evidence suggests that a sizable percentage of industrial and construction stormwater dischargers are also failing to self-identify themselves to regulators, and hence these unreported dischargers remain both unpermitted and unregulated (GAO, 2005; Duke and Augustenborg, 2006). In contrast to industrial pipes that carry wastes from factories out to receiving waters, the physical presence of stormwater dischargers may be less visible or obvious. Thus, particularly for some industries and construction, if a stormwater discharger does not apply for a permit, the probability of detecting it is quite low.

In Maine, less than 20 percent of the stormwater dischargers that fall within the regulatory jurisdiction of the federal stormwater program actually applied for permits before 2005—more than a decade after the federal regulations were promulgated (Richardson, 2005). Yet there is no record of enforcement action taken by Maine against the unpermitted dischargers during that interim period. Indeed, in the one enforcement action brought by citizens in Maine for an unpermitted discharge, the discharger claimed ignorance of the stormwater program. In Washington, the State Department of Ecology speculates that between 10 and 25 percent of all businesses that should be covered by the federal stormwater permit program are actually permitted (McClure, 2004). In a four-state study, Duke and Augustenborg (2006) found a higher percentage of stormwater dischargers—between 50 and 80 percent—had applied for permits by 2004, but they concluded that this was still "highly incomplete" compliance for an established permit program.

In 2007, the committee sent a short survey to each state stormwater program inquiring as to whether and how they tracked non-filing stormwater dischargers, but only six states replied to the questions and only two of the six states had any methods for tracking non-filers or conducting outreach to encourage all covered parties to apply for permits (see Appendix C). While the low response rate cannot be read to mean that the states do not take the stormwater program seriously, the responses that were received lend some support to the possibility that there is substantial noncompliance at the filing stage.

In response to this problem of unpermitted discharges, the EPA appears to be targeting enforcement against stormwater dischargers that do not have permits. In several cases, the EPA pursued regulated industries that failed to apply for stormwater permits (EPA Region 9, 2005; Kaufman et al., 2005). The EPA has also brought enforcement actions against at least three construction companies for failing to apply for a stormwater permit for their construction runoff (EPA Region 1, 2004). Such enforcement actions help to make the stormwater program more visible and give the appearance of a higher probability of enforcement associated with non-compliance. Nevertheless, the non-intuitive features of needing a permit to discharge stormwater, coupled with a rational perception of a low probability of being caught, likely encourage some dischargers to fail to enter the regulatory system.

Absence of Regulatory Prioritization

Many states have been overwhelmed with the sheer numbers of permittees, particularly industry and construction sites, and lack a prioritization strategy to identify high-risk sources in particular need of rigorous and enforceable permit conditions. For example, in California major facilities like the Los Angeles International Airport and the Los Angeles and Long Beach ports are covered under California's MSGP along with a half-acre metal plating facility in El Segundo—all subject to the same level of compliance scrutiny even after nearly two decades of implementation! Similarly, a multiphase, 20-year, thousand-acre residential development such as Newhall Land Development in North Los Angeles County is covered by the same California CGP as a one-acre residential home construction project in West Los Angeles, and subject to the same level of compliance scrutiny. The lack of an EPA strategy to identify and address high-risk industrial facilities and construction sites (i.e., those that pose the greatest risk of discharging polluted stormwater) remains an enormous deficiency. Phase I MS4s, for example, are left to their own devices to determine how to identify the most significant contributors to their stormwater systems (Duke, 2007).

Limited Public Participation

Public participation is more limited in the stormwater program in comparison to the wastewater permit program, providing less citizen-based oversight over stormwater discharges. Typically, during the issuance of an individual NPDES permit (for either wastewater or stormwater) the public has a chance to comment and review the draft permit requirements that are specifically prescribed for a certain site and discharge. While the same is true about the public participation during the adoption of a general stormwater permit, those general permits contain only the framework of the requirements and the menu of conditions, but do not prescribe specific requirements. Instead, it is up to the permittee to tailor the compliance to the specific conditions of the site in the form of a SWPPP. However, at this phase neither the public nor the regulators have access to the site-specific plan developed by the permittee to comply with the obligations of the permit. In the case of general permits, then, the discharger has enormous flexibility in designing its compliance activities.

Citizens also encounter difficulties in enforcing stormwater permit requirements. Citizens have managed to sue facilities for unpermitted stormwater discharges: this is a straightforward process because citizens need only verify that the facility should be covered and lacks a permit (Richardson, 2005). Overseeing facility compliance with stormwater permit requirements is a different story, however, and citizens are stymied at this stage of ensuring facility compliance. Citizens can access a facility's SWPPP, but only if they request the plan from the facility in writing (EPA, 2006, p. 25). Moreover, the facility is given the authority to make a determination—apparently without regulator oversight—of whether the plan contains confidential business information and thus cannot be disclosed to citizens (EPA, 2006, p. 26). But, even if the facility sends the plan to the citizens, it will be nearly impossible for them to independently assess whether the facility is in compliance unless the citizens station telescopes, conduct air surveillance of the site, or are allowed to access the facility's records of its own self-inspections. Moreover, to the extent that the stormwater outfalls are on the facility's property**,** citizens might not be able to conduct their own sampling without trespassing.

Not surprisingly, significant progress has nevertheless been made in reducing stormwater pollution when stormwater becomes a visible public issue. This increased visibility is often accomplished with the help of local environmental advocacy groups who call attention to the endangered species, tourism, or drinking water supplies that are jeopardized by stormwater contamination. Box 2-8 describes two cases of active public participation in the management of stormwater.

BOX 2-8
Citizen Involvement/Education in Stormwater Regulations

The federal Clean Water Act, under Section 505, authorizes citizen groups to bring an action in U.S. or state courts if the EPA or a state fails to enforce water quality regulations. Unsurprisingly, the few areas nationally where stormwater quality has become a visible public issue and significant progress has been made in reducing stormwater pollution have prominent local environmental advocacy groups actively involved.

Heal the Bay, Santa Monica, California. In Southern California, Santa Monica-based Heal the Bay has utilized research, education, community action, public advocacy, and political activism to improve the quality of stormwater discharges from MS4s in Southern California. Heal the Bay operates an aquarium to educate the public, conducts stream teams to survey local streams, posts a beach report card on the web to inform swimmers on beach quality, appears before the California Water Boards to comment on NPDES stormwater permits, and works with lawmakers to sponsor legislative bills that protect water quality.

In 1998, the organization helped co-author legislation to notify the public when shoreline water samples show that water may be unsafe for swimming. California regulations (AB411) require local health agencies (county or city) to monitor water quality at beaches that are adjacent to a flowing storm drain and have 50,000 visitors annually (from April 1 to October 31). At a minimum, these beaches are tested on a weekly basis for three specific bacteria indicators: total coliform, fecal coliform, and *enterococcus*. Local health officials are required to post or close the beach, with warning signs, if state standards for bacterial indicators are exceeded. The monitoring data collected are available to the public.

In order to better inform and engage the public, Heal the Bay has followed up with a web-based Weekly Beach Report Card (*http://healthebay.org/brc/statemap.asp*) and the release of an Annual California Beach Report Card assigning an "A" to "F" letter grade to more than 500 beaches throughout the state based on their levels of bacterial pollution. Heal the Bay's Annual Beach Report Card is a comprehensive evaluation of California coastal water quality based on daily and weekly samples gathered at beaches from Humboldt County to the Mexican border. A poor grade means beachgoers face a higher risk of contracting illnesses such as stomach flu, ear infections, upper respiratory infections, and skin rashes than swimmers at cleaner beaches.

Heal the Bay was instrumental in passing Proposition O in the City of Los Angeles which sets aside half a billion dollars to improve the quality of stormwater discharges. In the 2007 term of the California Legislature, the organization has sponsored five legislative bills to address marine debris, including plastic litter transported in stormwater runoff, that

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Box 2-8 Continued

foul global surface waters (*Currents*, Vol. 21, No. 2, p.8, 2007). Heal the Bay also coordinates its actions and partners with other regional and national environmental organizations, such as the WaterKeepers and the NRDC, in advancing water quality protection nationally.

Save Our Springs, Austin, Texas. Citizen groups have played a very influential role in the development of a rigorous stormwater control program in the City of Austin, Texas. Catalyzed in 1990 by a proposal for extensive development that threatened the fragile Barton Springs area, a citizens group named Save Our Springs Legal Defense Fund (later renamed Save our Springs Alliance) formed to oppose the development. It orchestrated an infamous all-night council meeting, with 800 citizens registering in opposition to the proposed development and ultimately led to the City Council's rejection of the 4,000-acre proposal and the formulation of a "no degradation" policy for the Barton Creek watershed. The nonprofit later sponsored the Save Our Springs Ordinance, a citizen initiative supported by 30,000 signatures, which passed by a 2 to 1 margin in 1992 to further strengthen protection of the area. The Save Our Springs Ordinance limits impervious cover in the Barton Springs watershed to a maximum of between 15 and 25 percent, depending on the location of the development in relation to the recharge and contributing zones. The ordinance also mandates that stormwater runoff be as clean after development as before. The ordinance was subject to a number of legal challenges, all of which were successfully defended by the nonprofit in a string of court battles.

Since its initial formation in 1990, the Save Our Springs Alliance has continued to serve a vital role in educating the community about watershed protection and organizing citizens to oppose development that threatens Barton Springs. The organization has also been instrumental in working with a variety of government and nonprofit organizations to set aside large areas of parkland and open spaces within the watershed. Other citizen groups, like the Save Barton Creek Association, also play a very active, complementary role to the Save Our Springs Alliance in protecting the watershed. These other nonprofits are sometimes allied and sometimes diverge to take more moderate stances to development proposals. The resulting constellation of citizen groups, citizen outreach, and community participation is very high in the Austin area and has unquestionably led to a much more informed citizenry and a more rigorous watershed protection program than would exist without such grassroots leadership.

Accounting for Future Land Use

One of the challenges of managing stormwater from urban watersheds thus involves anticipating and channeling future urban growth. Currently, the CWA does little to anticipate and control for future sources of stormwater pollution in urban watersheds. Permits are issued individually on a technology-based basis, allowing for uncontrolled cumulative increases in pollutant and volume loads over time as individual sources grow in number. The TMDL process in theory requires states to account for future growth by requiring a "margin of safety" in loading projections. However, it is not clear how frequently future growth is included in individual TMDLs or how vigorous the growth calculations are (for example, see EPA [2007a, pp. 12, 37], mentioning considerations of future land use as a consideration in stormwater related TMDLs for only a few—Potash Brook and the lower Cuyahoga River—of the 17 TMDLs described in the report). In any event, as already noted a TMDL is generally triggered only after waters have been impaired, which does nothing to anticipate and channel land development before waters become degraded.

The fact that stormwater regulation and land-use regulation are largely decoupled in the federal regulatory system is understandable given the CWA's industrial and municipal wastewater focus and concerns about federalism, but this limited approach is not a credible approach to stormwater management in the future. Federal incentives must be developed to encourage states and municipalities to channel growth in a way that acknowledges, estimates, and minimizes stormwater problems.

Picking up the Slack at the Municipal and State Level

Because it involves land use, any stormwater discharge program strikes at a target that is traditionally within the province of state and even more likely local government regulation. Indeed, it is possible that part of the reason for the EPA's loosely structured permit program is its concern about intruding on the province of state and local governments, particularly given their superior expertise in regulating land-use practices through zoning, codes, and ordinances.

In theory, it is perfectly plausible that some state and local governments will step into the void and overcome some of the problems that afflict the federal stormwater discharge program. If local or state governments required mandatory monitoring or more rigorous and less ambiguous SCMs, they would make considerable progress in developing a more successful stormwater control program. In fact, some states and localities have instituted programs that take these steps. For example, Oregon has established its own benchmarks based on industrial stormwater monitoring data, and it uses the benchmark exceedances to deny industries coverage under Oregon's MSGP. In such cases, the facility operator must file for an individual stormwater discharge NPDES permit. Some municipalities are also engaging in these problems, such as the City of Austin and its ban on coal tar sealants.

Despite these bursts of activity, most state and local governments have not taken the initiative to fill the gaps in the EPA's federal program (see Tucker [2005] for some exceptions). Because they involve some expense, stormwater discharge requirements can increase resident taxes, anger businesses, and strain already busy regulatory staff. Moreover, if the benefits of stormwater controls are not going to materialize in waters close to or of value to the community instituting the controls, then the costs of the program from the locality's standpoint are likely to outweigh its benefits. Federal financial support for state and local stormwater programs is very limited (see section below). Until serious resources are allocated to match the seriousness and complexity of the problem and the magnitude of the caseload, it seems unlikely that states and local communities will step in to fill the gaps in EPA's program. These impediments help explain why there appear to be so many stormwater sources out of compliance with the stormwater discharge permit program as discussed above, at least in the few states that have gone on record.

Funding Constraints

Without a doubt, the biggest challenge for states, regions, and municipalities is having adequate fiscal resources dedicated to implement the stormwater program. Box 2-9 highlights the costs of the program for the State of Wisconsin, which has been traditionally strong in stormwater management. Phase I regulations require that a brief description of the annual proposed budget for the following year be included in each annual report, but this requirement has been dispensed with entirely for Phase II.

Ever since the promulgation of the stormwater amendments to the CWA and the issuance of the stormwater regulations, the discharger community pointed out that this statutory requirement had the flavor of an unfunded mandate. Unlike the initial CWA that provided significant funding for research, design, and construction of wastewater treatment plants, the stormwater amendments did not provide any funding to support the implementation of the requirements by the municipal operators. The lack of a meaningful level of investment in addressing the more complex and technologically challenging problem of cleaning up stormwater has left states and municipalities in the difficult position of scrambling for financial support in an era of multiple infrastructure funding challenges.

While a number of communities have passed stormwater fees linked to water quality as described below, a significant number of communities still do not have that financial resource. Municipalities that have not formed utility districts or imposed user fees have had to rely on general funds, where stormwater permit compliance must compete with public safety, fire protection, and public libraries. This circumstance explains why elected local government officials have been reluctant to embrace the stormwater program. Stormwater quality management is often not regarded as a municipal service, unlike flood control or wastewater conveyance and treatment. A concerted effort will need to be made by all stakeholders to make the practical and legal case that stormwater quality management is truly another municipal service like trash collection, wastewater treatment, flood control, etc. Even in states that do collect fees to finance stormwater permit programs, the programs appear underfunded relative to other types of water pollution initiatives. Table 2-10 shows the water quality budget of the California EPA, Los Angeles Regional Water Board. The amount of money per regulated entity (see Table 2-4) dedicated to the stormwater program pales in comparison to the wastewater portion of the NPDES program, and it has

BOX 2-9
Preliminary Cost Estimates for Complying with Stormwater Discharge Permits in Wisconsin

The Wisconsin Department of Natural Resources (WDNR) was delegated authority under the CWA to administer the stormwater permit program under Chapter NR 216. There are 75 municipalities regulated under individual MS4 permits and 141 MS4s regulated under a general permit for a total of 216 municipalities with stormwater discharge permits.

As part of the "pollution prevention" minimum measure the municipalities are required to achieve compliance with the developed urban area performance standards in Chapter NR 151.13. By March 10, 2008, municipalities subject to a municipal stormwater permit under NR 216 must reduce their annual TSS loads by 20 percent. These same permitted municipalities are required to achieve an annual TSS load reduction of 40 percent by March 10, 2013. The reduction in TSS is compared to no controls, and any existing SCMs will be given credit toward achieving the 20 or 40 percent. As part of their compliance with NR151.13 developed area performance standards, the municipalities are preparing stormwater plans describing how they will achieve the 20 and 40 percent TSS reduction. They are required to use an urban runoff model, such as WinSLAMM or P8, to do the pollutant load analysis.

As the permitted municipalities comply with the six minimum control measures and submit the stormwater plans for their developed area urban areas, the WDNR is learning how much it is going to cost to achieve the requirements in the stormwater discharge permits. Some cities have already been submitting annual reports that include the cost of the six minimum measures. Nine of the permitted municipalities in the southeast part of Wisconsin have been submitting their annual reports for at least four years. The average population of these nine communities is 17,700 with a range of about 6,000 to 65,000. The average cost of the six minimum measures in 2007 for the nine municipalities is $162,900 with a range of $11,600 to $479,000. These costs have not changed significantly from year to year. The average per capita cost is $9 with a range of $1 to $16 per person. Street cleaning and catch basin cleaning (Figures 2-3 and 2-4) cost are included in the cost for the pollution prevention measure, and most of the cities were probably incurring costs for these two activities before the issuing of the permit. On average the street cleaning and catch basin cleaning represent about 40 percent of the annual cost for the six minimum measures. These two activities will help the cities achieve the 20 and 40 percent TSS performance standards for developed urban areas.

Information is available on the preliminary cost of achieving the 40 percent TSS performance standard for selected cities in Wisconsin. The costs were prepared for 15 municipalities by Earth Tech Inc. in Madison, Wisconsin. Areas of the municipality developed after October 2004 are not included in the TSS load analysis. At this point in the preparation of the stormwater plans the costs are just capital cost estimates done at the planning level (Table 2-9). Because the municipalities receive credit for their existing practices, these capital costs represent the additional practices needed to achieve the annual 40 percent TSS reduction. The costs per capita appear to decline for cities with a population over 50,000. All of the costs in Table 2-9 will increase when other costs, such as maintenance and land cost, are included.

For most of the 15 municipalities, the capital costs are for retrofitting dry ponds with permanent pools, installing new wet detention ponds, and improved street cleaning capabilities. Because of their lower cost, the regional type practices have received more attention in the stormwater plans than the source area practices, such as proprietary devices and biofilters. Municipalities with a higher percentage of newer areas will usually have lower cost because the newer developments tend to have stormwater control measures designed to achieve a high level of TSS control, such as wet detention ponds. Older parts of a municipality are usually limited to practices with a lower TSS reduction, such as street cleaning and catch basin cleaning. Of course, retrofitting older areas with higher efficiency practices is expensive,

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BOX 2-9 Continued

and the cost can go higher than expected when unexpected site limitations occur, such as the presence of underground utilities.

Over the next five years all of the 15 municipalities must budget the costs in Table 2-9. It is not clear yet how much of a burden these costs represent to the taxpayers in each municipality. All the permits will be reviewed for compliance with the performance standards in 2013.

TABLE 2-9 Planning-Level Capital Cost Estimate to Meet 40 Percent TSS Reduction

Population	Number of Cities	Average Cost ($)	Minimum Cost ($)	Maximum Cost ($)	Avg. Cost per Capita per Year over 5 Years ($)
5,000 to 10,000	5	1,380,000	425,000	2,800,000	34
10,000 to 50,000	6	4,600,00	2,700,00	9,200,000	35
50,000 to 100,000	4	9,200,000	7,000,000	12,500,000	26

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FIGURE 2-3 Catch basin cleaning. SOURCE: Robert Pitt, University of Alabama.

FIGURE 2-4 Street cleaning. SOURCE: Courtesy of the U.S. Geological Survey.

TABLE 2-10 Comparison of Fiscal Year (FY) 02–03 Budget with FY 06–07 Budget for Water Quality Programs at the California EPA, Los Angeles Regional Water Board

Program	**Funding Source**	**2002–2003**	**2006–2007**
NPDES[1]	Federal	$2.8 million	$2.6 million
Stormwater	State	$2.3 million	$2.1 million
TMDLs	Federal	$1.47 million	$1.38 million
Spills, Leaks, Investigation Cleanup	State	$1.32 million	$2.87 million
Underground Storage Tanks	State	$2.78 million	$2.74 million
Non-Chapter 15 (Septics)	State	$0.93 million	$0.93 million
Water Quality Planning	Federal	$0.2 million	$0.21 million
Well Investigation	State	$1.36 million	$0.36 million
Water Quality Certification	Federal	$0.2 million	$0.23 million
Total		$17.1 million	$15.82 million

[1]The NPDES row is entirely wastewater funding, as there is no federal money for implementing the stormwater program. Note that the stormwater program in the table is entirely state funded.

declined over time. Furthermore, of the more than $5 billion dollars in low-interest loans provided in 2006 for investments in water quality improvements, 96 percent of that total funding went to wastewater treatment (EPA, 2007d).

There are a number of potential methods that agencies can use to collect stormwater quality management fees, as described more extensively in Chapter 5. A number of states now levy permit fees, with some permits costing in excess of $10,000, to help defray the costs of implementation and enforcement of their stormwater programs. The State of Colorado, for example, has developed an elaborate fee structure for separate types of general permits for industry and construction, as well as MS4s (see *http://www.cdphe.state.co.us/wq/permitsunit/stormwater/StormwaterFees.pdf*). The ability of a state agency to collect fees generally must first be authorized by the state legislatures (see, e.g., Revised Code of Washington 90.48.465, providing the state agency with the authority to "collect expenses for issuing and administering each class of permits"). The lack of state legislative authorization may limit some state agencies from creating such programs on their own. In fact, in those states where fees cannot be levied against permittees, the stormwater programs appear to be both underfinanced and understaffed. Some municipalities have even experienced political backlash because of the absence of a strong state or federal program requiring them to engage in rigorous stormwater management (see Box 2-10).

Stormwater Management Expertise

Historically, engineering curriculum dealt with stormwater management by focusing on the flood control aspects, with little attention given to the water quality aspects. Thus, there has been a significant gap in knowledge and a lack

BOX 2-10
A City's Ability to Pay for Stormwater, Water, and Sewage Utility Fees

With the implementation of the stormwater permit program of the CWA, stormwater utilities are becoming more common as a way to jointly address regional stormwater quality and drainage issues. One such program is the Jefferson County, Alabama, Storm Water Management Authority (SWMA), formed in 1997 under state legislation that enables local governments to pool their resources in a regional stormwater authority to meet regulations required by the CWA. Jefferson County, the City of Birmingham, and 22 other regional municipalities in Jefferson, part of Shelby and part of St. Clair counties, Alabama, were required to comply with CWA regulations. The act gave the stormwater program the ability to develop a funding mechanism for the program and to form a Public Corporation.

Over the years, SWMA has been responsible for many activities. One of their first goals was to develop a comprehensive GIS database to map outfalls, land uses, stormwater practices, and many other features that were required as part of the permit program. Another major activity conducted by SWMA was the collection of water samples from about 150 sites in the authority's jurisdiction, both during wet and dry weather. SWMA also inspects approximately 4,000 outfalls during dry weather to check for inappropriate connections to the storm drainage system. SWMA coordinates public volunteer efforts with local environmental groups, including the Alabama Water Watch, the Alabama River Alliance, the Black Warrior Riverkeeper, and the Cahaba River Society. SWMA also inspects businesses and industries (including construction sites) within their jurisdictions that are not permitted by the Alabama Department of Environmental Management (ADEM). SWMA does not enforce rules or issue fines, although it can report violators to the state. In its most famous case, it reported McWane Inc. for pollution that led to investigations by the state and the federal government, and ultimately a trial and criminal convictions.

The Birmingham News (Bouma, 2007) reported that from 1997 to 2005, SWMA's responsibilities under the CWA increased substantially, although their fees did not rise. In late 2005, SWMA proposed that member cities increase their stormwater charges from $5 a year to $12 a year per household for residences and from $15 to $36 per year for businesses. At that point, the Business Alliance for Responsible Development (BARD), a group of large businesses, utilities, mining interests, developers and landowners, began to argue that the group was financially irresponsible, and its attorneys convinced member cities that they could save money by withdrawing from SWMA. Even though SWMA withdrew its fee increase request, many local municipalities have pulled out of SWMA, significantly reducing the agency's budget and ability to conduct comprehensive monitoring and reporting. BARD claims the pollution control programs of the ADEM are sufficient. In their countersuit, several environmental groups maintain that ADEM has failed to adequately protect the state's waters because the agency is underfunded, understaffed, and ineffective at enforcement. Much of the Cahaba and Black Warrior River systems within Jefferson County have such poor water quality that they frequently violate water quality standards (*http://www.southernenvironment.org*). SWMA has been significantly impaired in its ability to monitor and report water quality violations with the withdrawal of many of its original member municipalities and the associated reduced budget.

At the same time, the sewer bill for a family of four in the region is expected to be about $63 per month in 2008. Domestic water rates have also increased, up to about $32 per month (*The Birmingham News*, Barnett Wright, December 30, 2007). Domestic water rates have increased in recent years in attempts to upgrade infrastructure in response to widespread and long-lasting droughts and to cover rising fuel costs. It is ironic that stormwater management agency fees are very small compared to these other urban water agency fees per household by orders of magnitude. The $12 per year stormwater fee was used to justify the dismantling of an agency that was doing its job and identifying CWA violators. In order to bring some reasonableness to the stormwater management situation and expected fees, it may be possible for the EPA to re-examine its guidelines of 2 percent of the household income for sewer fees to reflect other components of the urban water system, and to ensure adequate enforcement of existing regulations, especially by underfunded state environmental agencies.

of qualified personnel. In areas where SCMs are just beginning to be introduced, many municipalities, industrial operators, and construction site operators are not prepared to address water quality issues; the problem is especially difficult for smaller municipalities and operators. The profession and academia are moving to correct this shortfall. Professional associations such as the Water Environment Federation (WEF) and the American Society for Civil Engineers (ASCE) are co-authoring an update of the WEF/ASCE Manual of Practice "Design of Urban Runoff Controls" that integrates quality and quantity, after years of issuing separate manuals of design and operation for the water quality and water quantity elements of stormwater management.

The split between water quantity and quality is evident in municipal efforts that have focused primarily on flood control issues and design of appropriate appurtenances tailored for this purpose. As discussed earlier, most municipal codes specify practices to collect and move water away as fast as possible from urbanized areas. Very little focus has been put on practices to mitigate the quality of the stormwater runoff. This is especially true in urbanized areas with separate municipal storm sewer systems. Even the designation "sewer" is borrowed from the sanitary sewer conveyance system terminology. In arid or semi-arid areas, these flood control systems have been maximally engineered such that river beds have become concrete channels. A typical example is the Los Angeles River, which most of the year resembles an empty freeway. This analysis does not intend to minimize the engineering feat of designing a robust and reliable flood control system. For example, during the unusually wet 2005 season in Southern California, the Los Angeles area did not have any major flooding incidents. However, based on recent studies (Stein and Ackerman, 2007) up to 80 percent of the annual metals loading from six watersheds in the Los Angeles area was transported by stormwater events.

Because of the historical lack of focus on stormwater quality, municipal departments in general are not designed to address the issue of pollution in urban runoff. Just recently and due to the stormwater regulations, cities have been adding personnel and creating new sections to deal with the issue. However, because of the complexities of the task, many duties are spread among various municipal departments, and more often than not coordination is still lacking. Perhaps most problematic is the fact that the local governmental entities in charge of stormwater management are often different from those that oversee land-use planning and regulation. This disconnect between land-use planning and stormwater management is especially true for large cities. It is not unusual for program responsibilities to be compartmentalized, with industrial aspects of the program handled by one group, construction by another, and planning and public education by other distinct units. Smaller cities may have one person handling all aspects of the program assisted by a consulting firm. While coordination may be ensured, the task can be overwhelming for a single staff person.

Beyond water quality issues, training to better understand the importance of volume control and the role of LID has not yet reached many practitioners.

Many established practices and industry standards in the fields of civil, geotechnical, and structural engineering were developed prior to the introduction of the current group of SCMs and can unnecessarily limit their use. Indeed, certain SCMs such as porous landscape detention, extended detention, and vegetated swales require special knowledge about soils and appropriate plant communities to ensure their longevity and ease of maintenance.

Supplementing the Clean Water Act with Other Federal Authorities that Can Control Stormwater Pollutants at the Source

EPA does have other supplemental authorities that are capable of making significant progress in reducing or even eliminating some of the problematic stormwater pollutants at the national level. Under both the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the TSCA, for example, EPA could restrict some of the most problematic pollutants at their source by requiring labels that alert consumers to the deleterious water quality impacts caused by widely marketed chemical products, restricting their use, or even banning them. This source-based regulation bypasses the need of individual dischargers or governments to be concerned with reducing the individual contaminants in stormwater.

The City of Austin's encounter with coal tar-based asphalt sealants provides an illustration of the types of products contributing toxins to stormwater discharges that could be far better controlled at the production or marketing stage. Through detective work, the City of Austin learned that coal tar-based asphalt sealants leach high levels of polycyclic aromatic hydrocarbons (PAHs) into surface waters (Mahler et al., 2005; Van Metre et al., 2006). The city discovered this because the PAHs were found in sediments in Barton Springs, which were in turn leading to the decline of the endangered Barton Creek salamander (Richardson, 2006). By tracing upstream, the city was able to find the culprit—a parking lot at the top of the hill that was recently sealed with coal tar sealant and produced very high PAH readings. Further tests revealed that coal tar sealants typically leach very high levels of PAHs, but other types of asphalt sealants that are not created from coal tar are much less toxic to the environment and are no more expensive than the coal tar-based sealants (City of Austin, 2004). As a result of its findings, the City of Austin banned the use of coal tar-based asphalt sealants. Several retailers, including Lowes and Home Depot followed the city's lead and refused to carry coal tar sealants. Dane County in the State of Wisconsin has now also banned coal tar sealants[1].

[1] See, e.g., Coal Tar-based pavement sealants studied, Science Daily, February 12, 2007, available at *http://www.sciencedaily.com/upi/index.php?feed=Science&article=UPI-1-2007 0212-10255500-bc-us-sealants.xml*; Matthew DeFour, Dane County bans Sealants with Coal Tar, Wisconsin State Journal, April 6, 2007, available at *http://www.madison.com/ wsj/home/local/index.php?ntid=128156&ntpid=5.*

For reasons that appear to inure to the perceived impotency of TSCA and the enormous burdens of restricting chemicals under that statute, EPA declined to take regulatory action under TSCA against coal tar sealants (Letter from Brent Fewell, Acting Assisting Administrator, U.S. EPA, to Senator Jeffords, October 16, 2006, p. 3). Yet, it had authority to consider whether this particular chemical mixture presents an "unreasonable risk" to health and the environment, particularly in comparison to a substitute product that is available at the same or even lower price [15 U.S.C. § 2605(a); *Corrosion Proof Fittings vs. EPA*, 947 F.2d 1201 (5th Cir. 1991)]. Indeed, if EPA had undertaken such an assessment, it might have even discovered that the coal tar sealants are not as inferior as Austin and others have concluded; alternatively it could reveal that these sealants do present an "unreasonable risk" since there are substantial risks from the sealant without corresponding benefits, given the availability of a less risky substitute.

A similar situation holds for other ubiquitous stormwater pollutants, such as the zinc in tires, roof shingles, and downspouts; the copper in brake pads; heavy metals in fertilizers; creosote- and chromated copper arsenate (CCA)-treated wood; and de-icers, including road salt. Each of these sources may be contributing toxins to stormwater in environmentally damaging amounts, and each of these products might have less deleterious and equally cost-effective substitutes available, yet EPA and other federal agencies seem not to be undertaking any analysis of these possibilities. The EPA's phase-out of lead in gasoline in the 1970s, which led to measurable declines in the concentrations of lead in stormwater by the mid-1980s (see Figure 2-5), may provide a model of the type of gradual regulatory ban EPA could use to reduce contaminants in products that are non-essential.

Some states are taking more aggressive forms of product regulation. For example, in the mid-1990s, numerous scientific studies conducted in California by stormwater programs, wastewater treatment plants, the University of California, California Water Boards, the U.S. Geological Survey, and EPA showed widespread toxicity in local creeks, stormwater runoff, and wastewater treatment plant effluent from pesticide residues, particularly diazinon and chlopyrifos (which are commonly used organophosphate pesticides available in hundreds of consumer products) (Kuivila and Foe, 1995; MacCoy et al., 1995). As a result, the California Water Boards and EPA listed many waters in urban areas of California as being impaired in accordance with CWA Section 303(d). Many cities and counties were required to implement expensive programs to control the pollution under the MS4 NPDES permits to restore the designated beneficial uses of pesticide-impaired waters. Figure 2-6 shows the results of one such action—a ban on diazinon.

In sum, even though there are a number of sources of pollutants—from roof tiles to asphalt sealants to de-icers to brake linings—that could be regulated more restrictively at the product and market stage, EPA currently provides little meaningful regulatory oversight of these sources with regard to their contri-

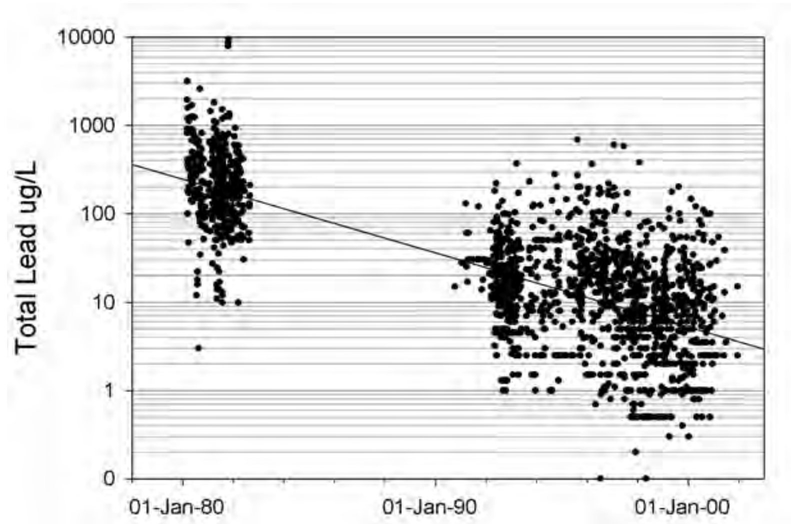

FIGURE 2-5 Trend of lead concentrations in stormwater in EPA rain zone 2 from 1980 to 2001. Although the range of lead concentrations for any narrow range of years is quite large, there is a significant and obvious trend in concentration for these 20 years. SOURCE: National Stormwater Quality Database (version 3).

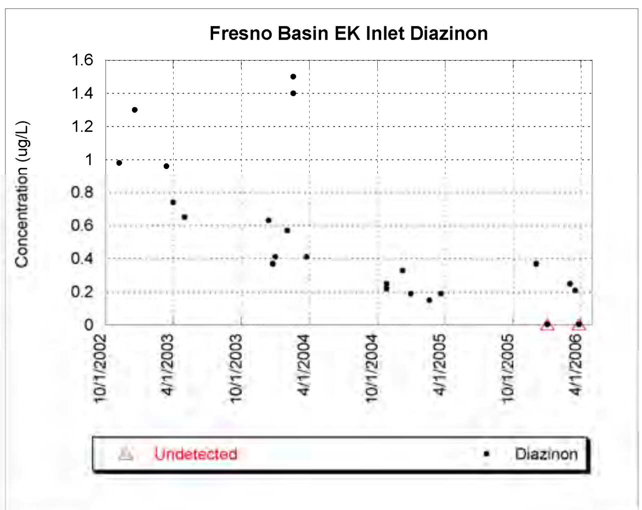

FIGURE 2-6 Trend of the organophosphate pesticide diazinon in MS4 discharges that flow into a stormwater basin in Fresno County, California, following a ban on the pesticide. The figure shows the significant drop in the diazinon concentration in just four years to levels where it is no longer toxic to freshwater aquatic life. EPA prohibited the retail sale of diazinon for crack and crevice and virtually all indoor uses after December 31, 2002, and non-agriculture outdoor use was phased out by December 31, 2004. Restricted use for agricultural purposes is still allowed. SOURCE: Reprinted, with permission, from Brosseau (2007). Copyright 2006 by Fresno Metropolitan Flood Control District.

bution to stormwater pollution. The EPA's authority to prioritize and target products that increase pollutants in runoff, both for added testing and regulation, seems clear from the broad language of TSCA [15 U.S.C. § 2605(a)]. The underutilization of this national authority to regulate environmentally deleterious stormwater pollutants thus seems to be a remediable shortcoming of EPA's current stormwater regulatory program.

CONCLUSIONS AND RECOMMENDATIONS

In an ideal world, stormwater discharges would be regulated through direct controls on land use, strict limits on both the quantity and quality of stormwater runoff into surface waters, and rigorous monitoring of adjacent waterbodies to ensure that they are not degraded by stormwater discharges. Future land-use development would be controlled to prevent increases in stormwater discharges from predevelopment conditions, and impervious cover and volumetric restrictions would serve as a reliable proxy for stormwater loading from many of these developments. Large construction and industrial areas with significant amounts of impervious cover would face strict regulatory standards and monitoring requirements for their stormwater discharges. Products and other sources that contribute significant pollutants through stormwater—like de-icing materials, urban fertilizers and pesticides, and vehicular exhaust—would be regulated at a national level to ensure that the most environmentally benign materials are used when they are likely to end up in surface waters.

In the United States, the regulation of stormwater looks quite different from this idealized vision. Since the primary federal statute—the CWA—is concerned with limiting pollutants into surface waters, the volume of discharges are secondary and are generally not regulated at all. Moreover, given the CWA's focus on regulating pollutants, there are few if any incentives to anticipate or limit intensive future land uses that generate large quantities of stormwater. Most stormwater discharges are regulated instead on an individualized basis with the demand that existing point sources of stormwater pollutants implement SCMs, without accounting for the cumulative contributions of multiple sources in the same watershed. Moreover, since individual stormwater discharges vary with terrain, rainfall, and use of the land, the restrictions governing regulated parties are generally site-specific, leaving a great deal of discretion to the dischargers themselves in developing SWPPPs and self-monitoring to ensure compliance. While states and local governments are free to pick up the large slack left by the federal program, there are effectively no resources and very limited infrastructure with which to address the technical and costly challenges faced by the control of stormwater. These problems are exacerbated by the fact that land use and stormwater management responsibilities within local governments are frequently decoupled. The following conclusions and recommendations are made.

EPA's current approach to regulating stormwater is unlikely to produce an accurate or complete picture of the extent of the problem, nor is it likely to adequately control stormwater's contribution to waterbody impairment. The lack of rigorous end-of-pipe monitoring, coupled with EPA's failure to use flow or alternative measures for regulating stormwater, make it difficult for EPA to develop enforceable requirements for stormwater dischargers. Instead, under EPA's program, the stormwater permits leave a great deal of discretion to the regulated community to set their own standards and self-monitor.

Implementation of the federal program has also been incomplete. Current statistics on the states' implementation of the stormwater program, discharger compliance with stormwater requirements, and the ability of states and EPA to incorporate stormwater permits with TMDLs are uniformly discouraging. Radical changes to the current regulatory program (see Chapter 6) appear necessary to provide meaningful regulation of stormwater dischargers in the future.

Future land development and its potential increases in stormwater must be considered and addressed in a stormwater regulatory program. The NPDES permit program governing stormwater discharges does not provide for explicit consideration of future land use. Although the TMDL program expects states to account for future growth in calculating loadings, even these more limited requirements for degraded waters may not always be implemented in a rigorous way. In the future, EPA stormwater programs should include more direct and explicit consideration of future land developments. For example, stormwater permit programs could be predicated on rigorous projections of future growth and changes in impervious cover within an MS4. Regulators could also be encouraged to use incentives to lessen the impact of land development (e.g., by reducing needless impervious cover within future developments).

Flow and related parameters like impervious cover should be considered for use as proxies for stormwater pollutant loading. These analogs for the traditional focus on the "discharge" of "pollutants" have great potential as a federal stormwater management tool because they provide specific and measurable targets, while at the same time they focus regulators on water degradation resulting from the increased volume as well as increased pollutant loadings in stormwater runoff. Without these more easily measured parameters for evaluating the contribution of various stormwater sources, regulators will continue to struggle with enormously expensive and potentially technically impossible attempts to determine the pollutant loading from individual dischargers or will rely too heavily on unaudited and largely ineffective self-reporting, self-policing, and paperwork enforcement.

Local building and zoning codes, and engineering standards and practices that guide the development of roads and utilities, frequently do not promote or allow the most innovative stormwater management. Fortunately, a variety of regulatory innovations—from more flexible and thoughtful zoning to using design review incentives to guide building codes to having separate ordinances for new versus infill development can be used to encourage more effective stormwater management. These are particularly important to promoting redevelopment in existing urban areas, which reduces the creation of new impervious areas and takes pressure off of the development of lands at the urban fringe (i.e., reduces sprawl).

EPA should provide more robust regulatory guidelines for state and local government efforts to regulate stormwater discharges. There are a number of ambiguities in the current federal stormwater program that complicate the ability of state and local governments to rigorously implement the program. EPA should issue clarifying guidance on several key areas. Among the areas most in need of additional federal direction are the identification of industrial dischargers that constitute the highest risk with regard to stormwater pollution and the types of permit requirements that should apply to these high-risk sources. EPA should also issue more detailed guidance on how state and local governments might prioritize monitoring and enforcement of the numerous and diverse stormwater sources within their purview. Finally, EPA should issue guidance on how stormwater permits could be drafted to produce more easily enforced requirements that enable oversight and enforcement not only by government officials, but also by citizens. Further detail is found in Chapter 6.

EPA should engage in much more vigilant regulatory oversight in the national licensing of products that contribute significantly to stormwater pollution. De-icing chemicals, materials used in brake linings, motor fuels, asphalt sealants, fertilizers, and a variety of other products should be examined for their potential contamination of stormwater. Currently, EPA does not apparently utilize its existing licensing authority to regulate these products in a way that minimizes their contribution to stormwater contamination. States can also enact restrictions on or tax the application of pesticides or even ban particular pesticides or other particularly toxic products. Austin, for example, has banned the use of coal-tar sealants within city boundaries. States and localities have also experimented with alternatives to road salt that are less environmentally toxic. These local efforts are important and could ultimately help motivate broader scale, federal restrictions on particular products.

The federal government should provide more financial support to state and local efforts to regulate stormwater. State and local governments do not have adequate financial support to implement the stormwater program in a rigorous way. At the very least, Congress should provide states with financial support for engaging in more meaningful regulation of stormwater discharges. EPA should also reassess its allocation of funds within the NPDES program. The agency has traditionally directed funds to focus on the reissuance of NPDES wastewater permits, while the present need is to advance the NPDES stormwater program because NPDES stormwater permittees outnumber wastewater permittees more than five fold, and the contribution of diffuse sources of pollution to degradation of the nation's waterbodies continues to increase.

REFERENCES

Athayde, D. N., P. E. Shelly, E. D. Driscoll, D. Gaboury, and G. Boyd. 1983. Results of the Nationwide Urban Runoff Program—Volume 1, Final report. EPA WH-554. Washington, DC: EPA.

Barbour, M. T., J. Diamond, B. Fowler, C. Gerardi, J. Gerritsen, B. Snyder, and G. Webster. 1999a. The status and use of biocriteria in water quality monitoring. Project 97-IRM-1. Alexandria, VA: Water Environment Research Foundation (WERF).

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999b. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second Edition. EPA/841-B-99-002. Washington, DC: EPA Office of Water.

Barbour, M. T., M. J. Paul, D. W. Bressler, A. H. Purcell, V. H. Resh, and E. Rankin. 2006. Bioassessment: a tool for managing aquatic life uses for urban streams. Research Digest #01-WSM-3 for the WERF.

Beckman, D. 2007. Presentation to the NRC Committee on Reducing Stormwater Discharge Contributions to Water Pollution, December 17, 2007.

Bouma, K. 2007. Agency may lose 40% of budget. The Birmingham News. January 18, 2007.

Brosseau, G. 2007. Presentation to the NRC Committee on Reducing Stormwater Pollution, December 17, 2007, Irvine, CA. Summarizing the Report: Fresno-Clovis Stormwater Quality Monitoring Program—Evaluation of Basin EK Effectiveness—Fresno Metropolitan Flood Control District, November 2006.

CA SWB (California State Water Board). 1999. Storm Water General Industrial Permit Non-Filer Identification and Communication Project: Final Report.

CA SWB. 2006. Storm Water Panel Recommendations—The Feasibility of Numeric Effluent Limits Applicable to Discharges of Storm Water Associated with Municipal, Industrial, and Construction Activities.

City of Austin. 2004. The Coal Tar Facts, available at *http://www.ci.austin.tx.us/watershed/downloads/coaltarfacts.pdf*. Last accessed August 20, 2008.

Connecticut DEP. 2007. A Total Maximum Daily Load Analysis for Eagleville Brook, Mansfield, CT, Final. 27 pp.

CWP (Center for Watershed Protection). 1998. Better Site Design: A Handbook for Changing Development Rules in Your Community. Ellicott City, MD: CWP.

Davies, S. P., L. Tsomides, J. L. DiFranco, and D. L. Courtemanch. 1999. Biomonitoring Retrospective: Fifteen Year Summary for Maine Rivers and Streams. Maine DEP (DEP LW1999-26).

Davies, S. P., and S. K. Jackson. 2006. The biological condition gradient: a descriptive model for interpreting change in aquatic ecosystems. Ecological Applications 16(4):1251–1266.

Davies, S. P., and L. Tsomides. 1997. Methods for Biological Sampling and Analysis of Maine's Inland Waters. MDEP, revised June 1997.

Davis, W. S. (ed.). 1990. Proceedings of the 1990 Midwest Pollution Control Biologists Meeting. U. S. Environmental Protection Agency, Chicago, Illinois. EPA 905/9-89-007.

Davis, W. S. 1995. Biological assessment and criteria: building on the past. Pp. 15–*30 In:* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making for Rivers and Streams. W. Davis and T. Simon (eds.). Boca Raton, FL: Lewis Publishers.

DeShon, J. D. 1995. Development and application of the invertebrate community index (ICI). Pp. 217–*243 In:* Biological Assessment and Criteria: Tools for Risk-Based Planning and Decision Making. W. S. Davis and T. Simon (eds.). Boca Raton, FL: Lewis Publishers.

Driscoll, E. D., P. E. Shelley, and E. W. Strecker. 1990. Pollutant loadings and impacts from highway stormwater runoff volume III: analytical investigation and research report. Federal Highway Administration Final Report FHWA-RD-88-008, 160 pp.

Duke, D. 2007. Industrial Stormwater Runoff Pollution Prevention: Regulations and Implementation. Presentation to the NRC Committee on Reducing Stormwater Discharge Contribution to Water Pollution, Seattle, WA, August 22, 2007.

Duke, L. D., and C. A. Augustenborg. 2006. Effectiveness of self-identified and self-reported environmental regulations for industry: the case of stormwater runoff in the U.S. Journal of Environmental Planning and Management 49:385.

Duke, L. D., and K. A. Shaver. 1999. Industrial storm water discharger identification and compliance evaluation in the City of Los Angeles. Environmental Engineering Science 16:249–263.

EPA (U.S. Environmental Protection Agency). 1996a. Overview of the Stormwater Program. EPA 833-R-96-008. Available at *http://www.epa.gov/npdes/pubs/owm0195.pdf*. Last accessed August 20, 2008.

EPA. 1996b. Biological Criteria: Technical Guidance for Streams and Rivers. EPA 822-B-94-001. Washington, DC: EPA Office of Science and Technology.

EPA. 2000a. Stressor Identification Guidance Document. EPA 822-B-00-025. Washington, DC: EPA Offices of Water and Research and Development.

EPA. 2000b. Report to Congress on the Phase I Storm Water Regulations. EPA-833-R-00-001. Washington, DC: EPA Office of Water.

EPA. 2002a. Summary of Biological Assessment Programs and Biocriteria Development for States, Tribes, Territories, and Interstate Commissions: Streams and Wadeable Rivers. EPA-822-R-02-048. Washington, DC: EPA.

EPA. 2002b. Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs. Memorandum dated November 22, 2002, from R. H. Wayland, Director, Office of Wetlands, Oceans, and Watersheds, and J. A. Hanlon, Director, Office of Wastewater Management, to Water Division Directors.

EPA. 2005a. Use of Biological Information to Better Define Designated Aquatic Life Uses in State and Tribal Water Quality Standards: Tiered Aquatic Life Uses. EPA-822-R-05-001. Washington, DC: Health and Ecological Criteria Division Office of Science and Technology, Office of Water.

EPA. 2005b. Proposed National Pollutant Discharge Elimination System (NPDES) General Permit for Stormwater Discharges from Industrial Activities, 70 Fed. Reg. 72116.

EPA. 2006. National Pollution Discharge Elimination System (NPDES), Proposed 2006 MSGP. Available at *http://www.epa.gov/npdes/pubs/msgp 2006_all-proposed.pdf*. Last accessed August 20, 2008.

EPA. 2007a. TMDLs with Stormwater Sources: A Summary of 17 TMDLs. Washington, DC: EPA.

EPA. 2007b. MS4 Program Evaluation Guidance Document. EPA-833-R-07-003. Washington, DC: EPA Office of Wastewater Management.

EPA. 2007c. Port of Los Angeles, Port of Long Beach Municipal Separate Storm Sewer System and California Industrial General Storm Water Permit Audit Report.

EPA. 2007d. Clean Water State Revolving Fund Programs: 2006 Annual Report. EPA-832-R-07-001. Washington, DC: EPA Office of Water.

EPA. 2008. Memorandum from Linda Boornazian, Water Permits Division, EPA Headquarters, to Water Division Directors, Regions 1–10. Clarification on which stormwater infiltration practices/technologies have the potential to be regulated as “Class V” wells by the Underground Injection Control Program. June 13, 2008. Washington, DC: EPA Office of Water.

EPA Region 1. 2004. Three NH Companies Agree to Pay Fine to Settle EPA Complaint; Case is Part of EPA Push to Improve Compliance with Stormwater Regulations. Press Release 04-08-05.

EPA Region 3. 2003. Nutrient and Siltation TMDL Development for Wissahickon Creek, Pennsylvania, Final Report. Available at *http://www.epa.gov/reg3wapd/tmdl/pa_tmdl/wissahickon/index.htm*. Last accessed August 20, 2008.

EPA Region 9. 2005. Press Release: EPA Orders Oakland Facility to Comply with its Stormwater Permit.

Gallant, A. L., T. R. Whittier, D. P. Larson, J. M. Omernik, and R. M. Hughes. 1989. Regionalization as a Tool for Managing Environmental Resources. EPA/600/3089/060. Corvallis, OR: EPA Environmental Research Laboratory.

General Accounting Office (GAO). 1989. EPA Action Needed to Improve the Quality of Heavily Polluted Waters. GAO/RCED 89-38. Washington, DC: GAO.

GAO. 2000. Water quality: Key EPA and State Decisions Limited by Inconsistent and Incomplete Data. GAO/RCED-00-54. Washington, DC: GAO.

GAO. 2005. Storm Water Pollution: Information Needed on the Implications of Permitting Oil and Gas Construction Activities. GAO-05-240. Washington, DC: GAO. Available at *http://www.gao.gov/new.items/d05240.pdf*. Last accessed August 20, 2008.

GAO. 2007. Report to Congressional Requesters, Further Implementation and Better Cost Data Needed to Determine Impact of EPA's Storm Water Program on Communities. GAO-07-479. Washington, DC: GAO.

Hawkins, C. P., R. H. Norris, J. N. Hogue, and J. W. Feminella. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecological Applications 10:1456–1477.

Hill, B. H., F. H. McCormick, A. T. Herlihy, P. R. Kaufmann, R. J. Stevenson, and C. Burch Johnson. 2000. Use of periphyton assemblage data as an index of biotic integrity. Journal of the North American Benthological Society 19(1):50–67.

Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomology 20:31.

Hilsenhoff, W. L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society 7:65.

Houck, O. 1999. TMDLs IV: the final frontier. Environmental Law Reporter 29:10469.

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: a method for assessing stream potentials. Environmental Management 10:629–635.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6):21–27.

Karr, J. R., and E. W. Chu. 1999. Restoring Life In Running Waters: Better Biological Monitoring. Washington, DC: Island Press.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55–68.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5.

Kaufman, B., L. R. Liebesman, and R. Persoen. 2005. Regulation of Stormwater Pollution: An Area of Increasing Importance to the Construction Industry. Mondaq Business Briefing, October 14, 2005. Available at *http://www.mondaq.com/article.asp?articleid=35276&lastestnews=*1. Last accessed October 31, 2008.

Kerans, B. L., and J. R. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecological Applications 4(4):768–785.

Klemm, D. J., K. A. Blocksom, F. A. Fulk, A. T. Herlihy, R. M. Hughes, P. R. Kaufmann, D. V. Peck, J. L. Stoddard, W. T. Thoeny, M. B. Griffith, and W. S. Davis. 2003. Development and evaluation of macroinvertebrate biotic integrity index (MBII) for regionally assessing Mid-Atlantic highlands streams. Environ. Mgt. 31(5):656-669.

Kuivila, K., and C. Foe. 1995. Concentrations, transport and biological effects of dormant spray pesticides in the San Francisco estuary, California. Environmental Toxicology and Chemistry 14(7):1141–1150.

MacCoy, D., K. L. Crepeau, and K. M. Kuivila. 1995. Dissolved pesticide data for the San Joaquin River at Vemalis and the Sacramento River at Sacramento, California, 1991-94. U.S. Geological Survey Report 95-l 10.

Mack, J. J. 2007. Developing a wetland IBI with statewide application after multiple testing iterations. Ecological Indicators 7(4):864–881.

Mahler, B. J., P.C. Van Metre, T.J.Bashara, J.T. Wilson, and D.A. Johns. 2005. Parking lot sealcoat: an unrecognized source of urban polycyclic aromatic hydrocarbons. Environmental Science and Technology 39:5560.

Maine DEP. 2006. Barberry Creek TMDL. 41 pp.

McClure, R. 2004. Stormwater Bill Raises Concern, Seattle Post-Intelligencer, February 25, p. B1.

National Wildlife Federation. 2000. Pollution Paralysis II: Red Code for Watersheds 1-2.

NRC (National Research Council). 2001. Assessing the TMDL Approach to Water Quality Management. Washington, DC: National Academies Press.

Ohio EPA (Ohio Environmental Protection Agency). 1987. Biological Criteria for the Protection of Aquatic Life: Volume II. Users Manual for Biological Field Assessment of Ohio Surface Waters. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, OH.

Ohio EPA. 1989a. Biological criteria for the protection of aquatic life: Volume III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities. Division of Water Quality Monitoring and Assessment, Columbus, Ohio.

Ohio EPA. 1989b. Addendum to biological criteria for the protection of aquatic life: Volume II. Users manual for biological field assessment of Ohio surface waters. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

Ohio EPA. 2007. Compensatory mitigation requirements for stream impacts in the State of Ohio and 3745-1-55 Compensatory mitigation requirements for wetlands. Division of Surface Water, Ohio EPA, Columbus, OH.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers 77(1):118–125.

Omernik, J. M. 1995. Ecoregions: a framework for environmental management. *In*: Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. W. Davis and T. Simon (eds.). Chelsea, MI: Lewis Publishers.

Richardson, D. C. 2006. Parking lot sealants. Stormwater May/June:40.

Richardson, J. 2005. Maine makes it clear: watch your stormwater; Businesses are being warned about meeting the rules on polluted runoff. Portland Press Herald, November 28, p. A1.

Shannon, C. E., and W. Weaver. 1949. The Mathematical Theory of Communication. Urbana, IL: University of Illinois Press.

Simpson, J., and R. H. Norris. 2000. Biological assessment of water quality: development of AUSRIVAS models and outputs. Pp. 125–*142 In:* Assessing the Biological Quality of Fresh Waters: RIVPACS and Other Techniques. J. F. Wright, D. W. Sutcliffe, and M. T. Furse (eds.). Ambleside, UK: Freshwater Biological Association.

Stein, E. D., and D. Ackerman. 2007. Dry weather water quality loadings in arid, urban watersheds of the Los Angeles Basin, California, USA. Journal of the American Water Resources Association 43(2):398–413.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):1267–1276.

Swamikannu, X., M. Mullin, and L. D. Duke. 2001. Final Report: Industrial Storm Water Discharger Identification and Compliance Evaluation in the City of Los Angeles. California State Water Resources Control Board Contract No. 445951-LD-57453. Santa Monica Bay Restoration Project, Los Angeles, CA. 44 pp.

TetraTech. 2002. Ventura County Program Evaluation. Prepared for the California Water Board, Los Angeles Region, and EPA.

TetraTech. 2006a. Assessment Report on Tetra Tech's Support of California's MS4 Stormwater Program. Produced for U.S. EPA Region IX California State and Regional Water Quality Control Boards.

TetraTech. 2006b. Los Angeles Construction Program Review. Tetra Tech, California Water Board, Los Angeles Region, and EPA, January.

TetraTech. 2006c. Review of Best Management Practices at Large Construction Sites. TetraTech, California Water Board Los Angeles Region, and EPA, August.

TetraTech. 2006d. Assessment Report of Tetra Tech's Support of California's Industrial Stormwater Program.

TetraTech. 2006e. Assessment Report of Tetra Tech's Support of California's Municipal Stormwater Program.

Trautman, M. 1957. The Fishes of Ohio. Columbus, OH: Ohio State University Press.

Tucker, L. 2005. Oregon and Washington to release tougher standards for stormwater permits. Daily Journal of Commerce (Portland, OR), December 12, p. 2.

Van Metre, P. C., B.J. Mahler, T.J. Bashara, J.T. Wilson, and D.A. Johns. 2005. Parking lot sealcoat: a major source of polycyclic aromatic hydrocarbons (PAHs) in urban and suburban environments. Environmental Science & Technology 39: 5560-5566.

Washington, H. G. 1984. Diversity, biotic and similarity indices: a review with special relevance to aquatic ecosystems. Water Research 18:653–694.

Weisberg, S. B., J. A. Ranasinghe, D. M. Dauer, L. C. Schaffner, R. J. Diaz, and J. B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay estuaries. Estuaries and Coasts 20(1):149–158.

Wells, C. 1995. Impervious cover reduction study: final report. City of Olympia Public Works Department. Water Resources Program. Olympia, WA. 206 pp.

Wenz, P. S. 2008. Greening Codes. Planning Magazine 74(6):12–16.

Wright, J. F., M. T. Furse, and P. D. Armitage. 1993. RIVPACS—a technique for evaluating the biological quality of rivers in the UK. European Water Pollution Control 3(4):15–25.

Wright, T., J. Tomlinson, T. Schueler, K. Cappiella, A. Kitchell, and D. Hirschman. 2006. Direct and Indirect Impacts of Urbanization on Wetland Quality. Wetlands & Watersheds Article #1. Ellicott City, MD: Center for Watershed Protection.

Yoder, C. O. 1978. A proposal for the evaluation of water quality conditions in Ohio's rivers and streams. Division of Industrial Wastewater, Columbus, OH. 43 pp. NR 216, 2004, Storm Water Discharge Permits, Administrative Rules No. 583.

Yoder, C. O., and E. T. Rankin. 1995. Biological criteria program development and implementation in Ohio. Pp. 109–*152 In:* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. W. S. Davis and T. P. Simon (eds.). Boca Raton, FL: CRC Press.

Yoder, C. O., and E. T. Rankin. 1998. The role of biological indicators in a state water quality management process. Environmental Monitoring and Assessment 51(1–2):61–88.

3
Hydrologic, Geomorphic, and Biological Effects of Urbanization on Watersheds

A watershed is defined as the contributing drainage area connected to an outlet or waterbody of interest, for example a stream or river reach, lake, reservoir, or estuary. Watershed structure and composition include both naturally formed and constructed drainage networks, and both undisturbed areas and human dominated landscape elements. Therefore, the watershed is a natural geographic unit to address the cumulative impacts of urban stormwater. Urbanization has affected change to natural systems that tends to occur in the following sequence. First, land use and land cover are altered as vegetation and topsoil are removed to make way for agriculture or subsequently buildings, roads, and other urban infrastructure. These changes, and the introduction of a built drainage network, alter the hydrology of the local area, such that receiving waters in the affected watershed can experience radically different flow regimes than they did prior to urbanization. This altered hydrology, when combined with the introduction of pollutant sources that accompany urbanization (such as people, domesticated animals, industries, etc.), has led to water quality degradation of many urban streams.

This chapter first discusses the typical land-use and land-cover composition of urbanized watersheds. This is followed by a description of changes to the hydrologic and geomorphic framework of the watershed that result from urbanization, including altered runoff, streamflow mass transport, and stream-channel stability. The chapter then discusses the characteristics of stormwater runoff, including its quantity and quality from different land covers, as well as the characteristics of dry weather runoff. Finally, the effects of urbanization on aquatic ecosystems and human health are explored.

LAND-USE CHANGES

Land use has been described as the human modification of the natural environment into the built environment, such as fields, pastures, and settlements. Important characteristics of different land uses are the modified surface characteristics of the land and the activities that take place within that land use. From a stormwater viewpoint, land uses are usually differentiated by building density and comprised of residential, commercial, industrial, institutional, recreational, and open-space land uses, among others. Each of these land uses usually has distinct activities taking place within it that affect runoff quality. In addition, each land use is comprised of various amounts of surface land cover, such as roofs, roads, parking areas, and landscaped areas. The amount and type of each cover also affect the quality and quantity of runoff from urban areas. Changes in land use and in the land covers within the land uses associated with development and redevelopment are therefore important considerations when studying local receiving water problems, the sources of these problems within the watershed, and the stormwater control opportunities.

Land-Use Definitions

Although there can be many classifications of residential land use, a crude and common categorization is to differentiate by density. High-density residential land use refers to urban single-family housing at a density of greater than 6 units per acre, including the house, driveway, yards, sidewalks, and streets. Medium density is between 2 and 6 units per acre, while low density refers to areas where the density is 0.7 to 2 units per acre. Another significant residential land use is multiple-family housing for three or more families and from one to three stories in height. These units may be adjoined up-and-down, side-by-side, or front-and-rear.

There are a variety of commercial land uses common in the United States. The strip commercial area includes those buildings for which the primary function is the sale of goods or services. This category includes some institutional lands found in commercial strips, such as post offices, court houses, and fire and police stations. This category does not include warehouses or buildings used for the manufacture of goods. Shopping centers are another common commercial area and have the unique distinction that the related parking lot that surrounds the buildings is at least 2.5 times the area of the building roof area. Office parks are a land use on which non-retail business takes place. The buildings are usually multi-storied and surrounded by larger areas of lawn and other landscaping. Finally, downtown central business districts are highly impervious areas of commercial and institutional land use.

Industrial areas can be differentiated by the intensity of the industry. For example, "manufacturing industrial" is a land use that encompasses those buildings and premises that are devoted to the manufacture of products, with many of the operations conducted outside, such as power plants, steel mills, and cement plants. Institutional areas include a variety of buildings, for example schools, churches, and hospitals and other medical facilities that provide patient overnight care.

Roads constitute a very important land use in terms of pollutant contributions. The "freeway" land use includes limited-access highways and the interchange areas, including any vegetated rights-of-ways. Finally, there are a variety of open-space categories, such as cemeteries, parks, and undeveloped land. Parks include outdoor recreational areas such as municipal playgrounds, botanical gardens, arboretums, golf courses, and natural areas. Undeveloped lands are private or publicly owned with no structures and have a complete vegetative cover. This includes vacant lots, transformer stations, radio and TV transmission areas, water towers, and railroad rights-of-way.

The preceding land-use descriptions are the traditional categories that make up the vast majority of the land in U.S. cities. However, there are emerging categories of land use, such as those espoused under the term New Urbanism, which combine several area types (such as commercial and high-density residential areas). Although land use can be broadly and generally categorized, local variations can be extremely important such that locally available land-use data and definitions should always be used. For example, local planning agencies typically do not separate the medium-density residential areas into subcategories. However, this may be necessary to represent different development trends that have occurred with time, and to represent newly emerging types of land uses for an area. Box 3-1 discusses the subtle influence that tree canopy could have on the residential land-use classification.

Trends in Urbanization

Researchers at Columbia University (de Sherbinin, 2002) state that 83 percent of the Earth's land surface has been affected by human settlements and activities, with the urbanized areas comprising about 4 percent of the total land use of the world. Urban areas are expanding world-wide, especially in developing countries. The United Nations Population Division estimates suggest that the

BOX 3-1
The Role of Tree Cover in Residential Land Use

Figure 3-1 shows two medium-density residential neighborhoods, one older and one newer. Tree canopy is obviously different in each case, and it may have an effect on seasonal organic debris in an area and possibly on nutrient loads (although nutrient discharges appear to be more related to homeowner fertilizer applications). Increased tree canopy cover also has a theoretical benefit in reducing runoff quantities due to increased interception losses. In both cases, however, monitoring data to quantify these benefits are sparse. Xiao (1998) examined the effect urban tree cover had on the rainfall volume striking the ground in Sacramento, California. The results indicated that the type of tree or type of canopy cover affected the amount of rainfall reduction measured during a rain event, such that large broad-leafed evergreens and conifers reduced the rainfall that reached the ground by 36 percent, while medium-sized conifers and deciduous trees reduced the rainfall by 18 percent. Cochran (2008) compared the volume and intensity of rain that reached the ground in an open area (no canopy cover) versus two areas with intact canopy covers in Shelby County, Alabama, over a year. The sites were sufficiently close to each other to assume that the rainfall characteristics were the same in terms of the intensity and the variation of intensity and volume during the storm. Rainfall "throughfall" was reduced by about 13.5 percent during the spring and summer months when heavily wooded cover existed. The rainfall characteristics at the leafless tree sites (winter deciduous trees) were not significantly different from the parking lot control sites. In many locations around the county, very high winds are associated with severe storms, significantly decreasing the interception losses. Of course, mature trees are known to provide other benefits in urban areas, including shading to counteract stormwater temperature increases and massive root systems that help restore beneficial soil structure conditions. Additional research is needed to quantify the benefits of urban trees through a comprehensive monitoring program.

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BOX 3-1 Continued

FIGURE 3-1 Two medium-density residential areas (no alleys); the area below is older. SOURCE: Robert Pitt, University of Alabama.

world's population will become mostly urbanized by 2010, whereas only 37 percent of the world's population was urbanized in 1970. De Sherbinin (2002) concludes that although the extent of urban areas is not large when compared with other land uses (such as agriculture or forestry) their environmental impact is significant. Population densities in the cities are large, and their political, cultural, and economic influence is great. Most industrial activity is also located near cities. The influence of urban areas extends beyond their boundaries due to the need for large amounts of land for food and energy production, to generate raw materials for industry, for building water supplies, for obtaining other resources such as construction materials, and for recreational areas. One study estimated that the cities of Baltic Europe require from 500 to more than 1,000 times the urbanized land area (in the form of forests, agricultural, marine, and wetland areas) to supply their resources and to provide for waste disposal (de Sherbinin, 2002).

Currently, considerable effort is being spent investigating land-use changes world-wide and in the United States in support of global climate change research. The U.S. Geological Survey (USGS, 1999) has prepared many research reports describing these changes; Figure 3-2 shows the results for one study in the Chicago and Milwaukee areas, and Figure 3-3 shows the results for a study in the Chesapeake Bay area. These maps graphically show the dramatic rate of change in land use in these areas. The very large growth in urban areas during the 20 years between 1975 and 1995 is especially astonishing. By 1995, Milwaukee and Chicago's urbanized areas more than doubled in size from prior years. Even more rapid growth has occurred in the Washington, D.C.–Baltimore area.

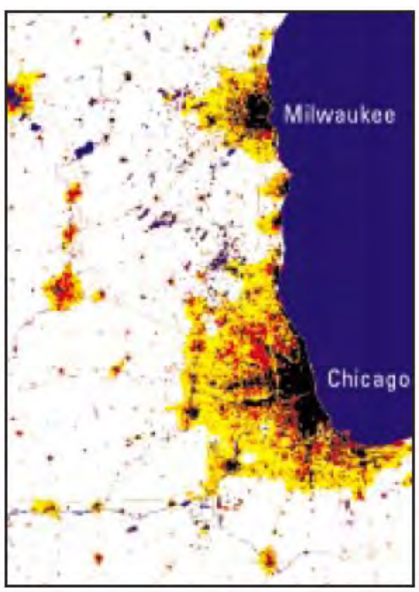

FIGURE 3-2 The extent of urban land in Chicago and Milwaukee in 1955 (black), 1975 (medium gray), and 1995 (light gray). SOURCE: USGS (1999).

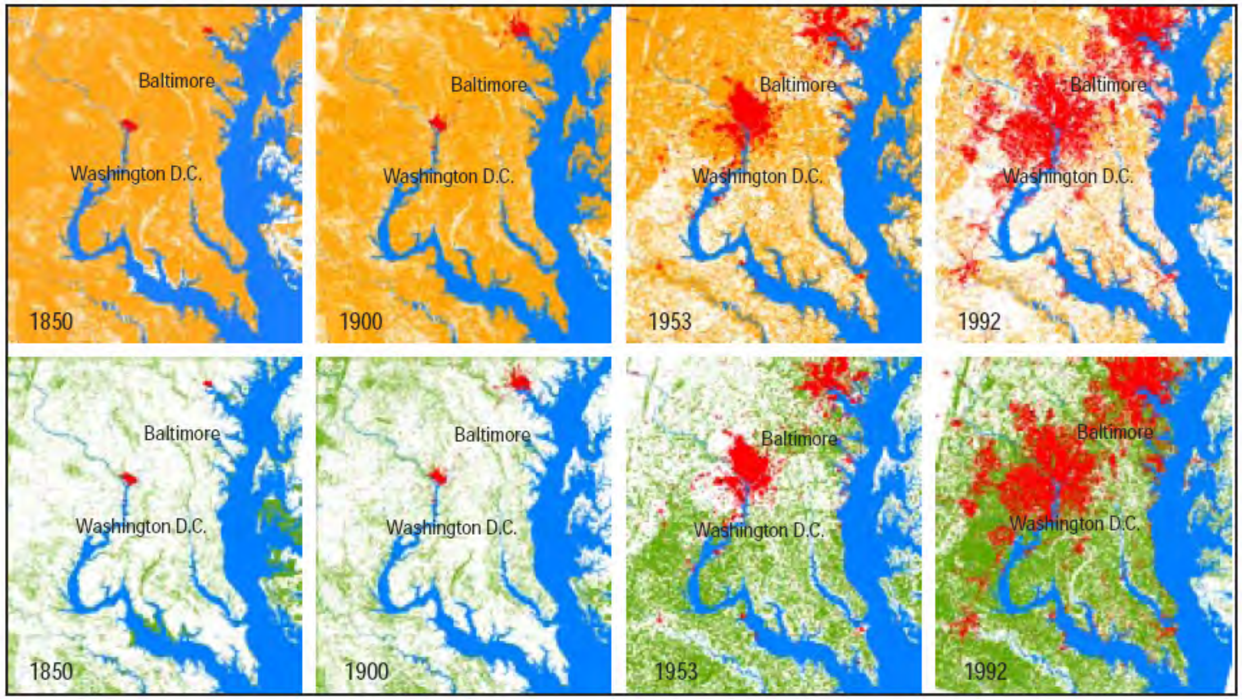

FIGURE 3-3 This series of maps compares changes in urban, agricultural, and forested lands in the Patuxent River watershed over the past 140 years. The top series shows the extent of urban areas (black) along with agriculture (gray), which was at its peak in the mid- to late 1800s. The bottom series show that urban (black) and forested land (gray) have increased since 1900. SOURCE: USGS (1999).

Many different metrics can be used to measure the rate of urbanization in the United States, including the number of housing starts and permits and the level of new U.S. development. The latter is tracked by the U.S. Department of Agriculture's (USDA) National Resources Inventory (USDA, 2000). The inventory, conducted every five years, covers all non-federal lands in the United States, which is 75 percent of the U.S. total land area. The inventory uses land-use information from about 800,000 statistically selected locations. From 1992 to 1997, about 2.2 million acres per year were converted from non-developed to developed status. According to the USDA (2000), the per capita developed land use (acres per person, a classical measure of urban sprawl) has increased in the United States between the years of 1982 and 1997 from about 0.43 to about 0.49 acres per person. The smallest amount of developed land used per person was for New York and Hawaii (0.15 acres), while the largest land consumption rate was for North Dakota, at about 10 times greater. Surprisingly, Los Angeles is the densest urban area in the country at 0.11 acres per person. The amount of urban sprawl is also directly proportionate to the population growth. According to Beck et al. (2003):

> In the 16 cities that grew in population by 10 percent or less between 1970 and 1990 (but whose population did not decline), developed area expanded 38 percent—more than in cities that declined in population but considerably less than in the cities where population increased more dramatically. Cities that grew in population by between 10 and 30 percent sprawled 54 percent on average. Cities that grew between 31 and 50 percent sprawled 72 percent on average. Cities that grew in population by more than 50 percent sprawled on average 112 percent. These findings confirm the common sense, but often unacknowledged proposition, that there is a strong positive relationship between sprawl and population growth.

In most areas, the per capita use of developed land has increased, along with the population growth. However, even some cities that had no population growth or had negative growth, such as Detroit, still had large amounts of sprawl (increased amounts of developed land used per person), but usually much less than cities that had large population growth. Los Angeles actually had an 8 percent decreased rate of land consumption per resident during this period, but the city still experienced tremendous growth in land area due to its very large population growth. The additional 3.1 million residents in the Los Angeles area during this time resulted in the development of almost an additional 400 square miles.

Land-Cover Characteristics in Urban Areas

As an area urbanizes, the land cover changes from pre-existing rural surfaces, such as agricultural fields or forests, to a combination of different surface types. In municipal areas, land cover can be separated into various common categories—pictured and described in Box 3-2—that include roofs, roads, parking areas, storage areas, other paved areas, and landscaped or undeveloped areas.

Most attention is given to impervious cover, which can be easily quantified for different types of land development. Given the many types of land cover described in Box 3-2, impervious cover is composed of two principal components: building rooftops and the transportation system (roads, driveways, and parking lots). Compacted soils and unpaved parking areas and driveways also have "impervious" characteristics in that they severely hinder the infiltration of water, although they are not composed of pavement or roofing material. In terms of total impervious area, the transportation component often exceeds the rooftop component (Schueler, 1994). For example, in Olympia, Washington, where 11 residential multifamily and commercial areas were analyzed in detail, the areas associated with transportation-related uses comprised 63 to 70 percent of the total impervious cover (Wells, 1995). A significant portion of these impervious areas—mainly parking lots, driveways, and road shoulders—experience only minimal traffic activity. Most retail parking lots are sized to accommodate peak parking usage, which occurs only occasionally during the peak holiday shopping season, leaving most of the area unused for a majority of the time. On the other hand, many business and school parking areas are used to their full capacity nearly every work day and during the school year. Other differences at parking areas relate to the turnover of parking during the day. Parked vehicles in business and school lots are mostly stationary throughout the work and school hours. The lighter traffic in these areas results in less vehicle-associated pollutant deposition and less surface wear in comparison to the greater parking turnover and larger traffic volumes in retail areas (Brattebo and Booth, 2003).

As described in Box 1-1, impervious cover is broken down into two main categories: directly connected impervious areas (or effective impervious area) and non-directly connected (disconnected) impervious areas (Sutherland, 2000; Gregory et al., 2005) (although it is recognized that these two states are end-members of a range of conditions). Directly connected impervious area includes impervious surfaces which drain directly to the sealed drainage system without flowing appreciable distances over pervious surfaces (usually a flow length of less than 5 to 20 feet over pervious surfaces, depending on soil and slope characteristics and the amount of runoff). Those areas are the most important component of stormwater runoff quantity and quality problems. Approximately 80 percent of directly connected impervious areas are associated with vehicle use such as streets, driveways, and parking (Heaney, 2000).

Values of imperviousness can vary significantly according to the method used to estimate the impervious cover. In a detailed analysis of urban imperviousness in Boulder, Colorado, Lee and Heaney (2003) found that hydrologic modeling of the study area resulted in large variations (265 percent difference)

BOX 3-2
Land Cover in Urban Areas

For any given land use, there is a range of land covers that are typical. Common land covers are described below, along with some indication of their contribution to stormwater runoff and their pollutant-generating ability.

Roofs. These are usually either flat or pitched, as both have significantly different runoff responses. Flat roofs can have about 5 to 10 mm of detention storage while pitched roofs have very little detention storage. Roofing materials are also usually quite different for these types of roofs, further affecting runoff quality. In addition, roof flashing and roof gutters may be major sources of heavy metals if made of galvanized metal or copper. Directly connected roofs have their roof drains efficiently connected to the drainage system, such as direct connections to the storm drainage itself or draining to driveways that lead to the drainage system. These directly connected roofs have much more of their runoff waters reaching the receiving waters than do partially connected roofs, which drain to pervious areas.

A directly connected roof drain

A disconnected roof drain (drains to pervious area)

Parking Areas. These can be asphalt or concrete paved (impervious surface) or unpaved (traditionally considered a pervious surface) and are either directly connected or drain to adjacent pervious areas. Areas that have rapid turnover of parked cars throughout the day likely have greater levels of contamination due to the frequent starting of the vehicles, an expected major source of pavement pollutants. Unpaved parking areas actually should be considered impervious surfaces, as the compacted surface does not allow any infiltration of runoff. Besides automobile activity in the parking areas, other associated activities contribute to contamination. For example, parked cars in disrepair awaiting service can contribute to parking area runoff contamination. In addition, maintenance of the pavement surface, such as coal-tar seal coating, can be significant sources of polycyclic aromatic hydrocarbons (PAHs) to the runoff.

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BOX 3-2 Continued

Paved parking area with frequent automobile movement

Contamination of paved parking areas due to commercial activities

Storage Areas. These can also be paved, unpaved, directly connected, or drained to pervious areas. As with parking areas, unpaved storage areas should not be considered pervious surfaces because the compacted material effectively hinders infiltration. Detention storage runoff losses from unpaved storage areas can be significant. In storage areas (especially in commercial and industrial land uses), activities in the area can have significant effects on runoff quality.

Contaminated paved storage area at vehicle junk yard

Heavy equipment storage area on concrete surface

Streets. Streets in municipal areas are usually paved and directly connected to the storm drainage system. In municipal areas, streets constitute a significant percentage of all impervious surfaces and runoff flows. Features that affect the quality of runoff from streets include the varying amounts of traffic on different roads and the amount and type of roadside vegetation. Large seasonal phosphorus loads can occur from residential roads in heavily wooded areas, for example.

Wide arterial street with little roadside vegetation (left) and narrow residential street with substantial vegetation (top, right)

Other Paved Areas. Other paved areas in municipal regions include driveways, playgrounds, and sidewalks. Depending on their slopes and local grading, these areas may drain directly to the drainage system or to adjacent pervious areas. In most cases, the runoff from these areas contributes little to the overall runoff for an area, and the runoff quality is of relatively better quality than from the other "hard" surfaces.

Landscaped and Turf Areas. Although these are some of the only true pervious surfaces in municipal areas, disturbed urban soils can be severely compacted, with much more reduced infiltration rates than are assumed for undisturbed regional soils. Besides the usually greater than expected quantities of runoff of pervious surfaces in urban areas, they can also contribute high concentrations of various pollutants. In areas with high rain intensities, erosion of sediment can be high from pervious areas, resulting in much higher concentrations of total suspended solids (TSS) than from paved areas. Also, landscaping chemicals, including fertilizers and pesticides, can be transported from landscaped urban areas. Undeveloped woods in urban areas can have close to natural runoff conditions, but many parks and other open-space areas usually have degraded runoff compared to natural conditions. Turf grass has unique characteristics compared to other landscaped areas in that the soil structure is usually more severely degraded compared to natural conditions. The normally shallower root systems are not as effective in restoring compacted soils and they can remain compacted due to some activities (pathways, parked cars, playing fields, etc.) that do not occur on areas planted with shrubs and trees.

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BOX 3-2 Continued

Soil erosion from turf areas with fine-grained soils during periods of high rain intensities

Undeveloped Areas. Undeveloped areas in otherwise urban locations differ from natural areas. In many situations, they can be previously disturbed (cleared and graded) areas that have not been sold or developed. They may be overgrown with various local vegetation types that thrive in disturbed locations. In other situations, undeveloped areas may be small segments of natural areas that have not been disturbed or revegetated. In this case, their stormwater characteristics may approach natural conditions but still be degraded due to adjacent activities and atmospheric deposition.

SOURCE: Pitt and Voorhees (1995, 2002). Photographs courtesy of Robert Pitt, University of Alabama.

in the calculations of peak discharge when impervious surface areas were determined using different methods. They concluded that the main focus should be on effective impervious area (EIA) when examining the effects of urbanization on stormwater quantity and quality.

Runoff from disconnected impervious areas can be spread over pervious surfaces as sheet flow and given the opportunity to infiltrate before reaching the drainage system. Therefore, there can be a substantial reduction in the runoff volume and a delay in the remaining runoff entering the storm drainage collection system, depending on the soil infiltration rate, the depth of the flow, and the available flow length. Examples of disconnected impervious surfaces are rooftops that discharge into lawns, streets with swales, and parking lots with runoff directed to adjacent open space or swales. From a hydrologic point of view, road-related imperviousness usually exerts a larger impact than rooftop-related imperviousness, because roadways are usually directly connected whereas roofs can be disconnected (Schueler, 1994).

Methods for Determining Land Use and Land Cover

Historically, land-use and land-cover information was acquired by a combination of field measurements and aerial photographic analyses—methods that required intensive interpretation and cross validation to guarantee that the analyst's interpretations were reliable (Goetz et al., 2003). Figure 3-4 is an example of a high-resolution panchromatic aerial photograph that was taken from an airplane in Toronto and used for measurements of urban surfaces (Pitt and McLean, 1986). Most recently, satellite images have become available at high spatial resolution for many areas (<1 to 5 m resolution) and have the advantage of digital multi-spectral information more complete than even that provided by digital orthophotographs. Minnesota has one of the longest records (over 20 years) of continuously recorded statistics on land cover and impervious surfaces derived from satellite images—information which has been incorporated into the

FIGURE 3-4 Example of a high-resolution panchromatic aerial photograph of an industrial area used for measurements of urban surfaces. SOURCE: Pitt and McLean (1986).

Minnesota Statewide Conservation and Preservation Plan. Some of the remaining problems to be overcome with satellite imagery include difficulties in obtaining consistent sequential acquisition dates, intensive computer processing time requirements, and large computer storage space requirements to store massive amounts of image information.

The recommended approach for conducting a survey of land uses and development characteristics (land cover and activities) for an area is to use both aerial photography and site surveys. Aerial photography has improved greatly in recent years, but it is still not suitable for obtaining all the information needed for developing a comprehensive stormwater management plan. Initially, aerial photos should be used to identify the locations and extents of the various land uses in the study area. Neighborhoods representing homogenous land uses should then be identified for site surveys. Usually, about 10 to 15 neighborhoods for each land use are sufficient for a community being studied (Burton and Pitt, 2002). After the field surveys are conducted, the aerials are again used to measure the actual areas associated with land surface cover. This information can be used with field survey data to separate the surfaces into the appropriate categories for analyses and modeling.

Box 3-3 presents a detailed study of land cover for several land uses in the southern United States using satellite imagery and ground surveys (Bochis, 2007; Bochis et al., 2008). The results presented here have been found to be broadly similar to other areas studied in the United States, although few studies have been as detailed, and there are likely to be regional differences.

The general conclusion of many land-use and land-cover studies is that in urban areas, the amount of impervious surfaces has increased since the early years of the 20th century because of the tendency toward increased automobile use and bigger houses, which is associated with an increase in the facilities necessary to accommodate them (wider streets, more parking lots, and garages). As shown in later sections of this report, the construction of impervious surfaces leads to multiple impacts on stream systems. Therefore, future development plans and water resource protection programs should consider reducing impervious cover in the potential expansion of communities. Wells (1995), Booth (2000), Stone (2004), and Gregory et al. (2005) show that reducing the size and dimensions of residential parcels, promoting cluster developments (clustered medium-density residential areas in conjunction with open space, instead of large tracts of low-density areas), building taller buildings, reducing the residential street width (local access streets), narrowing the width and/or building one-side sidewalks, reducing the size of paved parking areas to reflect the average parking needs instead of peak needs, and using permeable pavement for intermittent/overflow parking can reduce the traditional impervious cover in communities by 10 to 50 percent. Many of these benefits can also be met by paying better attention to how the pavement and roof areas are connected to the drainage system. Impervious surfaces that are “disconnected” by allowing their drainage water to flow to adjacent landscaped areas can result in reduced runoff quantities.

BOX 3-3
Land Use and Land Cover for the Little Shades Creek Watershed

Data collected by Bochis-Micu and Pitt (2005) and Bochis (2007) for the Little Shades Creek watershed near Birmingham, Alabama, were acquired using IKONOS satellite imagery (provided by the Jefferson County Storm Water Management Authority) as an alternative to classical aerial photography to map the characteristics of the land uses in the monitored watershed areas, supplemented with verified ground truth surveys. IKONOS is the first commercially owned satellite that provides 1-m-resolution panchromatic image data and 4-m multi-spectral imagery (Goetz et al., 2003).

This project was conducted to evaluate the effects of variable site conditions associated with each land-use category. About 12 homogeneous neighborhoods were investigated in each of the 16 major land uses in this 2,500-hectare watershed. Detailed land-cover measurements were made using a variety of techniques, as listed above, including field surveys for small details that were not visible with remote sensing tools (such as roof drain connectiveness, pavement texture, and landscaping maintenance practices). Each of these individual neighborhoods was individually modeled to investigate the resultant variability in runoff volume and pollutant discharges. These were statistically evaluated to determine if the land-use categories properly stratified these data by explaining significant fractions of the variability. Bochis-Micu and Pitt (2005) and Bochis (2007) concluded that land-use categories were an appropriate surrogate that can be used to describe the observed combinations of land surfaces. However, proper stormwater modeling should examine the specific land surfaces in each land-use category in order to better understand the likely sources of the pollutants and the effectiveness of candidate stormwater control measures (SCMs).

This watershed has an overall impervious cover of about 35 percent, of which about 25 percent is directly connected to the drainage system. Table 3-1 shows the average land covers for each of the surveyed land uses, along with the major source areas in each of the directly connected and disconnected impervious and pervious surface categories. The impervious covers include streets, driveways, parking, playgrounds, roofs, walkways, and storage areas. The directly connected areas are indicated as “connected” or “draining to impervious” and do not include the pervious area or the impervious areas that drain to pervious areas. As expected, the land uses with the least impervious cover are open space (vacant land, cemeteries, golf courses) and low-density residential, and the land uses with the largest impervious covers are commercial areas, followed by industrial areas. For a typical high-density residential land use in this region (having 15 or more units per hectare), the major land cover was found to be landscaped areas, subdivided into front- and back-yard categories, while 25 percent of this land-use area is covered by impervious surfaces broken down into three major subcategories: roofs, streets, and driveways. The subareas making up each land use show expected trends, with roofs and streets being the predominant directly connected impervious covers in residential areas, and parking and storage areas also being important in commercial and industrial areas.

continues next page

BOX 3-3 Continued

TABLE 3-1 Little Shades Creek Watershed Land Cover Information (percent and the predominant land cover)

Land Use	Directly Connected Impervious Cover (%)	Disconnected Impervious Cover (%)	Pervious Cover (%)
High-Density Residential	14 (streets and roof)	10 (roofs)	76 (front and rear landscaping)
Medium-Density Residential (<1960 to 1980)	11 (streets and roofs)	8 (roofs)	81 (front and rear landscaping)
Medium-Density Residential (>1980)	14 (streets and roofs)	5 (roofs)	80 (front and rear landscaping)
Low-Density Residential	6 (streets)	4 (roofs)	89 (front and rear landscaping)
Apartments	21 (streets and parking)	22 (roofs)	58 (front and rear landscaping)
Multiple Families	28 (roofs, parking , and streets)	7 (roofs)	65 (front and rear landscaping)
Offices	59 (parking, streets, and roofs)	3 (parking)	39 (front and rear landscaping)
Shopping Centers	64 (parking, roofs, and streets)	4 (roofs)	31 (front landscaping)
Schools	16 (roofs and parking)	20 (playground)	64 (front and rear landscaping, large turf)
Churches	53 (parking and streets)	7 (parking)	40 (front landscaping)
Industrial	39 (storage, parking, and streets)	18 (storage and roofs)	44 (front and rear landscaping)
Parks	32 (streets and parking)	33 (playground)	34 (large turf and undeveloped)
Cemeteries	7 (streets)	15 (parking)	78 (large turf)
Golf Courses	2 (streets)	4 (roofs)	95 (large turf)
Vacant	5 (streets)	1 (driveways)	94 (undeveloped and large turf)

SOURCE: Bochis-Micu and Pitt (2005) and Bochis (2007). Reprinted, with permission, from Bochis (2007). Copyright 2007 by Celina Bochis.

HYDROLOGIC AND GEOMORPHIC CHANGES

The watershed provides an organizing framework for the management of stormwater because it determines the natural patterns of water flow as well as the constituent sediment, nutrient, and pollutant loads. In undeveloped watersheds, hillslope hydrologic flow-path systems co-evolve with microclimate, soils, and vegetation to form topographic patterns within which ecosystems are spatially arranged and adjusted to the long-term patterns of water, energy, and nutrient availability. The landforms that comprise the watershed include the network patterns of streams, rivers, and their associated riparian zones and floodplains, as well as component freshwater lakes, reservoirs, wetlands, and estuaries.

This section starts with a discussion of precipitation measurement and characteristics before turning to the typical changes in hydrology and geomorphology of the watershed brought on by urbanization. In both the terrestrial and aquatic phases, retention and residence time of sediment and solutes decreases with increasing flow volume and velocity. This results in relatively high retention and low export of water and nutrients in undeveloped watersheds compared to decreasing retention and greater pollutant export in disturbed or developed systems.

The Storm in Stormwater

The magnitude and frequency of stormwater discharges are not just determined by rainfall. Instead, they are the combined product of storm and interstorm characteristics, land use, the natural and built drainage system, and any stormwater control measures (SCMs) that have been implemented. The total volume and peak discharge of runoff, as well as the mobilization and transport of pollutants, are dependent on all aspects of the storm magnitude, catchment antecedent moisture conditions, and the interstorm period. Therefore, information on the frequency distribution of storm events and properties is an important aspect of understanding the distribution of pollutant concentrations and loads in stormwater discharges. In northern climates, runoff production from precipitation can be significantly delayed by the accumulation, ripening, and melt of snowpacks, such that much of the annual load of certain pollutants may be mobilized in peak flow from snowmelt events. Therefore, measurement of precipitation and potential accumulation in both liquid and solid form is critical for stormwater assessment.

Precipitation Measurements

Any given storm is characterized by the storm's total rainfall (depth), its duration, and the average and peak intensity. A *storm hyetograph* depicts measured precipitation depth (or intensity) at a precipitation gauge as a function of time; an example is shown in Figure 3-5. This figure illustrates the typical high degree of variability of precipitation over the total duration of a storm. In this example, the total storm depth is 50.9 mm, the duration is 19 hours, and the peak intensity is 0.56 mm/minute (peak depth of 2.79 mm divided by the measurement increment of 5 minutes). The average intensity is 0.045 mm/minute, quite a bit lower than the peak intensity, since the storm duration is punctuated by periods of low and no measurable precipitation.

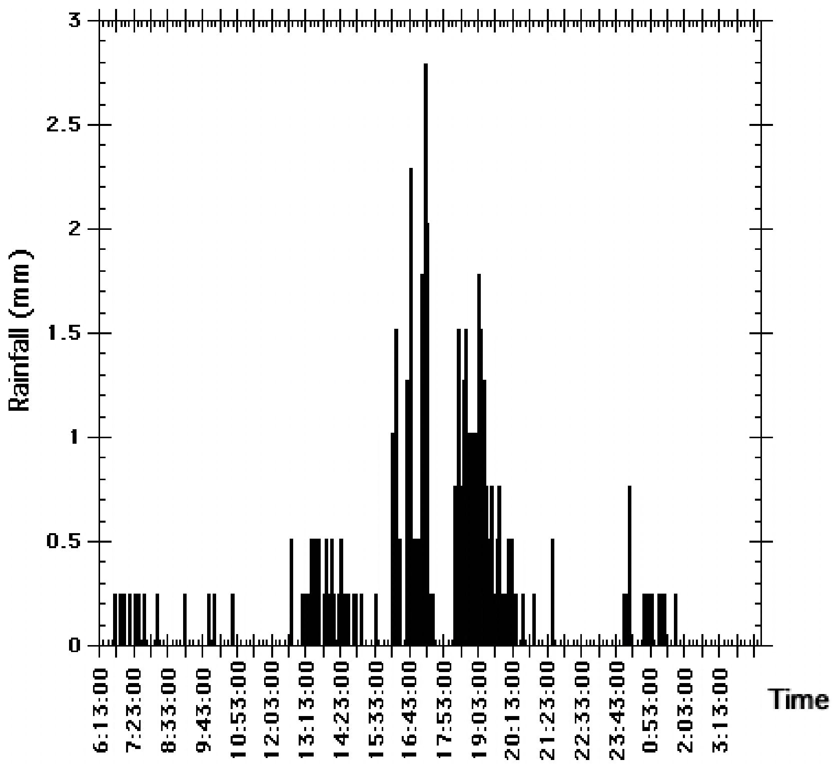


FIGURE 3-5 Example of a storm hyetograph at location RG2, September 20–21, 2001, Valley Creek watershed, Chester County, Pennsylvania. The time increment of measurement is 5 minutes, while the entire duration of this storm is about 16 hours.

In addition to measurements of individual storm events, precipitation data are routinely collected for longer time periods and compiled and analyzed annually when trying to understand local rainfall patterns and their impact on baseflow, water quality, and infrastructure design. Figure 3-6 shows the rainfall during 2007 at both humid (Baltimore) and arid (Phoenix) locations. Especially apparent in the Baltimore data is the fact that the majority of storm events are less than 20 mm in depth.

Several networks of precipitation gauges are available in the United States; gauge data are available online from the National Climatic Data Center (NCDC) (*http://ncdc.nws.noaa.gov*). High-resolution precipitation data (i.e., with measurement intervals of an hour or less) are typically not recorded except at primary weather service meteorological stations, while daily precipitation records are more extensively collected and available through the Cooperative Weather Observer Program (*http://www.nws.noaa.gov/om/coop/*). This distinction is important to stormwater managers because most stormwater applications require short-duration measurements or model results (minutes to hours). Fortunately, a combination of precipitation gauges and precipitation radar estimates are available to estimate precipitation depth and duration, as well as additional methods to estimate snowfall and snowpack water equivalent depth and conditions. (A thorough description of precipitation measurement by radar is given by Krajewski and Smith [2001]). While most of the conterminous United States is covered by NEXRAD radar for estimation of high-temporal-resolution precipitation at current resolutions of ~4 km, the radar backscatter information requires calibration and correction with precipitation gauge data, and satellite estimates

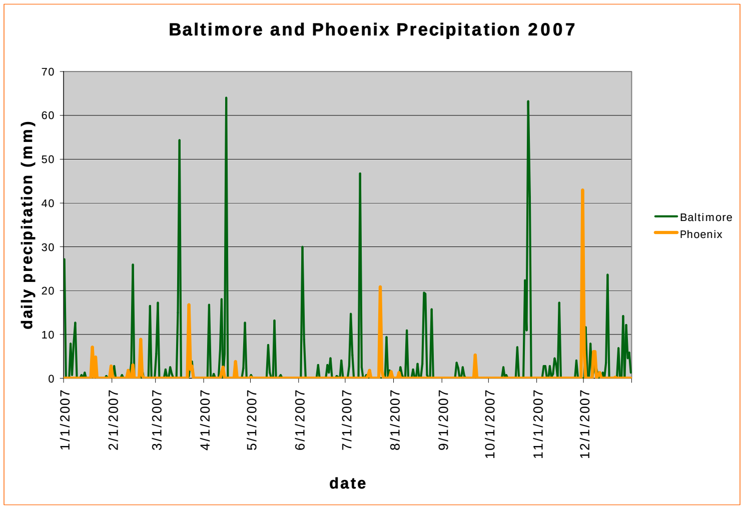


FIGURE 3-6 Daily precipitation totals for the Baltimore-Washington and Phoenix airports for 2007. SOURCE: Data from the National Weather Service.

of precipitation are generally not sufficiently reliable for stormwater applications. It goes without saying that the measurement, quality assurance, and maintenance of long-term precipitation records are both vital and nontrivial to stormwater management.

Precipitation Statistics

The basic characterization of precipitation is by depth-duration-frequency curves, which describe the return period, recurrence interval, and exceedance probability (terms all denoting frequency) of different precipitation intensities (depths) over different durations. The methodology for determining the curves is described in Box 3-4. Precipitation durations of interest in stormwater management range from a few minutes (important for determining peak discharge from small urban drainage areas) to a year (where the interest is in the total annual volume of runoff production). As an example, one might be interested in the return period of the 1-inch, 1-hour event, or the 1-inch, 24-hour event; the latter would have a much shorter return period, because accumulating an inch of rain over a day is much more common than accumulating the same amount over just an hour.

BOX 3-4
Determining Depth-Duration-Frequency Curves

Depth-duration-frequency curves are developed from precipitation records using either annual maximum data series or annual exceedance data series. Annual maximum data series are calculated by extracting the annual maximum precipitation depths of a chosen duration from a record. In cases where there are only a few years of data available (less than 20 to 25 years), then an annual exceedance series (a type of "partial duration series") for each storm duration can be calculated, where N largest values from N years are chosen. An annual maximum series excludes other extreme values of record that may occur in the same year. For example, the second highest value on record at an observing station may occur in the same year as the highest value on record but will not be included in the annual maximum series. The design precipitation depths determined from the annual exceedance series can be adjusted to match those derived from an annual maximum series using empirical factors (Chow et al., 1988; NOAA Atlas data series, see *http://www.weather.gov/oh/hdsc/currentpf.htm*, e.g., Bonnin et al., 2006). Hydrologic frequency analysis is then applied the data series to determine desired return periods by fitting a probability distribution to the data to determine the return periods[1] of interest. The process is repeated for other chosen storm durations.

[1]Analysis of annual maximum series produces estimates of the average period between years when a particular value is exceeded ("average recurrence interval"). Analysis of partial duration (annual exceedance) series gives the average period between cases of a particular magnitude ("annual exceedance probability"). The two results are numerically similar at rarer average recurrence intervals but differ at shorter average recurrence intervals (below about 20 years). NOAA (e.g., Bonnin et al., 2006) notes that the use of the terminology "average recurrence interval" and "annual exceedance probability" typically reflects the analysis of the two different series, but that sometimes the term "average recurrence interval" is used as a general term for ease of reference.

The National Weather Service has developed an online utility to estimate the return period for a range of depth–duration events for any place in the conterminous United States (*http://hdsc.nws.noaa.gov/hdsc/pfds/*). Figures 3-7 and 3-8 show examples of precipitation depth-duration-frequency curves for a humid location (Baltimore, Maryland) and an arid site (Phoenix, Arizona). As an illustration of the climatic influence on the depth-duration-frequency curves, the 2-year, 1-hour storm is associated with a depth of 1.2 inches of precipitation in Baltimore, whereas this same recurrence interval and duration are associated with a depth of only 0.6 inch of precipitation in Phoenix. Durations from 5 minutes to one day are shown because this is the range typically used in the design of stormwater management facilities. The shorter durations provide expected magnitude and frequency for brief but significant precipitation intensity peaks that can mobilize and transport large amounts of pollutants and erode soil, and they are used in high-resolution stormwater models. More commonly, however, stormwater regulations are written for 24-hour durations at 2-, 10-, 25-, 50-, or 100-year recurrence intervals.

Because storm magnitudes and frequencies vary by climatic region, it is reasonable to expect them to change during recurring climate events (e.g., El Niño) or over the long term by climate change. Alteration in convective precipitation by major urban centers has been documented for some time (Huff and Changnon, 1973). Some evidence exists that precipitation regimes are shifting systematically toward an increase in more intense rainfall events, which is consistent with modeled projections of global climate change increases in hydrologic extremes. Kunkel et al. (1999) analyzed precipitation data from 1,295 weather stations from 1931 to 1996 across the contiguous United States and found that storms with extreme levels of precipitation have increased in frequency. The analysis considered short-duration events (1, 3, and 7 days) of 1-year and 5-year return intervals. A linear trend analysis using Kendall's slope estimator statistic indicated that the overall trend in 7-day, 1-yr events for the conterminous United States is upward at a rate of about 3 percent per decade for 1931 to 1996; the upward trend in 7-day, 5-year events is about 4 percent per decade. These two time series are shown in Figure 3-9. An increased frequency of intense precipitation events will shift depth-frequency-duration curves for a given location, with a given return period being associated with a more intense event. Alternatively, the return period for a given intensity (or depth) of an event will be reduced if the event is occurring more frequently. In light of climate change, depth-duration-frequency curves will need to be updated regularly in order to ensure that stormwater management facilities are not underdesigned for an increasing intensity of precipitation. Additional implications of climate change for stormwater management are discussed in Box 3-5.

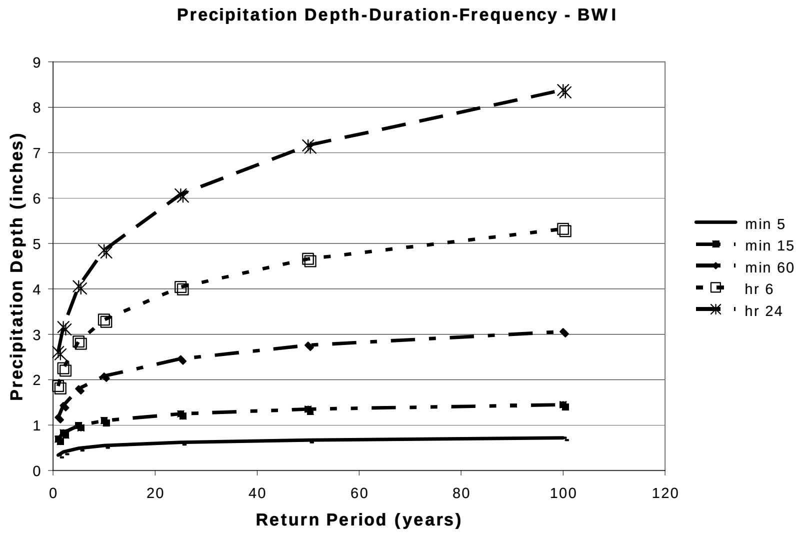


FIGURE 3-7 Depth-duration-frequency curves for Baltimore, Maryland. SOURCE: Data from the National Weather Service.

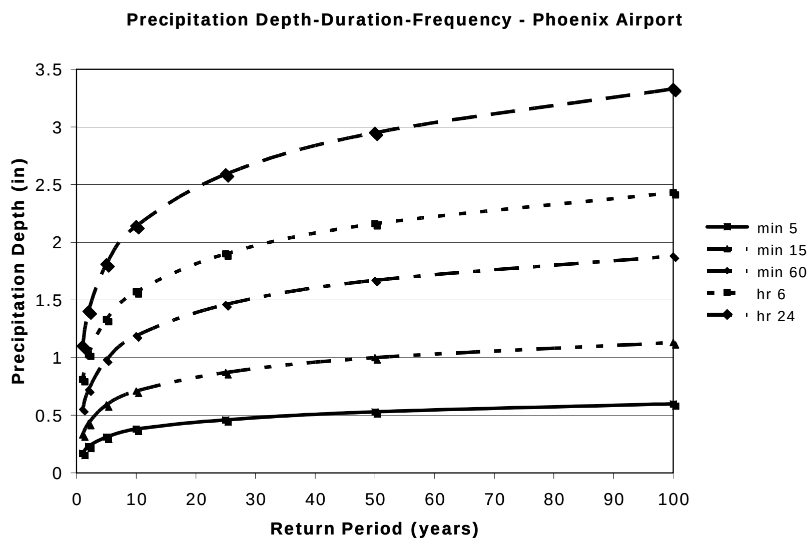


FIGURE 3-8 Depth-duration-frequency curves for Phoenix, Arizona. SOURCE: Data from the National Weather Service.

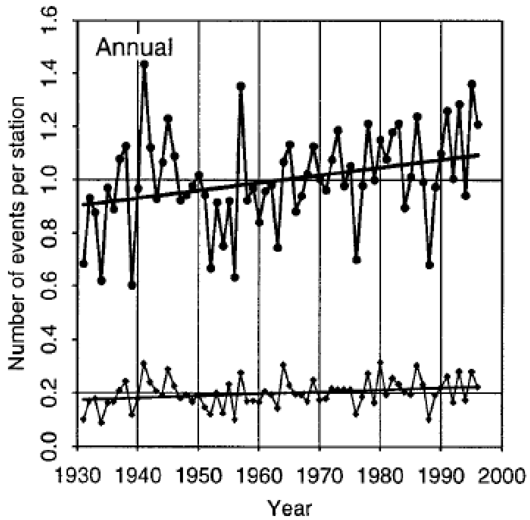


FIGURE 3-9 Nationally averaged annual U.S. time series of the number of precipitation events of 7-day duration exceeding 1-year (dots) and 5-year (diamonds) recurrence intervals. SOURCE: Reprinted, with permission, from Kunkel et al. (1999). Copyright 1999 by American Meteorological Society.

BOX 3-5
Climate Change and Stormwater Management

An ongoing report series issued by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research summarizes the evidence for climate change to date and expected impacts of climate change, including impacts on the water resources sector (*http://www.climatescience.gov/*). According to the Intergovernmental Panel on Climate Change (IPCC 2007), annual precipitation will likely increase in the northeastern United States and will likely decrease in the southwestern United States over the next 100 years. In the western United States, precipitation increases are projected during the winter, whereas decreases are projected for the summer. As temperatures warm, precipitation will increasingly fall as rain rather than snow, and snow season length and snow depth are very likely to decrease in most of the country. More extreme precipitation events are also projected, which, when coupled with an anticipated increase in rain-on-snow events, would contribute to more severe flooding due to increases in extreme stormwater runoff.

The predictions for increases in the intensity and frequency of extreme events have significant implications for future stormwater management. First, many of the design standards currently in use will need to be revised, since they are based on historical data. For example, depth-duration-frequency curves used for design storm data will need to be updated, because the magnitude of the design storms will change. Even with revised design standards, in light of future uncertainty, new SCMs will need to be designed conservatively to allow for additional storage that will be required for regions with predicted trends in increased precipitation. In addition, existing SCM designs based on old standards may prove to be undersized in the future. Implementation of a monitoring program to check existing SCM inflows against original design inflows may be prudent to aid in judging whether retrofit of existing facilities or additional stormwater infrastructure is needed.

Design Storms

Given that only daily precipitation records are widely available, but short-duration data are required for stormwater analysis and prediction, *design storms* have been developed for the different regions of the United States by different state and federal resource agencies. A *design storm* is a specified temporal pattern of rainfall at a location, created using an overall storm duration and frequency relevant to the design problem at hand. Examples of design storms include the 24-hour, 100-year event for flood control and the 24-hour, 2-year event for channel protection. The magnitude of the design storm can be derived from data at a single gauge, or from synthesized regional data published by state or federal agencies. The simplest form of a design storm is a triangular hyetograph where the base is the duration and the height is adjusted so that the area under the curve equals the total precipitation. In instances where the hyetograph is to be used to estimate sequences of shorter duration intensities (i.e., minutes to a few hours) within larger duration events, depth-duration-frequency curve data can be used to synthesize a design storm hyetograph (see Chow et al., 1988). An example design storm for the 100-year storm event for St. Louis based on NOAA Atlas 14 depth-duration-frequency data is shown in Figure 3-10.

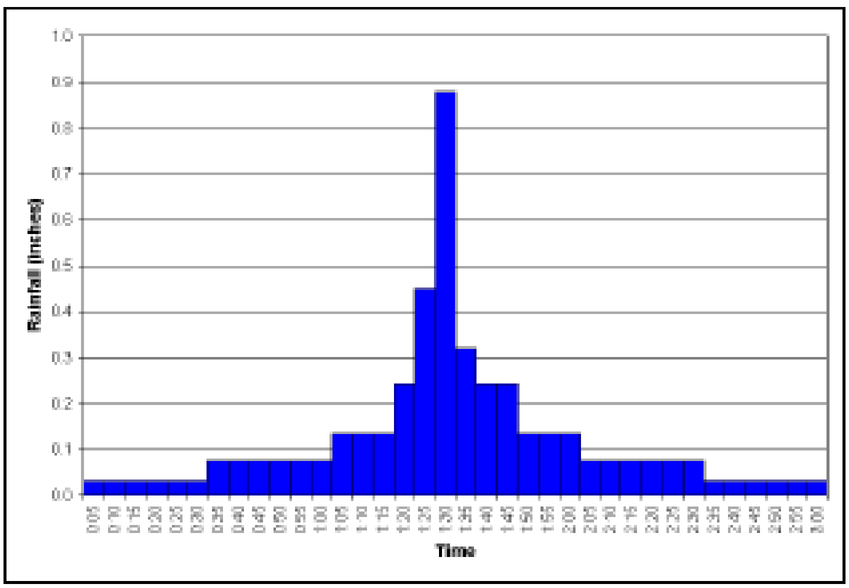


FIGURE 3-10 Hundred-year design storm for St. Louis based on NOAA Atlas 14 data. SOURCE: Hoblit et al. (2004) based on data from Bonnin et al. (2003).

Conversion of Precipitation to Runoff

Dynamics of Watershed Flowpaths

Precipitation falling on the land surface is subject to evaporative loss to the atmosphere by vegetation canopy and leaf litter interception, evaporation directly from standing water on the surface and upper soil layers or impervious surfaces, and later transpiration through root uptake by vascular plants. Snowpack is also subject to sublimation (conversion of snow or ice directly to vapor), which results in the loss of a portion of the snow prior to melt. The rate of evaporative loss depends on local weather conditions (temperature, humidity, wind speed, solar radiation) and the rate and duration of precipitation. Precipitation (or snowmelt) in excess of interception and potential evaporative loss rates is then partitioned into infiltration and direct runoff.[1]

There is a gradation of flowpaths transporting water, sediment, and solutes through a watershed, ranging from rapid surface flowpaths through generally slower subsurface flowpaths. Residence times generally increase from surface to subsurface flowpaths, with rapid surface flow providing the major contribution to flood flow while subsurface flowpaths contribute to longer-term patterns of surface wetness. Watershed characteristics that influence the relative dominance of surface versus subsurface flowpaths include infiltration capacity as affected by land cover, soil properties, and macropores; subsurface structure or soil horizons with varying conductivity; antecedent soil moisture and groundwater levels; and the precipitation duration and intensity for a particular storm.

The distribution and activity of flowpaths result in changing patterns of soil moisture and groundwater depth, which result in patterns of soil properties, vegetation, and microbial communities. These ecosystem patterns, in turn, can have strong influences on the hydraulics of flow and biogeochemical transformations within the flowpaths, with important implications for sources, sinks, and transport of solutes and sediment in the watershed. Riparian areas, wetlands, and the benthos of streams and waterbodies are nodes of interaction between surface and groundwater flowpaths, yielding reactive environments in which “hot spots” of biogeochemical transformation develop (McClain et al., 2003). Thus, any alteration of surface and subsurface hydrologic flowpaths, for

[1] The term *runoff* is often used in two senses. For a given precipitation event, direct *storm runoff* refers to the rainfall (minus losses) that is shed by the landscape to a receiving waterbody. In an area of 100 percent imperviousness, the runoff nearly equals the rainfall (especially for larger storms). Over greater time and space scales, *surface water runoff* refers to streamflow passing through the outlet of a catchment, including base flow from groundwater that has entered the stream channel. The raw units of runoff in either case are volume per time, but the volumetric flowrate (discharge) is often divided by contributing area to express runoff in units of depth per time. In this way, unit runoff rates from various-sized watersheds can be compared to account for differences other than the contributing area.

example due to urbanization, not only alters the properties of soil and vegetation canopy but also reforms the ecosystem distribution of biogeochemical transformations.

Runoff Measurements

Surface water runoff for a given area is measured by dividing the discharge at a given point in the stream channel by the contributing watershed area. The basic variables describing channel hydraulics include width, mean depth, slope, roughness, and velocity. Channel discharge is the product of width, depth, and velocity and is typically estimated by either directly measuring each of these three components, or by development of a rating curve of measured discharge as a function of water depth, or stage relative to a datum, of the channel that is more easily estimated by a staff gauge or pressure transducer. The establishment of a gauging station to measure discharge typically requires a stable cross section so that stage can be uniquely related to discharge. Maintenance of reliable, long-term gauge sites is expensive and requires periodic remeasurement to update rating curves, as well as to remove temporary obstructions that may raise stage relative to unobstructed conditions.

Most stream gauging in the United States is carried out by the USGS, and can be found on-line at *http://waterdata.usgs.gov/nwis*. Recent reviews of standard methods of stream gauging and the status of the USGS stream gauging network are given by the USGS (1998) and the National Research Council (NRC, 2004). A major concern is the overall decline in the number of active gauges, particularly long-term gauges, as well as the representativeness of the stream gauge network relative to the needs of stormwater permitting. For example, restored streams typically lack any gauged streamflow or water quality information prior to or following restoration. This makes it very difficult to assess both the potential for successful restoration and whether project goals are met.

Support of existing and development of new gauges is often in collaboration through a co-funding mechanism with other agencies. Municipal co-funding for stations in support of National Pollutant Discharge Elimination System (NPDES) permitting is common and has tended to shift the concentration of active gauges toward more urban areas. Note that the USGS river monitoring system was originally designed for resource inventory, and therefore did not originally sample many headwater streams, particularly intermittent and ephemeral channels that are typically most proximal to stormwater discharges. While this is beginning to change with municipal co-funding, headwater streams are still underrepresented in the National Water Information System relative to their ecological significance.

Reliable records for stream discharge are vital because the frequency distribution and temporal trends of flows must be known to evaluate long-term loading to waterbodies. Magnitude and frequency analysis of sediment and other stream constituent loads consists of a transport equation as a function of discharge, integrated over the discharge frequency distribution (e.g., Wolman and Miller, 1960). Different constituent loads have different forms of dependency on discharge, but are often nonlinear such that long-term or expected loads cannot be simply evaluated from mean flow conditions. Similar to precipitation, discharge levels often follow an Extreme Value distribution, dependent on climate, land use, and hydrogeology, but which is typically dampened compared to precipitation due to the memory effects of subsurface storage and flows (e.g., Winter, 2007).

Impacts of Urbanization on Runoff

Shift from Infiltration and Evapotranspiration to Surface Runoff

Replacement of vegetation with impervious or hardened surfaces affects the hydrologic budget—the quantity of water moving through each component of the hydrologic cycle—in a number of predictable ways. As the percent of the landscape that is paved over or compacted is increased, the land area available for infiltration of precipitation is reduced, and the amount of stormwater available for direct surface runoff becomes greater, leading to increased frequency and severity of flooding. Reduced infiltration of precipitation leads to reduced recharge of the groundwater reservoir; absent new sources of recharge, this can lead to reduction in base flow of streams (e.g., Simmons and Reynolds, 1982; Rose and Peters, 2001). Vegetation removal also results in a lower amount of evapotranspiration compared to undeveloped land. This can have particularly profound hydrologic effects in those regions of the country where a significant percent of precipitation is evapotranspirated, such as the arid Southwest (Ng and Miller, 1980). Figure 3-11 illustrates the changes to these components of the hydrologic budget as the percent of impervious area is increased.

It should be noted that the conversion in hydrology from infiltrated water to surface runoff following urbanization is not entirely straightforward in all cases. Leaking pressurized water supply pipes and sanitary sewers, subsurface discharge of septic system effluent (Burns et al., 2005), infiltration of stormwater from unlined detention ponds, and lawn irrigation can offset reduced infiltration of precipitation, such that stream baseflow levels may actually be increased, especially during low base flow months, when such effects would be most pronounced (Konrad and Booth, 2005; Meyer, 2005). Cracks in sealed surfaces can also provide concentrated points of infiltration (Sharp et al., 2006).

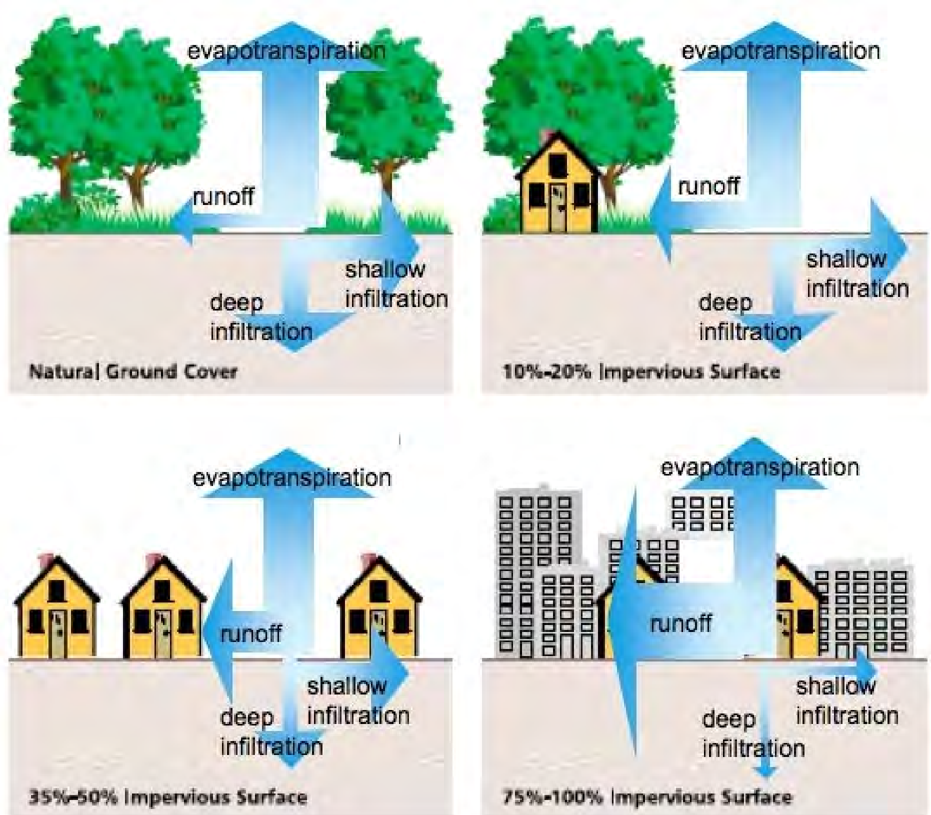


FIGURE 3-11 As land cover changes from vegetated and undeveloped (upper left) to developed with increased connected impervious surfaces (lower right), the partitioning of precipitation into other components of the hydrologic cycle is shifted. Evapotranspiration and shallow and deep infiltration are reduced, and surface runoff is increased. SOURCE: Adapted from the Federal Interagency Stream Restoration Working Group (FISRWG, 2000).

Relationship Between Imperviousness, Drainage Density, and Runoff

Excess runoff due to urbanization is a direct reflection of the land uses onto which the precipitation falls, as well as the presence of drainage systems that receive stormwater from many separate source areas before it enters receiving waters. Thus, a functional way of partitioning urban areas is by the nature of the impervious cover and by its connection to the drainage system, underlying the differentiation of total impervious area and effective impervious area discussed in Box 1-2.

As examples of how runoff changes with urbanization, Figure 3-12 shows daily stream flow values for a low-density suburban catchment and a high-density urban catchment in the Baltimore, Maryland area. The low-density site (Figure 3-12A) shows a strong seasonal signal and a marked decline in flow during an extreme drought in 2002. In contrast, the more densely urbanized catchment (Figure 3-12B) shows a much greater variability in flow that is dominated by impervious surface runoff, and a dampened response to the drought because natural groundwater flow is a much smaller component of the total discharge.

The percentage of time a discharge level is equaled or exceeded is displayed by flow duration curves, which show the cumulative frequency distributions of flows for a given duration. Examples for three catchments in the Baltimore area are given in Figure 3-13, showing the tendency for urban areas to produce high flows with much longer aggregate durations.

As another example of how runoff changes with imperviousness, a locally calibrated version of WinSLAMM was used to investigate the relationships between watershed and runoff characteristics for 125 individual neighborhoods in

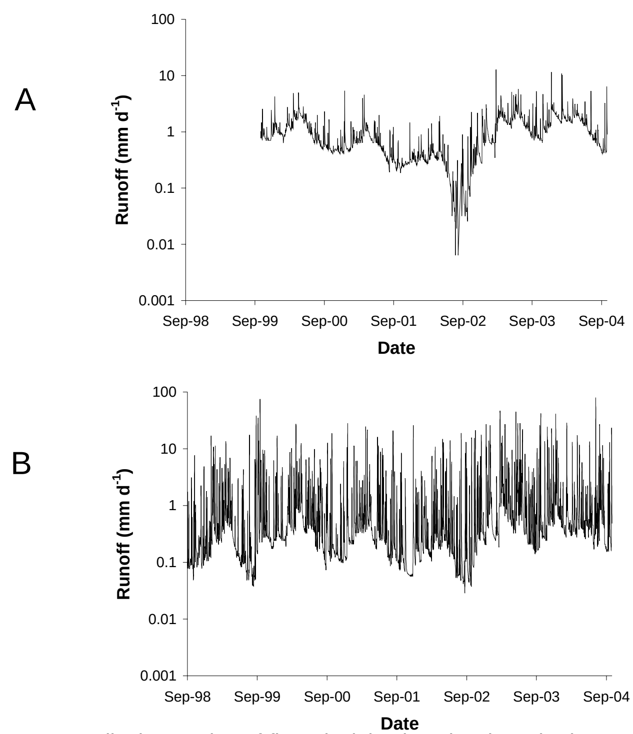


FIGURE 3-12 Daily time series of flows in (A) a low-density suburban and forested catchment (Baisman Run, *http://waterdata.usgs.gov/md/nwis/uv/?site_no=01583580*) and (B) a catchment dominated by medium- to high-density residential and commercial land uses (Dead Run, *http://waterdata.usgs.gov/md/nwis/uv/?site_no=01589330*). Both lie within the Piedmont physiographic province.

Urban Stormwater Management in the United States
http://www.nap.edu/catalog/12465.html

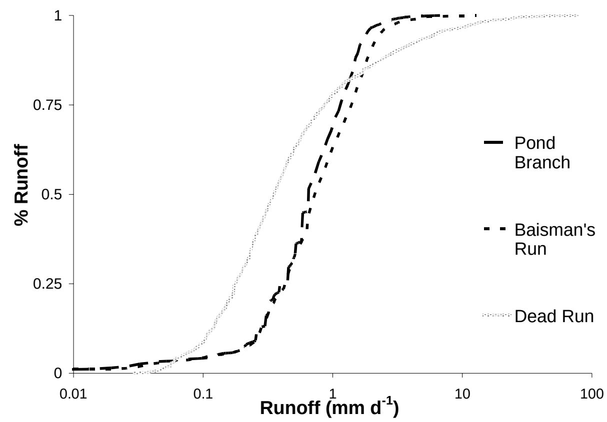
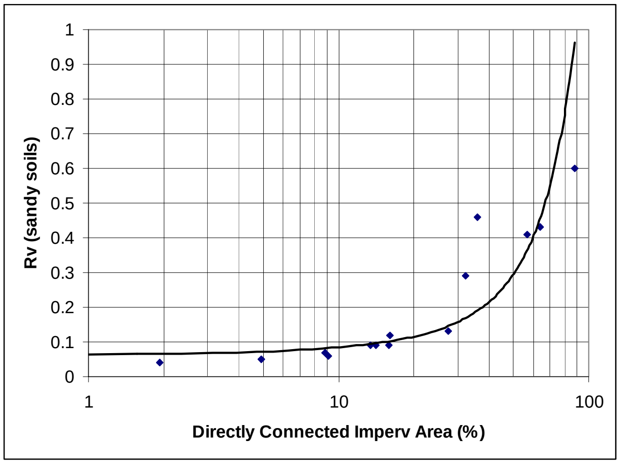


FIGURE 3-13 Flow duration curves for three watersheds with distinct land use in the Baltimore, Maryland area. Pond branch is a forested reference site, Baisman's Run is exurban, and Dead Run is urban. Urban areas have flashier runoff with greater frequency of low and high extreme flows.

Jefferson County, Alabama (Bochis-Micu and Pitt, 2005). Figure 3-14 shows the relationships between the directly connected impervious area values and the calculated volumetric runoff coefficient (R_v, which is the volumetric fraction of the rainfall that occurs as runoff), based on 43 years of local rain data. As expected, there is a strong relationship between these parameters for both sandy and clayey soil conditions. It is interesting to note that the R_v values are relatively constant until values of directly connected impervious cover of 10 to 15 percent are reached (at R_v values of about 0.07 for sandy soil areas and 0.16 for clayey soil areas)—the point where receiving water degradation typically has been observed to start (as discussed later in the chapter). The 25 to 30 percent directly connected impervious levels (where significant degradation is usually observed) is associated with R_v values of about 0.14 for sandy soil areas and 0.25 for clayey soil areas; this is where the curves start to greatly increase in slope.

Relationship Between Runoff and Rainfall Conditions

The runoff that results from various land uses also varies depending on rainfall conditions. For small rain depths, almost all the runoff originates solely from directly connected impervious areas, as disconnected areas have most of their flows infiltrated (Pitt, 1987). For larger storms, both directly connected



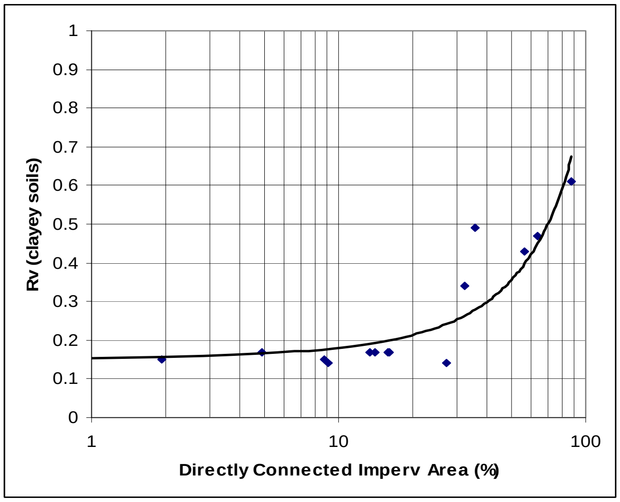


FIGURE 3-14 Relationships between the directly connected impervious area (%) and the calculated volumetric runoff coefficients (R_v) for sandy soil (top) and clayey soil (bottom). SOURCE: Reprinted, with permission, from Bochis-Micu and Pitt (2005). Copyright 2005 by Water Environment Federation, Alexandria, Virginia.

and disconnected impervious areas contribute runoff to the stormwater management system. For example, Figure 3-15 (created using WinSLAMM; Pitt and Voorhees, 1995) shows the relative runoff contributions for a large commercial/mall area in Hoover, Alabama, for different rains (Bochis, 2007). In this example, about 80 percent of the runoff originates from the parking areas for the smallest runoff-producing rains. This contribution decreases to about 55 percent at rain depths of about 0.5 inch (13 mm). This decrease in the importance of parking areas as a source of runoff volume is associated with an increase in runoff contributions from streets and directly connected roofs. In many areas, pervious areas are not hydrologically active until the rain depths are relatively large and are not significant runoff contributors until the rainfall exceeds about 25 mm for many land uses and soil conditions. However, compacted urban soils can greatly increase the flow contributions from pervious areas during smaller rains. Burges and others (1998), for example, found that more than 60 percent of the storm runoff in a suburban development in western Washington State originated from nominally "green" parts of the landscape, primarily lawns.

A further example illustrating the relationship between rainfall and runoff is given for Milwaukee, summarized in Box 3-6. The two curves of Figure 3-16 show a relationship between rainfall and runoff that is typical of urban areas. Very small storms (< 0.05 inch) produce no measurable runoff, owing to removal by interception storage and evaporation. Storms that deposit up to one inch of rainfall constitute about 90 percent of the storm events in this region, but these events produced only about 50 percent of the runoff. Very large events (greater than 3 inches of precipitation) are rare and destructive, accounting for only a few percent of the annual rainfall events.

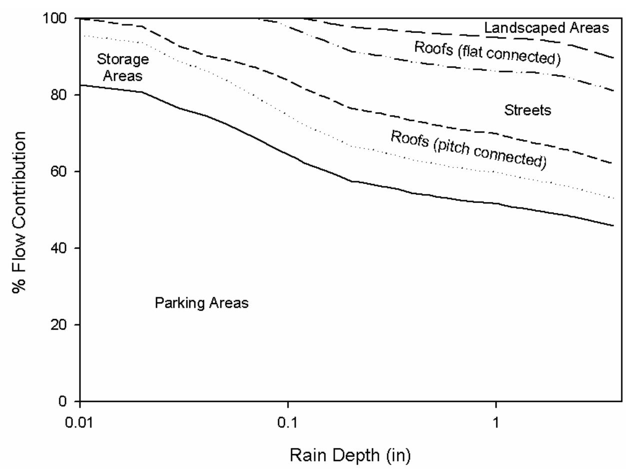


FIGURE 3-15 Surfaces contributing to runoff for a commercial/mall area. SOURCE: Reprinted, with permission, from Bochis (2007). Copyright 2007 by Celina Bochis.

BOX 3-6
Example Rainfall and Runoff Distributions

Figure 3-16 is an example of rainfall and runoff observed at Milwaukee, Wisconsin (Bannerman et al., 1983), as monitored during the Nationwide Urban Runoff Program (NURP) (EPA, 1983). This observed distribution is interesting because of the unusually large rains that occurred twice during the monitoring program. These two major rains would be in the category of design storms for conventional drainage systems. These plots indicate that these very large events, in the year they occurred, caused a measureable fraction of the annual pollutant loads and runoff volume discharges, but smaller events were responsible for the vast majority of the discharges. In typical years, when these rare design events do not occur, their pro-rated contributions would be even smaller.

More than half of the runoff from this typical medium-density residential area was associated with rain events that were smaller than 0.75 inch. Two large storms (about 3 and 5 inches in depth), which are included in the figure, distort this figure because, on average, the Milwaukee area only expects one 3.5-inch storm about every five years, and 5-inch storms even less frequently. If these large rains did not occur, such as for most years, then the significance of the smaller rains would be even greater. The figure also shows the accumulated mass discharges of different pollutants (suspended solids, chemical oxygen demand [COD], phosphates, and lead) monitored during the Milwaukee NURP project. When these figures are compared, it is seen that the runoff and pollutant mass discharge distributions are very similar and that variations in the runoff volume are much more important than variations in pollutant concentrations (the mass divided by the runoff volume) for determining pollutant mass discharges.

These rainfall and runoff distributions for Milwaukee can thus be divided into four regions:

- **Less than 0.5 inch.** These rains account for most of the events, but little of the runoff volume, and they are therefore easiest to control. They produce much less pollutant mass discharge and probably have less receiving water effects than other rains. However, the runoff pollutant concentrations likely exceed regulatory standards for several categories of critical pollutants (bacteria and some total recoverable heavy metals). They also cause large numbers of overflow events in uncontrolled combined sewers. These rains are very common, occurring once or twice a week (accounting for about 60 percent of the total rainfall events and about 45 percent of the total runoff-generating events), but they only account for about 20 percent of the

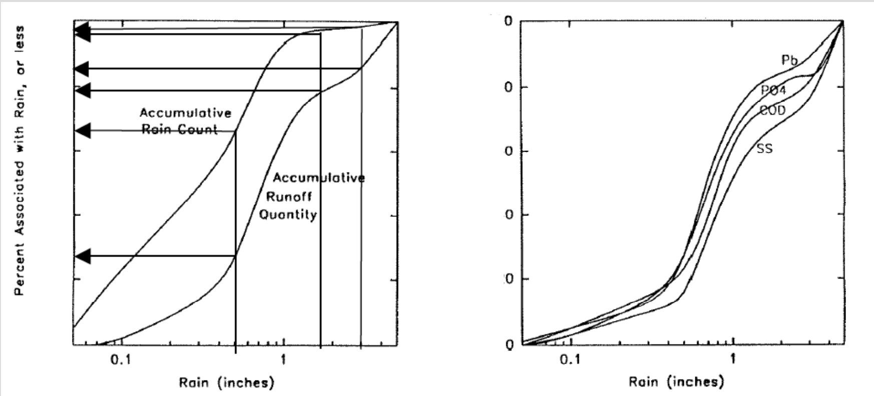


FIGURE 3-16 Milwaukee rainfall and runoff probability distributions, and pollutant mass discharge probability distributions (1981 to 1983). Rain count refers to the number of rain events. SOURCE: Data from Bannerman et al. (1983).

continues next page

BOX 3-6 Continued

annual runoff and pollutant discharges. Rains less than about 0.05 inch did not produce noticeable runoff.

• **0.5 to 1.5 inches**. These rains account for the majority of the runoff volume (about 50 percent of the annual volume for this Milwaukee example) and produce moderate to high flows. They account for about 35 percent of the annual rain events, and about 20 percent of the annual runoff events, by number. These rains occur on average about every two weeks from spring to fall and subject the receiving waters to frequent high pollutant loads and moderate to high flows.

• **1.5 to 3 inches**. These rains produce the most damaging flows from a habitat destruction standpoint and occur every several months (at least once or twice a year). These recurring high flows, which were historically associated with much less frequent rains, establish the energy gradient of the stream and cause unstable streambanks. Only about 2 percent of the rains are in this category, but they are responsible for about 10 percent of the annual runoff and pollutant discharges.

• Greater than **3 inches.** The rains in this category are included in design storms used for traditional drainage systems in Milwaukee, depending on the times of concentration and rain intensities. These rains occur only rarely (once every several years to once every several decades, or less frequently) and produce extremely large flows that greatly exceed the capacities of the storm drainage systems, causing extensive flooding. The monitoring period during the Milwaukee NURP was unusual in that two of these events occurred. Less than 2 percent of the rains were in this category (typically <<1 percent would be in this category), and they produced about 15 percent of the annual runoff quantity and pollutant discharges. However, when they do occur, substantial property and receiving water damage results (mostly associated with habitat destruction, sediment scouring, and the flushing of organisms great distances downstream and out of the system). The receiving water can conceivably recover naturally to pre-storm conditions within a few years. These storms, while very destructive, are sufficiently rare that the resulting environmental problems do not justify the massive controls that would be necessary to decrease their environmental effects.

Alteration of the Drainage Network

As shown in Figure 3-17, urbanization disrupts natural systems in ways that further complicate the hydrologic budget, beyond the imperviousness effects on runoff discussed earlier. As an area is urbanized, lower-order stream channels are typically re-routed or encased in pipes and paved over, resulting in a highly altered drainage pattern. The buried stream system is augmented by an extensive system of storm drains and pipes, providing enhanced drainage density (total lengths of pipes and channels divided by drainage area) compared to the natural system. Figure 3-18 shows how the drainage density of Baltimore today compares to the natural watershed before the modern stormwater system was fully developed. The artificial drainage system occupies a greater percentage of the landscape compared to natural conditions, permanently altering the terrestrial component of the hydrologic cycle.

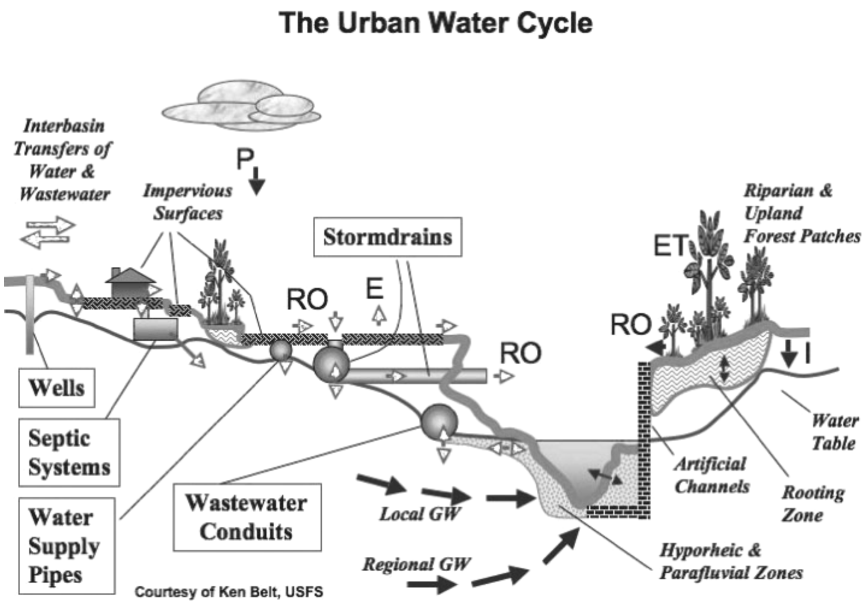
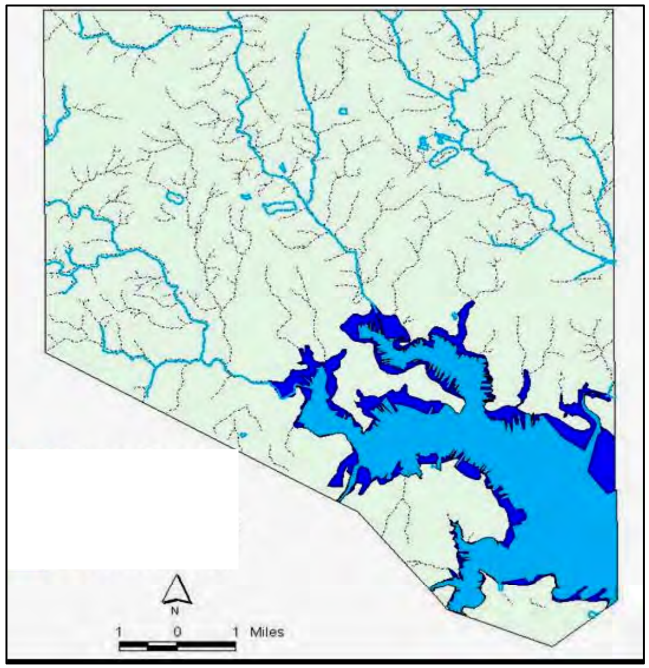


FIGURE 3-17 Alteration of the natural hydrologic cycle by the presence of piped systems. Black arrows represent the natural system; outlined arrows indicate short-circuiting due to piped systems. Note that several elements of the water cycle shown in this diagram are not considered in this report, such as septic systems, interbasin transfers of water and wastewater, and the influence of groundwater withdrawals. SOURCE: Courtesy of Kenneth Belt, USDA Forest Service, Baltimore, Maryland.

Flowpaths are altered in other ways by urban infrastructure. Buried stormwater and sewer pipes can act as infiltration galleries for groundwater, causing shortened groundwater flowpaths between groundwater reservoirs and stream systems. Natural surface water pathways are often interrupted or reversed, as shown by the blue lines in Figure 3-19 for a drainage system in Baltimore. Understanding how the system operates as a whole can often require knowledge of the history of construction conditions and field verification of the actual flow paths.

Large-scale infrastructure such as dams, ponds, and bridges can also have a major impact on stormwater flows. Figure 3-20 illustrates the interruption of the drainage network by bridges and culverts, even in places where there have been attempts to keep excessive development out of the riparian corridor. Simulations and post-flood mapping in areas around Baltimore have shown that bridge abutments such as those shown in Figure 3-20 can slow down channel floodwaters during storms. This is because water backs up behind bridges constructed



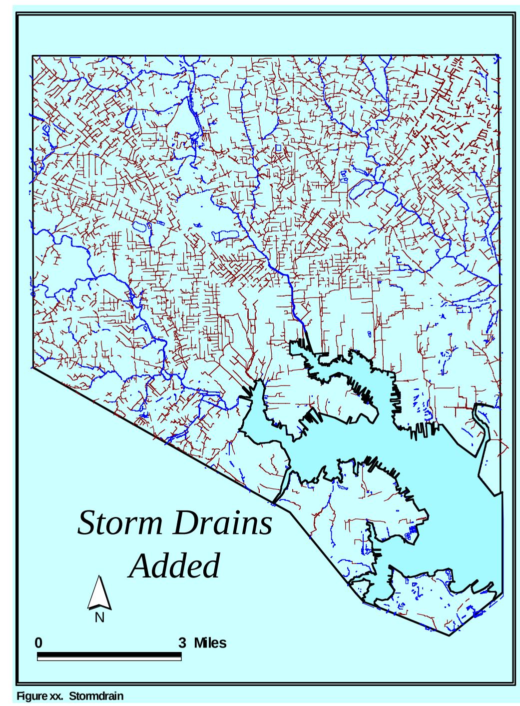


FIGURE 3-18 Baltimore City before and after development of its stormwater system. The left-hand panel shows first- and second-order streams lost to development. The right-hand panel shows the increase in drainage density resulting from construction of the modern storm-drain network. SOURCE: Courtesy of William Stack, Baltimore Department of Public Works.

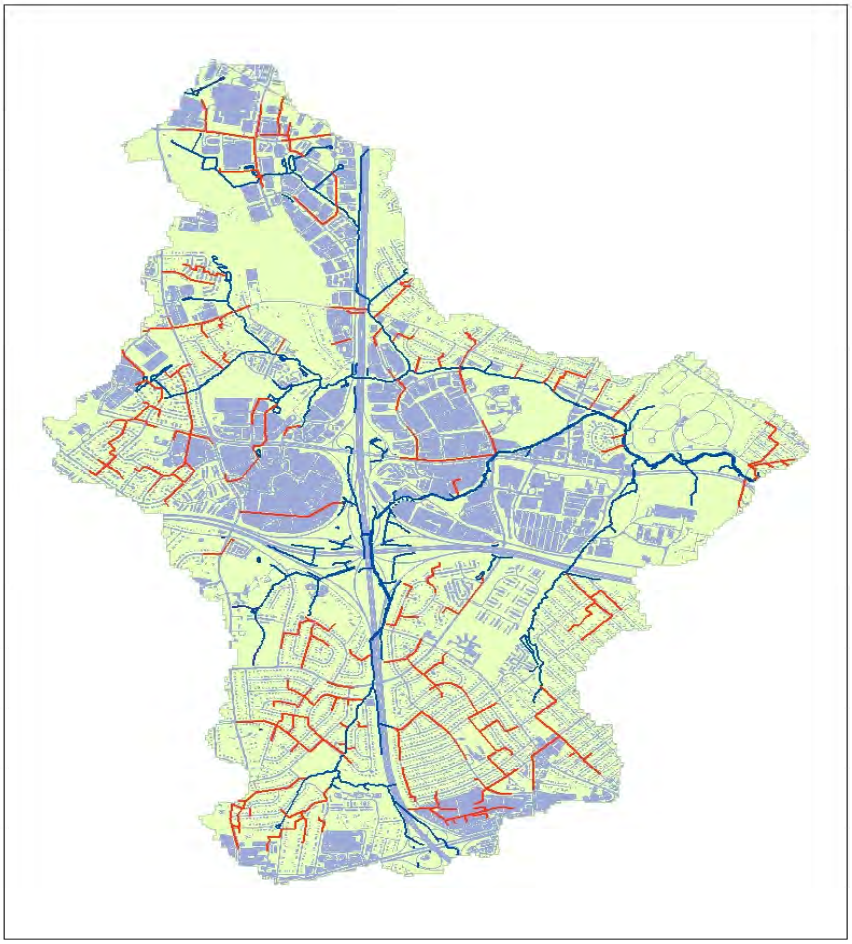


FIGURE 3-19 Dead Run drainage system, Baltimore, Maryland. Black lines indicate surface (daylighted) drainage; dark grey indicates the subsurface storm-drain system. The surface drainage system is highly disconnected. From the coverage it is difficult to impossible to discern the flow direction of some of the surface drainage components. SOURCE: Reprinted, with permission, from Meierdierks et al. (2004). Copyright 2004 by the American Geophysical Union.

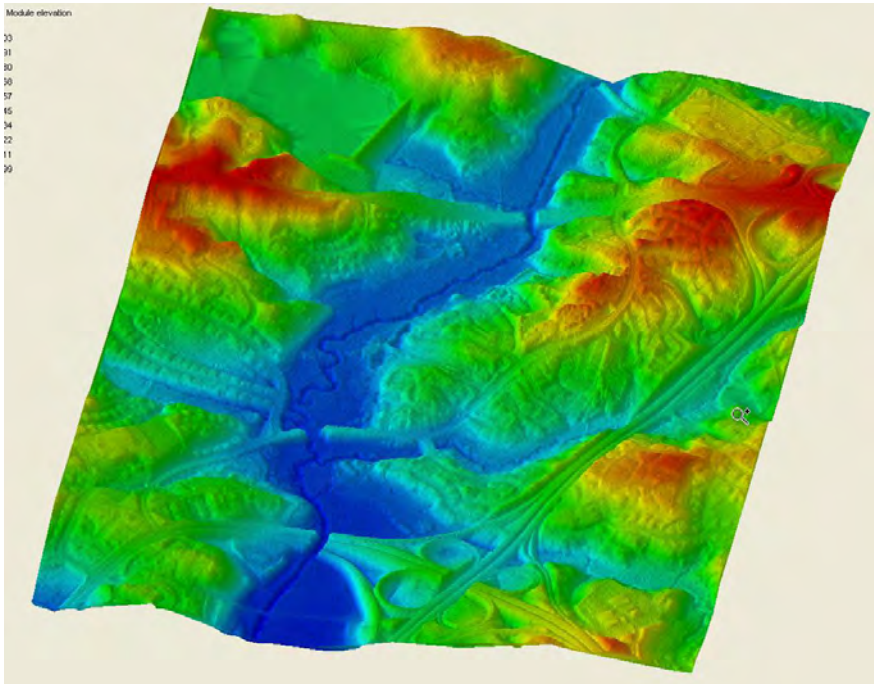


FIGURE 3-20 Shaded-relief lidar image of a portion of the Middle Patuxent River valley in Howard County, Maryland, showing the pervasive interruption of the drainage network by bridges and culverts, even in places where there is an attempt to keep excessive development out of the riparian corridor. SOURCE: Reprinted, with permission, from Miller, University of Maryland, Baltimore County. Copyright 2006 by Andrew J. Miller.

across the floodplain and spreads out over land surfaces and then flows back into channels as floodwaters subside. Although reducing the severity of downstream flooding, this phenomenon also interrupts the transport of sediment, leading to local zones of both enhanced deposition and downstream scour.

Alteration of Travel Times

The combination of impervious surface and altered drainage density provides significantly more rapid hydraulic pathways for stormwater to enter the nearest receiving waterbody compared to a natural landscape. This is illustrated quantitatively by Figure 3-21, which shows that the lag time—the difference in time between the center of mass of precipitation and the center of mass of the storm response hydrograph—is reduced for an urbanized landscape compared to a natural one.

The increase in surface runoff volumes and reduction in lag times between

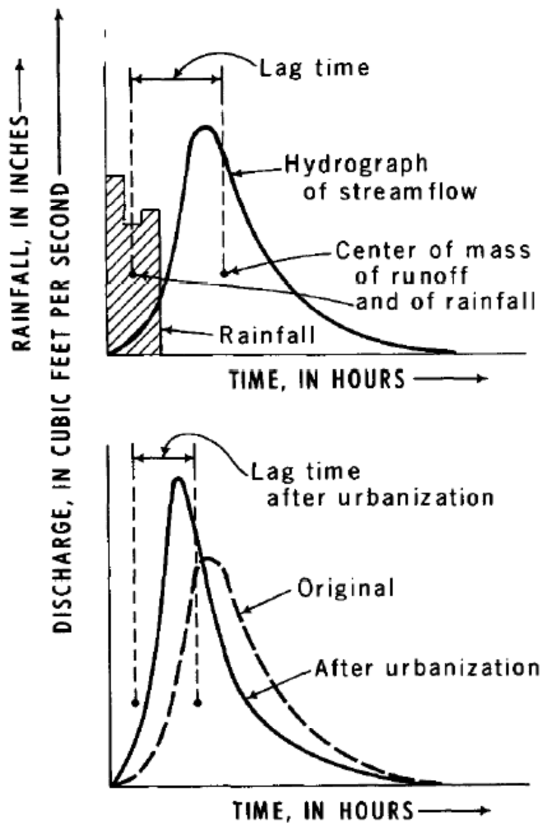


FIGURE 3-21 Illustration of the effect of urbanization on storm hydrograph lag time, the difference in time between the center of mass of rainfall and runoff response before and after urbanization. SOURCE: Leopold (1968).

precipitation and a waterbody's response give rise to greater velocities and volumetric discharges in receiving waters. Storm hydrographs in a developed setting peak earlier and higher than they do in undeveloped landscapes. This altered flow regime is of concern to property owners because upstream development can increase the probability of a flood-prone property being inundated. Properties in the floodplain and near stream channels are particularly susceptible to flooding from upstream development. Such increased flood risk is accompanied by associated potential property damages and costs of replacement or repair.

Various descriptors can be used to quantify the effects of urbanization on streamflow including flood frequency, flow duration, mean annual flood, discharge at bankfull stage, and frequency of bankfull stage. The "classic" view of urban-induced changes to runoff was presented by Leopold (1968), who provided several quantitative descriptors of the effects of urbanization on the mean annual flood. For example, Figure 3-22 shows the ratio of discharge before and after urbanization for the mean annual flood for a 1-square-mile area as a function of percentage of impervious area and percentage area served by a storm-drain system. This shows that for unsewered areas, increases from 0 to 100 percent impervious area will increase the peak discharge by a factor of 2.5. However, for 100 percent sewered areas, the ratio of peak discharges ranges from 1.7 to 8 for 0 to 100 percent impervious area. Clearly both impervious surfaces and the presence of a storm-drain system combine to increase discharge rates in receiving waters. Combining this information with regional flood frequency data, a discharge–frequency relationship can be developed that shows the expected discharge and recurrence interval for varying degrees of storm-drain coverage and impervious area coverage. An example is shown in Figure 3-23, using data from the Brandywine Creek watershed in Pennsylvania (Leopold, 1968). Bankfull flow for undeveloped conditions in general has a recurrence interval of about 1.5 years (which, in the particular case of the Brandywine, was 67 cubic feet per second); with 40 percent of the watershed area paved, this discharge would occur about three times as often.

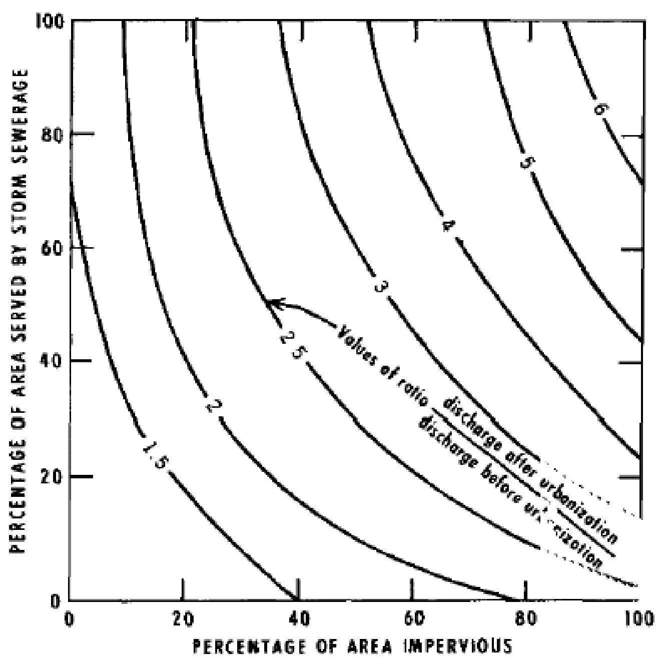


FIGURE 3-22 Ratio of peak discharge after urbanization to peak discharge before urbanization for the mean annual flood for a 1-square-mile drainage area, as a function of percent impervious surface and percent area drained by storm sewers. SOURCE: Leopold (1968).

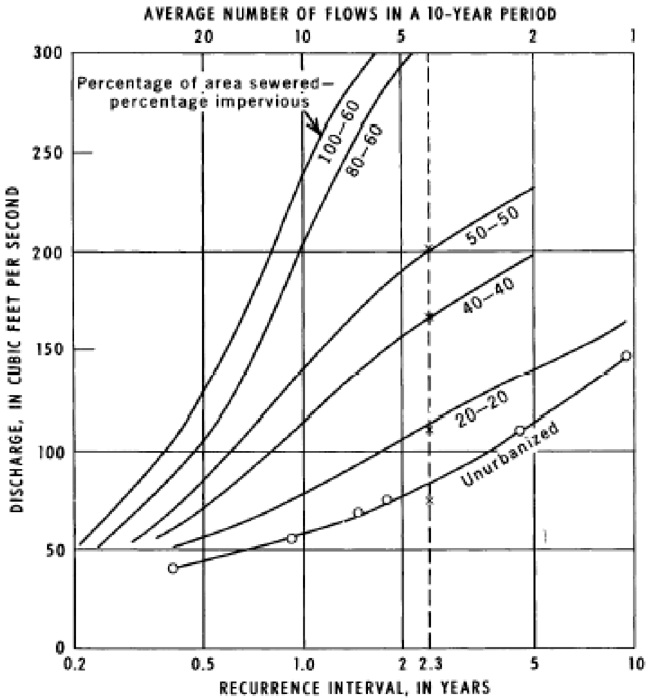


FIGURE 3-23 Flood frequency curves as a function of percent impervious area and percent of area serviced by storm sewers. The unurbanized data are from Brandywine Creek, Pennsylvania. SOURCE: Leopold (1968).

Over the past four decades since this first quantitative characterization of urban hydrology, a much greater variety of hydrologic changes resulting from urbanization has been recognized. Increases in peak discharge are certainly among those changes, and they will always gather attention because of their direct impact on human infrastructure and potential for more frequent and more severe flooding. The extended duration of flood flows, however, also affects natural channels because of the potential increase in erosion. Ecological effects of urban-altered flow regimes are even more diverse, because changes in the sequence and frequency of high flows, the rate of rise and fall of the hydrograph, and even the season of the year in which high flows can occur all have significant ecological effects and can be dramatically altered by watershed urbanization (e.g., Rose and Peters, 2001; Konrad et al., 2005; Roy et al., 2005; Poff et al., 2006).

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The overarching conclusion of many studies is that the impact of urbanization on the hydrologic cycle is dramatic. Increased impervious area and drainage connectedness decreases stormwater travel times, increases flow rates and volumes, and increases the erosive potential of streams. The flooding caused by increased flows can be life-threatening and damaging to property. As described below, changes to the hydrologic flow regime also can have deleterious effects on the geomorphic form of stream channels and the stability of aquatic ecosystems. Although these impacts are commonly ignored in efforts to improve "water quality," they are inextricably linked to measured changes in water chemistry and must be part of any attempt to recover beneficial uses that have been lost to upstream urbanization.

Geomorphology

Watershed geomorphology is determined by the arrangement, interactions, and characteristics of component landforms, which include the stream-channel network, the interlocking network of ridges and drainage divides, and the set of hillslopes between the channel (or floodplain) and ridge. The stream and ridge systems define complementary networks, with the ridge (or drainage divide) network separating the drainage areas contributing to each reach in the stream network. At the hillslope scale, the ridges provide upper boundaries of all surface flowpaths which converge into the complementary stream reaches. A rich literature describes the topology and geometry of stream and ridge networks (e.g., Horton, 1945; Strahler, 1957, 1964; Shreve, 1966, 1967, 1969; Smart, 1968; Abrahams, 1984; Rodriguez-Iturbe et al., 1992).

Besides stream channels, a variety of other water features and landforms make up a watershed. Fresh waterbodies (ponds, lakes, and reservoirs) are typically embedded within the stream network, while wetlands may be either embedded within the stream network or separated and upslope from the channels. Estuaries represent the interface of the stream network with the open ocean. Additional fluvial and colluvial landforms include alluvial fans, landslide features, and a set of smaller features within or near the channels and floodplains including bar deposits, levees, and terraces. Each of these landforms are developed and maintained by the fluvial and gravitational transport and deposition of sediment, and are therefore potentially sensitive to disruption or alteration of flowpaths, hydrologic flow regimes, and sediment supply.

Stream Network Form and Ordering Methods

Most watersheds are fully convergent, with tributary streams combining to form progressively larger channels downstream. The manner is which streams from different source areas join to produce mainstreams strongly influences the propagation of stormwater discharge and pollutant concentrations, and the consequent level of ecological impairment in the aquatic ecosystem.

Methods for indexing the topologic position of individual reaches within the drainage network have been introduced by Horton (1945), Strahler (1957), Shreve (1966, 1967) and others. All stream topologic systems are dependent on the identification of first-order streams—the most upstream element of the network—and their lengths and drainage areas. Unfortunately, no universal standards exist to define where the stream head is located, or whether perennial, intermittent, and ephemeral channels should be considered in this determination. While this may seem like a trivial process, the identification and delineation of these sources effectively determines what lengths and sections of channels are defined to be *waterbodies* and, thus, the classification of all downstream waterbodies.

Nadeau and Rains (2007) have recently reviewed stream-channel delineation in the United States using standardized maps and hydrographic datasets to better relate climate to the extent of perennial, intermittent, and ephemeral channel types. Because this may influence the set of stream channels that are regulated by the Clean Water Act (CWA), it is the subject of current legal arguments in courts up to and including the Supreme Court (e.g., *Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers*, 531 U.S. 159 [2001], *John A. Rapanos et al. vs. United States* [U.S., No. 04-1034, 2005]). In addition to the stream-channel network, additional features (discussed below) that are embedded in or isolated from the delineated stream network (lakes, ponds, and wetlands) are subject to regulation under the CWA based on their proximity or interaction with the defined stream and river network. Therefore, definition of the extent and degree of connectivity of the nation's stream network, with an emphasis on the headwater region, is a critical determinant of the set of waterbodies that are regulated for stormwater permitting (Nadeau and Rains, 2007).

Stream Reach Geomorphology

Within the channel network, stream reaches typically follow a regular pattern of changes in downstream channel form. Hydraulic geometry equations, first introduced by Leopold and Maddock (1953), describe the gross geomorphic adjustment of the channel (in terms of average channel depth and width) to the flow regime and sometimes the sediment supply. Within this general pattern of larger flows producing larger channels, variations in channel form are evident, particularly the continuum among straight, meandering, or braided patterns. These forms are dependent on the spatial and temporal patterns of discharge, sediment supply, transport capacity, and roughness elements.

Most natural channels have high width-to-depth ratios and complexity of channel form compared with engineered channels. Meanders are ubiquitous self-forming features in channels, created as accelerated flow around the outside of the meander entrains and transports more sediment, producing greater flow depths and eroding the bank, while decelerated flow on the inside of the meander results in deposition and the formation of lower water depth and bank gradients. These channels typically show small-scale alternation between larger cross sections with lower velocities and defining pools, and smaller cross sections with higher velocity flow in riffles. Braided streams form repeated subdivision and reconvergence of the channel in multiple threads, with reduced specific discharge compared to a single channel. Natural obstructions including woody debris, boulders, and other large (relative to channel dimensions) features all contribute to hydraulic and habitat heterogeneity. The complexity of these channel patterns contributes to hydraulic roughness, further dissipating stream energy by increasing the effective wetted perimeter of the channel through a valley and deflecting flow between banks.

Embedded Standing Waterbodies

Standing waterbodies include natural, constructed, or modified ponds and lakes and are characterized by low or near-zero lateral velocity. They can be thought of as extensions of pools within the drainage network, although there is no clear threshold at which a pool can be defined as a pond or lake. When they are embedded within the channel network, they are characterized with much greater cross-sectional area (width x depth), lower surface water slopes (approaching flat), and lower velocities than a stream reach of similar length. Therefore, standing waterbodies function as depositional zones, have higher residence times, and provide significant storage of water, sediment, nutrients, and other pollutants within the stream network.

Riparian Zone

The riparian area is a transitional zone between the active channel and the uplands, and between surface water and groundwater. The area typically has shallower groundwater levels and higher soil moisture than the surrounding uplands, and it may support wetlands or other vegetation communities that require higher soil moisture. Riparian zones provide important ecosystem functions and services, such as reducing peak flood flows, transforming bioavailable nutrients into organic matter, and providing critical habitat.

In humid landscapes, a functioning riparian area commonly is an area where shallow groundwater forms discharge seeps, either directly to the surface and then to the stream channel or through subsurface flowpaths to the stream channel. The potential for high moisture and organic material content provides an environment conducive to anaerobic microbial activity, which can provide effective sinks for inorganic nitrogen by denitrification, reducing nitrate loading to the stream channel. However, the width of the effective riparian zone depends on local topographic gradients, hydrogeology, and the channel geomorphology (Lowrance et al., 1997). In steeply incised channels and valleys, or areas with deeper flowpaths, the riparian zone may be narrow and relatively well drained.

Under more arid conditions with lower groundwater levels, riparian areas may be the only areas within the watershed with sufficient moisture levels to support significant vegetation canopy cover, even though saturation conditions may occur only infrequently. Subsurface flowpaths may be oriented most commonly from the channel to the bed and banks, forming the major source of recharge to this zone from periodic flooding. In monsoonal climates in the U.S. southwest, runoff generated in mountainous areas or from storm activity may recharge riparian aquifers well downstream from the storm or snowmelt activity. Channelization that reduces this channel-to-riparian recharge may significantly impair riparian and floodplain ecosystems that provide critical habitat and other ecosystem services (NRC, 2002).

Floodplains

The presence and distribution of alluvial depositional zones, including floodplains, is dependent on the distribution and balance of upstream sediment sources and sediment transport capacity, the temporal and spatial variability of discharge, and any geological structural controls on valley gradient. Lateral migration of streams contributes to the development of floodplains as the outer bank of the migrating channel erodes sediment and deposition occurs on the opposite bank. This leads to channels that are closely coupled to their floodplains, with frequent overbank flow and deposition, backwater deposits, wetlands, abandoned channels, and other floodplain features. During major events, overbank flooding and deposition adds sediment, nutrients, and contaminants to the floodplain surface, and may significantly rework preexisting deposits and drainage patterns. Constructional landforms typical of urbanized watersheds, such as levees, tend to disconnect streams from their floodplains.

Changes in Geomorphology from Urbanization

Changes to channel morphology are among the most common and readily visible effects of urban development on natural stream systems (Booth and Henshaw, 2001). The actions of deforestation, channelization, and paving of the uplands can produce tremendous changes in the delivery of water and sediment into the channel network. In channel reaches that are alluvial, the responses are commonly rapid and often dramatic. Channels widen and deepen, and in some cases may incise many meters below the original level of their beds. Alternatively, channels may fill with sediment derived from farther upstream to produce a braided form where a single-thread channel previously existed.

The clearest single determinant of urban channel change is the alteration of the hydrologic response of an urban watershed, notably the increase in streamflow discharges. Increases in runoff mobilize sediment both on the land surface and within the stream channel. Because transport capacity increases nonlinearly with flow velocity (Vogel et al., 2003), much greater transport will occur in higher flow events. However, the low frequency of these events may result in decreasing cumulative sediment transport during the highest flows, as described by standard magnitude and frequency analysis (Wolman and Miller, 1960), such that the maximum time-integrated sediment transport occurs at moderate flows (e.g., bankfull stage in streams in the eastern United States).

If the increase in sediment transport caused by the shift in the runoff regime is not matched by the sediment supply, channel bed entrenchment and bank erosion and collapse lead to a deeper, wider channel form. Increases in channel dimensions caused by increased discharges have been observed in numerous studies, including Hammer (1972), Hollis and Luckett (1976), Morisawa and LaFlure (1982), Neller (1988), Whitlow and Gregory (1989), Moscrip and Montgomery (1997), and Booth and Jackson (1997). MacRae (1997), reporting on other studies, found that channel cross-sectional areas began to enlarge after about 20 to 25 percent of the watershed was developed, commonly corresponding to about 5 percent impervious cover. When the watersheds were completely developed, the channel enlargements were about 5 to 7 times the original cross-sectional areas. Channel widening can occur for several decades before a new equilibrium is established between the new cross-section and the new discharges.

Construction results in a large—but normally temporary—increase in sediment load to aquatic systems (e.g., Wolman and Schick, 1967). Indeed, erosion and sediment transport rates can reach up to more than 200 Mg/ha/yr on construction sites, which is well in excess of typical rates from agricultural land (e.g., Wolman and Schick, 1967; Dunne and Leopold, 1978); rates from undisturbed and well-vegetated catchments are negligible (e.g., <<1 Mg/ha/yr). The increased sediment loads from construction exert an opposing tendency to channel erosion and probably explain much of the channel narrowing or shallowing that is sometimes reported (e.g., Leopold, 1973; Nanson and Young, 1981; Ebisemiju, 1989; Odemerho, 1992).

Additional sediment is commonly introduced into the channel network by the erosion of the streambank and bed itself. Indeed, this source can become the largest single fraction of the sediment load in an urbanizing watershed (Trimble, 1997). For example, Nelson and Booth (2002) reported on sediment sources in the Issaquah Creek watershed, an urbanizing, mixed-use watershed in the Pacific Northwest. Human activity in the watershed, particularly urban development, has caused an increase of nearly 50 percent in the annual sediment yield, now estimated to be 44 tons/km^2/yr^1. The main sources of sediment in the watershed are landslides (50 percent), channel-bank erosion (20 percent), and stormwater discharges (15 percent).

The higher flow volumes and peak discharge caused by urbanization also tend to preferentially remove fine-grained sediment, leaving a lag of coarser bed material (armoring) or removing alluvial material entirely and eroding into the geologic substrate (Figure 3-24). The geomorphic outcome of these changes is a

FIGURE 3-24 Example of an urban stream that has eroded entirely through its alluvium to expose the underlying consolidated geologic stratum below (Thornton Creek, Seattle, Washington). SOURCE: Derek Booth, Stillwater Sciences, Inc.

mix of erosional enlargement of some stream reaches, significant sedimentation in others, and potential head-ward downcutting of tributaries as discharge levels from small catchments increase. The collective effects of these processes have been described by Walsh et al. (2005) as "Urban Stream Syndrome," which includes not only the visible alteration of the physical form of the channel but also the consequent deterioration of stream biogeochemical function and aquatic trophic structures.

Other changes also accompany these geomorphic changes. Episodic inundation of the floodplain during floods may be reduced in magnitude and frequency, depending on the increases in peak flow relative to the deepening and resultant increase in flow capacity of the channel. Where deeply entrenched, this channel morphology will lower the groundwater level adjacent to the channel. The effectiveness of riparian areas in filtering or removing solutes is thus reduced because subsurface water may reach the channel only by flowpaths now well below the organic-rich upper soil horizons. Removal of fine-grained stream-bottom sediment, or erosion down to bedrock, may substantially lower the exchange of stream water with the surrounding groundwater of the hyporheic zone.

In addition to these indirect effects on the physical form of the stream channel, urbanization also commonly modifies streams directly to improve drainage, applying channel straightening and lining to reduce friction, increase flow capacity, and stabilize channel position (Figure 3-25). The enlarged and often

FIGURE 3-25 Example of a channelized urban stream for maximized flood conveyance and geomorphic stability (Los Angeles River, California). SOURCE: Robert Pitt, University of Alabama.

lined and straightened stream-channel cross section reduces the complexity of the bed and the contact between the stream and floodplain, and increases transport efficiency of sediment and solutes to receiving waterbodies. Enhanced sedimentation of receiving waterbodies, in turn, reduces water clarity, decreases depth, and buries the benthic environment.

POLLUTANT LOADING IN STORMWATER

Hydrologic flowpaths influence the production of particulate and dissolved substances on the land surface during storms, as well as their delivery to the stream-channel network. Natural watersheds typically develop a sequence of ecosystem types along hydrologic flowpaths that utilize available limiting resources, thereby reducing their export farther downslope or downstream, such that in-stream concentrations of these nutrients are low. As a watershed shifts from having mostly natural pervious surfaces to having heavily disturbed soils, new impervious surfaces, and activities characteristic of urbanization, the runoff quality shifts from relatively lower to higher concentrations of pollutants. Anthropogenic activities that can increase runoff pollutant concentrations in urban watersheds include application of chemicals for fertilization and pest control; leaching and corrosion of pollutants from exposed materials; exhaust emissions, leaks from, and wear of vehicles; atmospheric deposition of pollutants; and inappropriate discharges of wastes.

Most lands in the United States that have been developed were originally grasslands, prairies, or forest. About 40 percent of today's developed land went through an agricultural phase (cropland or pastureland) before becoming urbanized, while more than half of today's developed land area has been a direct conversion of natural covers (USDA, 2000). Agricultural land can produce stormwater runoff with high pollutant concentrations via soil erosion, the introduction of chemicals (fertilizers, pesticides, and herbicides), animal operations that are major sources of bacteria in runoff, and forestry operations. Indeed, urban stormwater may actually have slightly lower pollutant concentrations than other nonpoint sources of pollution, especially for sediment and nutrients. The key difference is that urban watersheds produce a much larger annual volume of runoff waters, such that the mass of pollutants discharged is often greater following urbanization. Some of the complex land-use–pollutant loading relationships are evident in Box 3-7, which shows the measured annual mass loads of nitrogen and phosphorus in four small watersheds of different land use monitored as part of the Baltimore Long-Term Ecological Research program. Depending on the nutrient and the year, the agricultural and urban watersheds had a higher nutrient export rate than the forested subwatershed.

Table 3-3 summarizes the comparative importance of urban land-use types in generating pollutants of concerns that can impact receiving waters (Burton and Pitt, 2002). This summary is highly qualitative and may vary depending on the site-specific conditions, regional climate, activities being conducted in each land use, and development characteristics. It should be noted that the rankings in Table 3-3 are relative to one another and classified on a per-unit-area basis. Furthermore, this table shows the parameters for each land-use category, such that the effects for a community at large would be dependent on the areas of each land use shown. Thus, although residential land use is shown to be a relatively smaller source of many pollutants, it is the largest fraction of land use in most communities, typically making it the largest stormwater source on a mass pollutant discharge basis. Similarly, freeway, industrial, and commercial areas can be very significant sources of many stormwater problems, and their discharge significance is usually much greater than their land area indicates. Construction sites are usually the overwhelming source of sediment in urban areas, even though they make up very small areas of most communities. A later table (Table 3-4) presents observed stormwater discharge concentrations for selected constituents for different land uses.

The following section describes stormwater characteristics associated with urbanized conditions. At any given time, parts of an urban area will be under construction, which is the source of large sediment losses, flow path disruptions, increased runoff quantities, and some chemical contamination. Depending on the time frame of development, increased stormwater pollutant discharges associated with construction activities may last for several years until land covers are stabilized. After construction has been completed, the characteristics of urban

BOX 3-7
Comparison of Nitrogen and Phosphorus Export from Watersheds with Different Land Uses

Land use is a significant influence on nutrient export as controlled by impervious area, sanitary infrastructure, fertilizer application, and other determinants of input, retention, and stormwater transport. Tables 3-2A and 3-2B compare dissolved nitrate, total nitrogen, phosphate, and total phosphorus loads exported from forest catchments with catchments in different developed land uses studied by the Baltimore Ecosystem Study (Groffman et al., 2004). Loads were computed with the Fluxmaster system (Schwarz et al., 2006) from weekly samples taken at outlet gauges. In these sites in Baltimore County, the forested catchment, Pond Branch, has nitrogen loads one to two orders of magnitude lower than the developed catchments. Baisman Run, with one-third of the catchment in low-density, septic-served suburban land use, has nitrogen export exceeding Dead Run, an older, dense urban catchment. In this case, nutrient load does not follow the direct variation of impervious area because of the switch to septic systems and greater fertilizer use in lower density areas. However, Figure 3-26 shows that as impervious area increases, a much greater proportion of the total nitrogen load is discharged in less frequent, higher runoff events (Shields et al., 2008), reducing the potential to decrease loads by on-site SCMs. Total phosphorus loads were similarly as low (0.05–0.6 kg P/ha/yr) as nitrogen in the Pond Branch catchment (forest) over the 2000–2004 time period, and one to two orders of magnitude lower compared to agricultural and residential catchments.

It should be noted that specific areal loading rates, even in undeveloped catchments, can vary significantly depending on rates of atmospheric deposition, disturbance, and climate conditions. The hydrologic connectivity of nonpoint pollutant source areas to receiving waterbodies is also a critical control on loading in developed catchments (Nadeau and Rains, 2007) and is dependent on both properties of the pollutant as well as the catchment hydrology. For example, total nitrogen was high in both the agricultural and low-density suburban sites. Total phosphorus, on the other hand, was high in the Baltimore Ecosystem Study agricultural catchment, but close to the concentration of the forest site in the low-density suburban site serviced by septic systems. This is because septic systems tend to retain phosphorus, while septic wastewater nitrogen is typically nitrified in the unsaturated zone below a spreading field and efficiently transported in the groundwater to nearby streams.

TABLE 3-2A Dissolved Nitrate and Total Nitrogen Export Rates from Forest and Developed Land-Use Catchments in the Baltimore Ecosystem Study

Catchment	**Land Use**	**Nitrate (kg N/ha/yr)**			**Total N (kg N/ha/yr)**		
		2000	2001	2002	2000	2001	2002
Pond Branch	Forest	0.11	0.08	0.04	0.47	0.37	0.17
McDonogh	Agriculture	17.6	12.9	4.3	20.5	14.5	4.5
Baisman Run	Mixed Forest and Suburban	7.2	3.8	1.5	8.2	4.2	1.7
Dead Run	Urban	3.0	2.9	2.9	5.6	5.3	4.2

TABLE 3-2B Dissolved Phosphate and Total Phosphorus Export Rates from Forest and Developed Land-Use Catchments in the Baltimore Ecosystem Study

Catchment	**Land Use**	**Phosphate (kg P/ha/yr)**			**Total P (kg P/ha/yr)**		
		2000	2001	2002	2000	2001	2002
Pond Branch	Forest	0.009	0.007	0.003	0.02	0.014	0.006
McDonogh	Agriculture	0.12	0.080	0.022	0.22	0.14	0.043
Baisman Run	Mixed Forest and Suburban	0.009	0.005	0.002	0.02	0.011	0.004
Dead Run	Urban	0.039	0.037	0.03	0.10	0.10	0.08

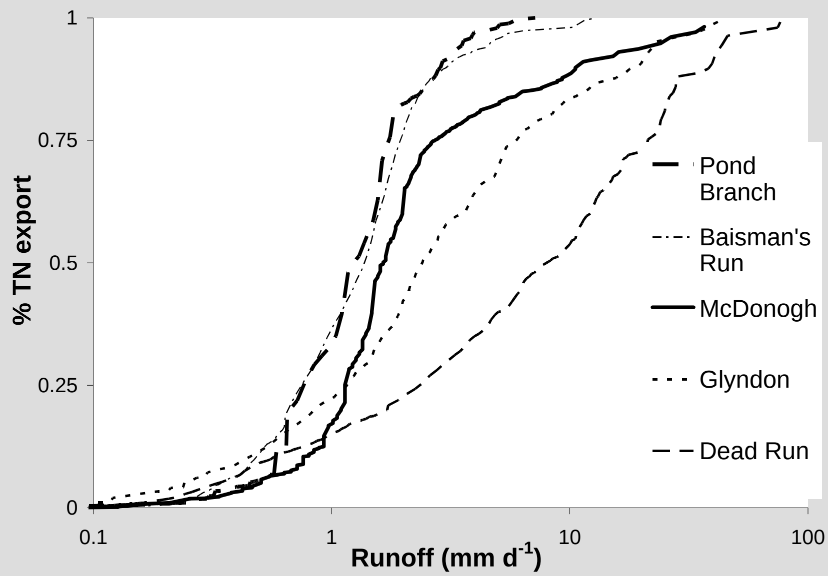

FIGURE 3-26 Cumulative transport of total nitrogen at increasing flow levels from catchments in Baltimore City and County including dominantly forest (Pond Branch), low-density development on septic systems and forest (Baisman Run), agricultural (McDonogh), medium-density suburban development on separate sewers (Glyndon), and higher-density residential, commercial, and highway land cover (Dead Run). SOURCE: Reprinted, with permission, from Shields et al. (2008). Copyright 2008 by the American Geophysical Union.

TABLE 3-3 Relative Sources of Parameters of Concern for Different Land Uses in Urban Areas

Problem Parameter	Residential	Commercial	Industrial	Freeway	Construction
High flow rates (energy)	Low	High	Moderate	High	Moderate
Large runoff volumes	Low	High	Moderate	High	Moderate
Debris (floatables and gross solids)	High	High	Low	Moderate	High
Sediment	Low	Moderate	Low	Low	Very high
Inappropriate discharges (mostly sewage and cleaning wastes)	Moderate	High	Moderate	Low	Low
Microorganisms	High	Moderate	Moderate	Low	Low
Toxicants (heavy metals/organics)	Low	Moderate	High	High	Moderate
Nutrients (eutrophication)	Moderate	Moderate	Low	Low	Moderate
Organic debris (SOD and DO)	High	Low	Low	Low	Moderate
Heat (elevated water temperature)	Moderate	High	Moderate	High	Low

NOTE: SOD, sediment oxygen demand; DO, dissolved oxygen.
SOURCE: Summarized from Burton and Pitt (2002), Pitt et al. (2008), and CWP and Pitt (2008).

runoff are controlled largely by the increase in volume and the washoff of pollutants from impervious surfaces. Stormwater in this phase is associated with increases in discharges of most pollutants, but with less sediment washoff than from construction and likely less sediment and nutrient discharges compared to any pre-urbanization agricultural operations (although increased channel erosion may increase the mass of sediment delivered in this phase; Pitt et al., 2007). A third significant urban land use is industrial activity. As described later, industrial site stormwater discharges are highly variable, but often greater than other land uses.

Construction Site Erosion Characteristics

Problems associated with construction site runoff have been known for many years. More than 25 years ago, Willett (1980) estimated that approximately 5 billion tons of sediment reached U.S. surface waters annually, of which 30 percent was generated by natural processes and 70 percent by human activities. Half of this 70 percent was attributed to eroding croplands. Although construction occurred on only about 0.007 percent of U.S. land in the 1970s, it accounted for approximately 10 percent of the sediment load to all U.S. surface waters and equaled the combined sediment contributions of forestry, mining, industrial, and commercial land uses (Willett, 1980).

Construction accounts for a much greater proportion of the sediment load in urban areas than it does in the nation as a whole. This is because construction sites have extremely high erosion rates and because urban construction sites are efficiently drained by stormwater drainage systems installed early during the construction activities. Construction site erosion losses vary greatly throughout the nation, depending on local rain, soil, topographic, and management conditions. As an example, the Birmingham, Alabama, area may have some of the highest erosion rates in the United States because of its combination of very high-energy rains, moderately to severely erosive soils, and steep slopes (Pitt et al., 2007). The typically high erosion rates mean that even a small construction project may have a significant detrimental effect on local waterbodies.

Extensive evaluations of urban construction site runoff problems have been conducted in Wisconsin for many years. Data from the highly urbanized Menomonee River watershed in southeastern Wisconsin indicate that construction sites have much greater potentials for generating sediment and phosphorus than do other land uses (Chesters et al., 1979). For example, construction sites can generate approximately 8 times more sediment and 18 times more phosphorus than industrial sites (the land use that contributes the second highest amount of these pollutants) and 25 times more sediment and phosphorus than row crops. In fact, construction sites contributed more sediment and phosphorus to the Menomonee River than any other land use, although in 1979, construction comprised only 3.3 percent of the watershed's total land area. During this early study, construction sites were found to contribute about 50 percent of the suspended sediment and total phosphorus loading at the river mouth (Novotny and Chesters, 1981).

Similar conclusions were reported by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in a 1978 modeling study of the relative pollutant contributions of 17 categories of point and nonpoint pollution sources to 14 watersheds in the southeast Wisconsin regional planning area (SEWRPC, 1978). This study revealed construction as the first or second largest contributor of sediment and phosphorus in 12 of the 14 watersheds. Although construction occupied only 2 percent of the region's total land area in 1978, it contributed approximately 36 percent of the sediment and 28 percent of the total phosphorus load to inland waters, making construction the region's second largest source of these two pollutants. The largest source of sediment was estimated to be cropland; livestock operations were estimated to be the largest source of phosphorus. By comparison, cropland comprised 72 percent of the region's land area and contributed about 45 percent of the sediment and only 11 percent of the phosphorus to regional watersheds. When looking at the Milwaukee River watershed as a whole, construction is a major sediment contributor, even though the amount of land under active construction is very low. Construction areas were estimated to contribute about 53 percent of the total sediment discharged by the

Milwaukee River in 1985 (total sediment load of 12,500 lb/yr), while croplands contributed 25 percent, streambank erosion contributed 13 percent, and urban runoff contributed 8 percent.

Line and White (2007) recently investigated runoff characteristics from two similar drainage areas in the Piedmont region of North Carolina. One of the drainage areas was being developed as part of a large residential subdivision during the course of the study, while the other remained forested or in agricultural fields. Runoff volume was 68 percent greater for the developing compared with the undeveloped area, and baseflow as a percentage of overall discharge was approximately zero compared with 25 percent for the undeveloped area. Overall annual export of sediment was 95 percent greater for the developing area, while export of nitrogen and phosphorus forms was 66 to 88 percent greater for the developing area.

The biological stream impact of construction site runoff can be severe. For example, Hunt and Grow (2001) describe a field study conducted to determine the impact to a stream from a poorly controlled construction site, with impact being measured via fish electroshocking and using the Qualitative Habitat Evaluation Index. The 33-acre construction site consisted of severely eroded silt and clay loam subsoil and was located within the Turkey Creek drainage, Scioto County, Ohio. The number of fish species declined (from 26 to 19) and the number of fish found decreased (from 525 to 230) when comparing upstream unimpacted reaches to areas below the heavily eroding site. The Index of Biotic Integrity and the Modified Index of Well-Being, common fisheries indexes for stream quality, were reduced from 46 to 32 and 8.3 to 6.3, respectively. Upstream of the area of impact, Turkey Creek had the highest water quality designation available, but fell to the lowest water quality designation in the area of the construction activity. Water quality sampling conducted at upstream and downstream sites verified that the decline in fish diversity was not due to chemical affects alone.

Municipal Stormwater Characteristics

The suite of stormwater pollutants generated by municipal areas is expected to be much more diverse than construction sites because of the greater variety of land uses and pollutant source areas found within a typical city. Many studies have investigated stormwater quality, with the U.S. Environmental Protection Agency's (EPA's) NURP (EPA, 1983) being the best known and earliest effort to collect and summarize these data. Unfortunately, NURP was limited in that it did not represent all areas of the United States or all important land uses. More recently, the National Stormwater Quality Database (NSQD) (CWP and Pitt, 2008; Pitt et al., 2008 for version 3) has been compiling data from the EPA's NPDES stormwater permit program for larger Phase I municipal separate storm sewer system (MS4) communities. As a condition of their Phase I permits, municipalities were required to establish a monitoring program to characterize their local stormwater quality for their most important land uses discharging to the

MS4. Although only a few samples from a few locations were required to be monitored each year in each community, the many years of sampling and large number of communities has produced a database containing runoff quality information for nearly 8,000 individual storm events over a wide range of urban land uses. The NSQD makes it possible to statistically compare runoff from different land uses for different areas of the country.

A number of land uses are represented in MS4 permits and also the database, including industrial stormwater discharges to an MS4. However, there is no separate compilation of quantitative mass emissions from specific industrial stormwater sources that may have been collected under industrial permit monitoring efforts. The observations in the NSQD were all obtained at outfall locations and do not include snowmelt or construction erosion sources. The most recent version of the NSQD contains stormwater data from about one-fourth of the total number of communities that participated in the Phase I NPDES stormwater permit monitoring activities. The database is located at *http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml*.

Table 3-4 is a summary of *some* of the stormwater data included in NSQD version 3, while Figure 3-27 shows selected plots of these data. The table describes the total number of observations, the percentage of observations above the detection limits, the median, and coefficients of variation for a few of the major constituents for residential, commercial, industrial, institutional, freeway, and open-space land-use categories, although relatively few data are available for institutional and open-space areas. It should be noted that even if there are significant differences in the median concentrations by the land uses, the range of the concentrations within single land uses can still be quite large. Furthermore, plots like Figure 3-27 do not capture the large variability in data points observed at an individual site.

There are many factors that can be considered when examining the quality of stormwater, including land use, geographical region, and season. The following is a narrative summary of the entire database and may not reflect information in Table 3-4 and Figure 3-29, which show only subsets of the data. First, statistical analyses of variance on the NSQD found significant differences among land-use categories for all of the conventional constituents, except for dissolved oxygen. (Turbidity, total solids, total coliforms, and total *E. coli* did not have enough samples in each group to evaluate land-use differences.) Freeway sites were found to be significant sources of several pollutants. For example, the highest TSS, COD, and oil and grease concentrations (but not necessarily the highest *median* concentrations) were reported for freeways. The median ammonia concentration in freeway stormwater is almost three times the median concentration observed in residential and open-space land uses, while freeways have the lowest orthophosphate and nitrite–nitrate concentrations—half of the concentration levels that were observed in industrial land uses.

In almost all cases the median metal concentrations at the industrial areas were about three times the median concentrations observed in open-space and residential areas. The highest lead and zinc concentrations (but not necessarily

TABLE 3-4 Summary of Selected Stormwater Quality Data Included in NSQD, Version 3.0

	TSS (mg/L)	COD (mg/L)	Fecal Colif. (mpn/100 mL)	Nitrogen, Total Kjeldahl (mg/L)	Phosphorus, Total (mg/L)	Cu, Total (µg/L)	Pb, Total (µg/L)	Zn, Total (µg/L)
All Areas Combined (8,139)								
Coefficient of variation (COV)	2.2	1.1	5.0	1.2	2.8	2.1	2.0	3.3
Median	62.0	53.0	4300	1.3	0.2	15.0	14.0	90.0
Number of samples	6780	5070	2154	6156	7425	5165	4694	6184
% samples above detection	99	99	91	97	97	88	78	98
All Residential Areas Combined (2,586)								
COV	2.0	1.0	5.7	1.2	1.6	1.9	2.1	3.3
Median	59.0	50.0	4200	1.2	0.3	12.0	6.0	70.0
Number of samples	2167	1473	505	2026	2286	1640	1279	1912
% samples above detection	99	99	89	98	98	88	77	97
All Commercial Areas Combined (916)								
COV	1.7	1.0	3.0	0.9	1.2	1.4	1.7	1.4
Median	55.0	63.0	3000	1.3	0.2	17.9	15.0	110.0
Number of samples	843	640	270	726	920	753	605	839
% samples above detection	97	98	89	98	95	85	79	99
All Industrial Areas Combined (719)								
COV	1.7	1.3	6.1	1.1	1.4	2.1	2.0	1.7
Median	73.0	59.0	2850	1.4	0.2	19.0	20.0	156.2
Number of samples	594	474	317	560	605	538	550	596
% samples above detection	98	98	94	97	95	86	76	99

All Freeway Areas Combined (680)								
COV	2.6	1.0	2.7	1.2	5.2	2.2	1.1	1.4
Median	53.0	64.0	2000	1.7	0.3	17.8	49.0	100.0
Number of samples	360	439	67	430	585	340	355	587
% samples above detection	100	100	100	99	99	99	99	99
All Institutional Areas Combined (24)								
COV	1.1	1.0	0.4	0.6	0.9	0.6	1.0	0.9
Median	18.0	37.5	3400	1.1	0.2	21.5	8.6	198.0
Number of samples	23	22	3	22	23	21	21	22
% samples above detection	96	91	100	91	96	57	86	100
All Open -Space Areas Combined (79)								
COV	1.8	0.6	1.2	1.2	1.5	0.4	0.9	0.8
Median	10.5	21.3	2300	0.4	0.0	9.0	48.0	57.0
Number of samples	72	12	7	50	77	15	10	16
% samples above detection	97	83	100	96	97	47	20	50

NOTE: The complete database is located at: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml. SOURCE: National Stormwater Quality Database.

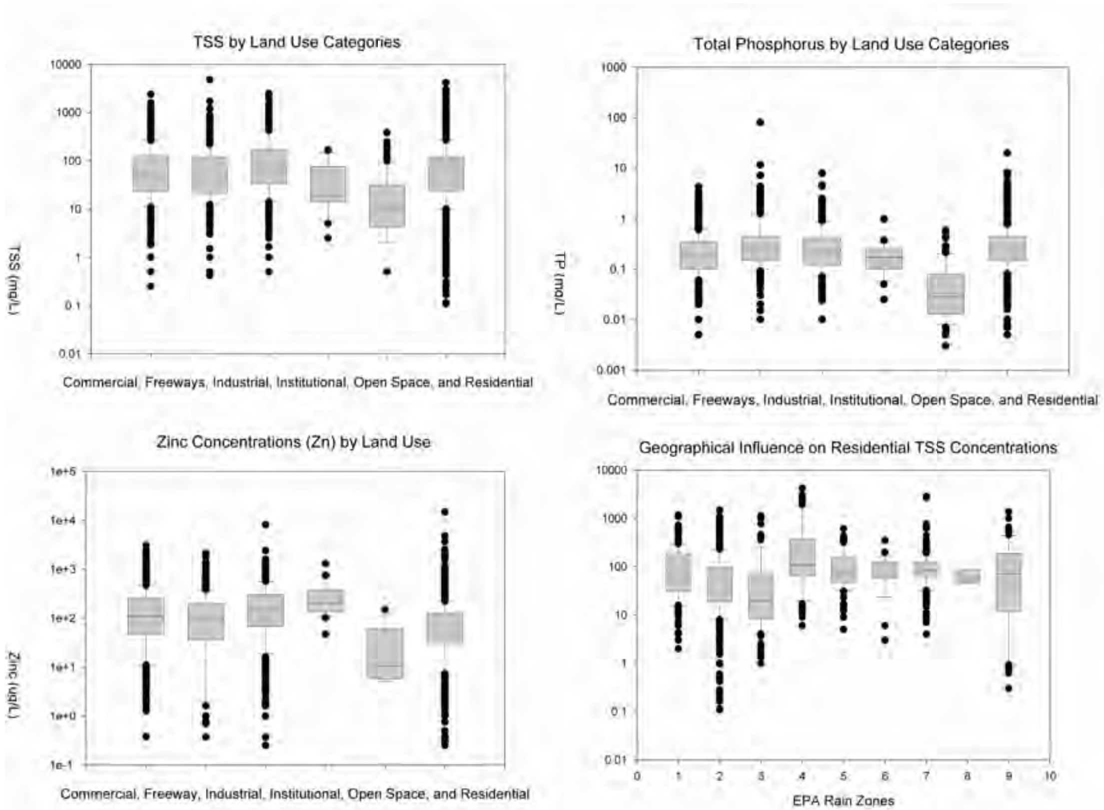

FIGURE 3-27 Grouped box and whisker plots of data from the NSQD. The median values are indicated with the horizontal line in the center of the box, while the ends of the box represent the 25th and 75th percentile values. The whickers extend to the 5th and 95th percentile values, and values outside of these extremes are indicated with separate dots. These groups were statistically analyzed and were found to have at least one group that is significantly different from the other groups. The ranges of the values in each group are large, but a very large number of data points is available for each group. The grouping of the data into these categories helps explain much of the total variability observed, and the large number of samples in each category allows suitable statistical tests to be made. Many detailed analyses are presented at the NSQD website (Maestre and Pitt, 2005).

the highest *median* concentrations) were found in industrial land uses. Lower concentrations of TDS, five-day biological oxygen demand (BOD_5), and fecal coliforms were observed in industrial land-use areas. By contrast, the highest concentrations of dissolved and total phosphorus were associated with residential land uses. Fecal coliform concentrations are also relatively high for residential and mixed residential land uses. Open-space land-use areas show consistently low concentrations for the constituents examined. There was no significant difference noted for total nitrogen among any of the land uses monitored.

In terms of regional differences, significantly higher concentrations of TSS, BOD_5, COD, total phosphorus, total copper, and total zinc were observed in arid and semi-arid regions compared to more humid regions. In contrast, fecal coliforms and total dissolved solids were found to be higher in the upper Midwest. More detailed discussions of land use and regional differences in stormwater quality can be found in Maestre et al. (2004) and Maestre and Pitt (2005, 2006). In addition to the information presented above, numerous researchers have conducted source area monitoring to characterize sheet flows originating from urban surfaces (such as roofs, parking lots, streets, landscaped areas, storage areas, and loading docks). The reader is referred to Pitt et al. (2005a,b,c) for much of this information.

Industrial Stormwater Characteristics

The NSQD, described earlier, has shown that industrial-area stormwater has higher concentrations of most pollutants compared to other land uses, although the variability is high. MS4 monitoring activities are usually conducted at outfalls of drainage systems containing many individual industrial activities, so discharge characteristics for specific industrial types are rarely available. This discussion provides some additional information concerning industrial stormwater beyond that included in the previous discussion of municipal stormwater. In general, there is a profound lack of data on industrial stormwater compared to municipal stormwater, and a correspondingly greater uncertainty about industrial stormwater characteristics.

The first comprehensive monitoring of an industrial area that included stormwater, dry weather base flows, and snowmelt runoff was conducted in selected Humber River catchments in Ontario (Pitt and McLean, 1986). Table 3-5 shows the annual mass discharges from the monitored industrial area in North York, along with ratios of these annual discharges compared to discharges from a mixed commercial and residential area in Etobicoke. The mass discharges of heavy metals, total phosphorus, and COD from industrial stormwater are three to six times that of the mixed residential and commercial areas.

Hotspots of contamination on industrial sites are a specific concern. Stormwater runoff from "hotspots" may contain loadings of hydrocarbons, trace metals, nutrients, pathogens and/or other toxicants that are greater than the loadings of "normal" runoff. Examples of these hotspots include airport de-icing

TABLE 3-5 Annual Storm Drainage Mass Discharges from Toronto-Area Industrial Land Use

Measured Parameter	Units	Annual Mass Discharges from Industrial Drainage Area	Stormwater Annual Discharge Ratio (Industrial Compared to Residential and Commercial Mixed Area)
Runoff volume	m^3/hr/yr	6,580	1.6
total solids	kg/ha/yr	6,190	2.8
total phosphorus	kg/ha/yr	4,320	4.5
TKN	g/ha/yr	16,500	1.2
COD	kg/ha/yr	662	3.3
Cu	g/ha/yr	416	4.0
Pb	g/ha/yr	595	4.2
Zn	g/ha/yr	1,700	5.8

SOURCE: Pitt and McLean (1986).

facilities, auto recyclers/junkyards, commercial garden nurseries, parking lots, vehicle fueling and maintenance stations, bus or truck (fleet) storage areas, industrial rooftops, marinas, outdoor transfer facilities, public works storage areas, and vehicle and equipment washing/steam cleaning facilities (Bannerman et al., 1993; Pitt et al., 1995; Claytor and Schueler, 1996).

The elevated concentrations and mass discharges found in stormwater at industrial sites are associated with both the activities that occur and the materials used in industrial areas, as discussed in the sections that follow.

Effects of Roofing Materials on Stormwater Quality

The extensive rooftops of industrial areas can be a significant pollutant source area. A summary of the literature on roof-top runoff quality, including both roof surfaces and underlying materials used as subbases (such as treated wood), is presented in Table 3-6. Good (1993) found that dissolved metals' concentrations and toxicity remained high in roof runoff samples, especially from rusty galvanized metal roofs during both first flush and several hours after a rain has started, indicating that metal leaching continued throughout the events and for many years. During pilot-scale tests of roof panels exposed to rains over a two-year period, Clark et al. (2008) found that copper roof runoff concentrations for newly treated wood panels exceeded 5 mg/L (a very high value compared to median NSQD stormwater concentrations of about 10 to 40 µg/L for different land uses) for the first nine months of exposure. These results indicated that copper continued to be released from these wood products at levels high enough to exceed aquatic life criteria for long periods after installation, and were not simply due to excess surface coating washing off in the first few storms after installation.

TABLE 3-6 Roof Runoff Analysis—A Literature Summary

Roof Type	Location	Water Quality Parameter								Reference
		Cu (µg/L)	Zn (µg/L)	Pb (µg/L)	Cd (µg/L)	As (µg/L)	pH	NH_4^+ (mg/L)	NO_3^- (mg/L)	
Polyester Tile Flat gravel	Duebendorf, Switzerland	6817 1905 140	2076 360 36	510 172 22	3.1 2.1 0.2					Boller (1997)
Plywood w/ roof paper/tar Rusty galvanized metal Old metal w/Al paint Flat tar surface w/fibrous reflective Al paint New anodized Al	Washington	$166^T/128^D$ $20^T/2^D$ $11^T/7^D$ $25^T/14^D$ $16^T/7^D$	$877^T/909^D$ $12200^T/11900^D$ $1980^T/1610^D$ $297^T/257^D$ $101^T/82^D$	$11^T/<5^D$ $302^T/35^D$ $10^T/<5^D$ $10^T/5^D$ $15^T/<5^D$			4.3 5.9 4.8 4.1 5.9			Good (1993)
Zinc-galvanized Fe	Dunedin City, New Zealand	560 µg/g	5901 µg/g	670 µg/g						Brown & Peake (2006)
Fe-Zn sheets Concrete slate tiles Asbestos cement sheets Aluminum sheets	Ile-Ife, Nigeria						6.77 7.45 7.09 6.68	0.06 0.05 0.06 0.05	1.52 3.34 2.26 6.18	Adeniyi and Olabanji (2005)
Cu panels	Munich, Germany	200–11100					6.7–7.0			Athanasiadis et al. (2006)
Galvanized metals (primarily Galvalume®)	Seattle, WA	10–1400	420–14700	ND						Tobiason (2004)
CCA wood Untreated wood	Florida					1200–1800 2–3				Khan et al. (2006)

Note: D, dissolved; T, total; ND, not detected.
SOURCE: Reprinted, with permission, from Clark et al. (2008). Copyright 2008 by American Society of Civil Engineers.

Traditional unpainted or uncoated hot-dip galvanized steel roof surfaces can also produce very high zinc concentrations. For example, pilot-scale tests by Clark et al. (2008) indicated that zinc roof runoff concentrations were 5 to 30 mg/L throughout the first two years of monitoring of a traditional galvanized metal panel. These are very high values compared to median stormwater values reported in the NSQD of 60 to 300 µg/L for different land uses. Factory-painted aluminum–zinc alloy panels had runoff zinc levels less than 250 µg/L, which were closer to the reported NSQD median values. The authors concluded that traditional galvanized metal roofing contributed the greatest concentrations of many metals and nutrients. In addition, they found that pressure-treated and waterproofed wood contributed substantial copper loads. The potential for nutrient release exists in many of the materials tested (possibly as a result of phosphate washes and binders used in the material's preparation or due to natural degradation).

Other researchers have investigated the effects of industrial rooftop runoff on receiving waters and biota. Bailey et al. (1999) investigated the toxicity to juvenile rainbow trout of runoff from British Columbia sawmills and found that much of the toxicity may have been a result of divalent cations on the industrial site, especially zinc from galvanized roofs.

Effects of Pavement and Pavement Maintenance on Stormwater Quality

Pavement surfaces can also have a strong influence on stormwater runoff quality. For example, concrete is often mixed with industrial waste sludges as a way of disposing of the wastes. However, this can lead to stormwater discharges high in toxic compounds, either due to the additives themselves or due to the mobilization of compounds via the additives. Salaita and Tate (1998) showed that high levels of aluminum, iron, calcium, magnesium, silicon, and sodium were seen in the cement-waste samples. A variety of sands, including waste sands, have been suggested as potential additives to cement and for use as fill in roadway construction. Wiebusch et al. (1998) tested brick sands and found that the higher the concentration of alkaline and alkaline earth metals in the samples, the more easily the heavy metals were released. Pitt et al. (1995) also found that concrete yard runoff had the highest toxicity (using Microtox screening methods) observed from many source areas, likely due to the elevated pH (about 11) from the lime dust washing off from the site.

The components of asphalt have been investigated by Rogge et al. (1997), who found that the majority of the elutable organic mass that could be identified consisted of *n*-alkanes (73 percent), carboxylic acids such as *n*-alkanoic acids (17 percent), and benzoic acids. PAHs and thiaarenes were 7.9 percent of the identifiable mass. In addition, heterocyclic aromatic hydrocarbons containing sulfur (S-PAH), such as dibenzothiophene, were identified at concentration levels similar to that of phenanthrene. S-PAHs are potentially mutagenic (similar to other PAHs), but due to their slightly increased polarity, they are more soluble in water and more prone to aquatic bioaccumulation.

In addition to the bitumens and asphalts, other compounds are added to paving (and asphaltic roofing) materials. Chemical modifiers are used both to increase the temperature range at which asphalts can be used and to prevent stripping of the asphalt from the binder. A variety of fillers may also be used in asphalt pavement mixtures. The long-term environmental effects of these chemicals in asphalts are unknown. Reclaimed asphalt pavements have also been proposed for use as fill materials for roadways. Brantley and Townsend (1999) performed a series of leaching tests and analyzed the leachate for a variety of organics and heavy metals. Only lead from asphalt pavements reclaimed from older roadways was found to be elevated in the leachate.

Stormwater quality from asphalt-paved surfaces seems to vary with time. Fish kills have been reported when rains occur shortly after asphalt has been installed in parking areas near ponds or streams (Anonymous, 2000; Perez-Rivas, 2000; Kline, 2002). It is expected that these effects are associated with losses of the more volatile and toxic hydrocarbons that are present on new surfaces. It is likely that the concentrations of these materials in runoff decrease as the pavement ages. Toxicity tests conducted on pavements several years old have not indicated any significant detrimental effects, except for those associated with activities conducted on the surface (such as maintenance and storage of heavy equipment; Pitt et al., 1995, 1999). However, pavement maintenance used to “renew” the asphalt surfaces has been shown to cause significant problems, which are summarized below.

A significant source of PAHs in the Austin, Texas, area (and likely elsewhere) has been identified as coal-tar sealants commonly used to “restore” asphalt parking lots and storage areas. Mahler et al. (2005) found that small particles of sealcoat that flake off due to abrasion by vehicle tires have PAH concentrations about 65 times higher than for particles washed off parking lots that are not seal coated. Unsealed parking lots receive PAHs from the same urban sources as do sealed parking lots (e.g., tire particles, leaking motor oil, vehicle exhaust, and atmospheric fallout), and yet the average yield of PAHs from the sealed parking lots was found to be 50 times greater than that from the control lots. The authors concluded that sealed parking lots could be the dominant source of PAHs in watersheds that have seal-coated surfaces, such as many industrial, commercial, and residential areas. Consequently, the City of Austin has restricted the use of parking lot coal-tar sealants, as have several Wisconsin communities.

Stored Materials Exposed to Rain

Although roofing and pavement materials make up a large fraction of the total surface covers and can have significant effects on stormwater quality, leaching of rain through stored materials may also be a significant pollutant source at industrial sites. Exposed metals in scrap yards can result in very high concentrations of heavy metals. For example, Table 3-7 summarizes data from three metals recycling facilities/scrap yards in Wisconsin and shows the large fraction of metals that are either dissolved in the runoff or associated with very fine particulate matter. For most of these metals, their greatest abundance is associated with the small particles (<20 μm in diameter), and relatively little is associated with the filterable fraction. These metals concentrations (especially zinc, copper, and lead) are also very high compared to that of most outfall industrial stormwater.

OTHER SOURCES OF URBAN RUNOFF DISCHARGES

Wet weather stormwater discharges from separate storm sewer outfalls are not the only discharges entering receiving waters from these systems. Dry weather flows, snowmelt, and atmospheric deposition all contribute to the pollutant loading of urban areas to receiving waters, and for some compounds may be the largest contributor. Many structural SCMs, especially those that rely on sedimentation or filtration, have been designed to function primarily with stormwater and are not nearly as effective for dry weather discharges, snowmelt, or atmospheric deposition because these nontraditional sources vary considerably in key characteristics, such as the flow rate and volume to be treated, sediment concentrsations and particle size distribution, major competing ions, association of pollutants with particulates of different sizes, and temperature. Information on the treatability of stormwater vs. snowmelt and other nontraditional sources of urban runoff can be found in Pitt and McLean (1986), Pitt et al. (1995), Johnson et al. (2003), and Morquecho (2005).

TABLE 3-7 Metal Concentration Ranges Observed in Scrapyard Runoff

Particle Size	**Iron (mg/L)**	**Aluminum (mg/L)**	**Zinc (mg/L)**
Total	20 – 810	15 – 70	1.6 – 8
< 63 μm diameter	22 – 767	15 – 58	1.5 – 7.6
< 38 μm diameter	21 – 705	15 – 58	1.4 – 7.4
< 20 μm diameter	15 – 534	12 – 50	1.1 – 7.2
< 0.45 μm diameter (filterable fraction)	0.1 – 38	0.1 – 5	0.1 – 6.7
	Copper (mg/L)	**Lead (mg/L)**	**Chromium (mg/L)**
Total	1.1 – 3.8	0.6 – 1.7	0.1 – 1.9
< 63 μm diameter	1.1 – 3.6	0.1 – 1.6	0.1 – 1.6
< 38 μm diameter	1.1 – 3.3	0.1 – 1.6	0.1 – 1.4
< 20 μm diameter	1.0 – 2.8	0.1 – 1.6	0.1 – 1.2
< 0.45 μm diameter (filterable fraction)	0.1 – 0.3	0.1 – 0.3	0.1 – 0.3

SOURCE: Reprinted, with permission, from Clark et al. (2000). Copyright 2000 by Shirley Clark.

Dry Weather Flows

At many stormwater outfalls, discharges occur during dry weather. These may be associated with discharges from leaking sanitary sewer and drinking water distribution systems, industrial wastewaters, irrigation return flows, or natural spring water entering the system (Figures 3-28 to 3-33). Possibly 25 percent of all separate stormwater outfalls have water flowing in them during dry weather, and as much as 10 percent are grossly contaminated with raw sewage, industrial wastewaters, and so forth (Pitt et al., 1993). These flow contributions can be significant on an annual mass basis, even though the flow rates are relatively small, because they have long duration. This is particularly true in arid areas, where dry weather discharges can occur daily. For example, despite the fact that rain is scarce from May to September in Southern California, an estimated 40 to 90 million liters of discharge flow per day into Santa Monica Bay through approximately 70 stormwater outlets that empty onto or across beaches (LAC DPW, 1985; SMBRP, 1994), such that the contribution of dry weather flow to the total volume of runoff into the bay is about 30 percent (NRC, 1984). Furthermore, in the nearby Ballona Creek watershed, dry weather discharges of trace metals were found to comprise from 8 to 42 percent of the total annual loading (McPherson et al., 2002). Stein and Tiefenthaler (2003) further found that the highest loadings of metals and bacteria in this watershed discharging during dry weather can be attributed to a few specific stormwater drains.

In many cases, stormwater managers tend to overlook the contribution of dry weather discharges, although the EPA's NPDES Stormwater Permit program requires municipalities to conduct stormwater outfall surveys to identify, and then correct, inappropriate discharges into separate storm sewer systems. The role of inappropriate discharges in the NPDES Stormwater Permit program, the developed and tested program to identify and quantify their discharges, and an extensive review of these programs throughout the United States can be found in the recently updated report prepared for the EPA (CWP and Pitt, 2004).

FIGURE 3-28 Washing of vehicle engine and allowing runoff to enter storm drainage system. SOURCE: Robert Pitt, University of Alabama.

FIGURE 3-29 Contamination of storm drainage with inappropriate disposal of oil. SOURCE: Courtesy of the Center for Watershed Protection.

FIGURE 3-30 Dry weather flows from Toronto industrial area outfall. SOURCE: Pitt and McLean (1986).

FIGURE 3-31 Sewage from clogged system overflowing into storm drainage system. SOURCE: Robert Pitt, University of Alabama.

FIGURE 3-32 Failing sanitary sewer, causing upwelling of sewage through soil, and draining to gutter and then to storm drainage system. SOURCE: Robert Pitt, University of Alabama.

FIGURE 3-33 Dye tests to confirm improper sanitary sewage connection to storm drainage system. SOURCE: Robert Pitt, University of Alabama.

Snowmelt

In northern areas, snowmelt runoff can be a significant contributor to the annual discharges from urban areas through the storm drainage system (see Figure 3-34). In locations having long and harsh winters, with little snowmelt until the spring, pollutants can accumulate and be trapped in the snowpack all winter until the major thaw when the contaminants are transported in short-duration events to the outfalls (Jokela, 1990). The sources of the contaminants accumulating in snowpack depend on the location, but they usually include emissions from nearby motor vehicles and heating equipment and industrial activity in the neighborhood. Dry deposition of sulfur dioxide from industrial and power plant smokestacks affects snow packs over a wider area and has frequently been studied because of its role in the acid deposition process (Cadle, 1991). Pollutants are also directly deposited on the snowpack. The sources of directly deposited pollutants include debris from deteriorated roadways, vehicles depositing petroleum products and metals, and roadway maintenance crews applying salt and anti-skid grit (Oberts, 1994). Urban snowmelt, like rain runoff, washes some material off streets, roofs, parking and industrial storage lots, and drainage gutters. However, snowmelt runoff usually has much less energy than striking rain and heavy flowing stormwater. Novotny et al. (1986) found that urban soil erosion is reduced or eliminated during winter snow-cover conditions. However, erosion of bare ground at construction sites in the spring due to snowmelt can still be very high (Figure 3-35).

FIGURE 3-34 Snowmelt photos. SOURCE: Roger Bannerman, Wisconsin Department of Natural Resources.

FIGURE 3-35 Construction site in early spring after snowmelt showing extensive sediment transport. SOURCE: Roger Bannerman, Wisconsin Department of Natural Resources.

Sources of Contaminants in Snowmelt

Several mechanisms can bring about contamination of snow and snowmelt waters. Initially, air pollutants can be incorporated into snowflakes as they form and fall to the ground. After it falls to the ground and accumulates, the snow can become further contaminated by dry atmospheric deposition, deposition of nearby lost fugitive dust materials (usually blown onto snow packs near roads by passing vehicles), and wash off of particulates from the exposed ground surfaces as it melts and flows to the drainage system.

Snowflakes can remove particulates and gases from the air by in-cloud or below-cloud capture. In-cloud capture of pollutants can occur during snowflake formation as super-cooled cloud water condenses on particles and aerosols that act as cloud condensation nuclei. This is known as nucleation scavenging and is a major pathway for air pollution to be incorporated into snow. Particles and gases may also be scavenged as snowflakes fall to the ground. Gases can also be absorbed as snow falls. Snowflakes are more effective below-cloud scavengers than raindrops because they are bigger and fall slower. Barrie (1991) reports that large snowflakes capture particles in the 0.2- to 0.4-μm-diameter range, not by impaction but by filtering the air that moves through the snow flakes as they fall to the ground.

Most of the contamination of snow in urban areas likely occurs after it lands on the ground. Table 3-8 shows the flow-weighted mean concentrations of pollutants found in undisturbed falling snow compared to snow found in urban snow cover (Bennett et al., 1981). Pitt and McLean (1986) also measured snowpack contamination as a function of distance from a heavily traveled road passing through a park. The contaminants in the snow were at much greater concentrations near the road (the major source of blown contamination on the snow) than farther away. (The pollutant levels in the fresh fallen snow are generally a small fraction of the levels in the snow collected from urban study areas.) Pierstorff and Bishop (1980) also analyzed freshly fallen snow and compared the quality to snow stored at a snow dump site. They concluded that "pollutant levels at the dump site are the result of environmental input occurring after the snow falls." Some pollutants in snowmelt have almost no atmospheric

TABLE 3-8 Comparison of Flow-Weighted Pollutant Concentration Means of Snow Samples from Boulder, Colorado

	Fresh Fallen	**High Density Land Use**	**Low Density Land Use**
COD	10	402	54
TS	86	2000	165
SS	16	545	4.5
TKN	0.19	2.69	2
NO_3	0.15	0	0
P	—	0.66	0.017
Pb	—	0.95	—

Note: The units are mg/L. SOURCE: Reprinted, with permission, from Bennett et al. (1981). Copyright 1981 by Water Pollution Control Federation.

sources. For example, Oliver et al. (1974) found negligible amounts of chlorides in samples of snow from rooftops, indicating that the high chloride level found in the snowmelt runoff water comes almost entirely from surface sources (i.e., road salting). Similar roadside snowpack observations along city park roads by Pitt and McLean (1986) also indicated the strong association of road salt with snowpack chloride levels.

Runoff and Pollutant Loading from Snowmelt

Snowmelt events can exhibit a first flush, in which there are higher concentrations of contaminants at the beginning compared to the total event averaged concentration. The enrichment of the first portion of a snowmelt event by soluble pollutants may be due to snowpack density changes, where water percolation and melt/freeze events that occur in the snowpack cause soluble pollutants to be flushed from throughout the snowpack to concentrate at the bottom of the pack (Colbeck, 1981). This concentrated layer leaves the snowpack as a highly concentrated pulse, as snow melts from the bottom due to warmth from the ground (Oberts, 1994).

When it rains on snow, heavy pollutant loads can be produced because both soluble and particulate pollutants are melted from the snowpack simultaneously. Also, the large volume of melt plus rain can wash off pollutants that have accumulated on various surfaces such as roads, parking lots, roofs, and saturated soil surfaces. The intensity of runoff from a rain-on-snow event can be greater than a summer thunderstorm because the ground is saturated or frozen and the rapidly melting snowpack provides added runoff volume (Oberts, 1994).

Figure 3-36 compares the runoff volumes associated with snowmelts alone to those associated with snowmelts mixed with rain from monitoring at an industrial area in Toronto (Pitt and McLean, 1986). Rain with snowmelt contributes over 80 percent of the total cold-weather event runoff volume.

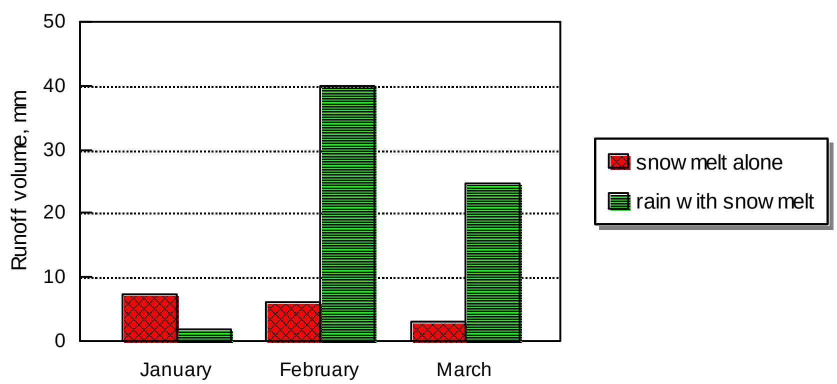

FIGURE 3-36 Runoff volumes for snowmelt events alone and when rain falls on melting snow packs (Toronto industrial area). SOURCE: Pitt and McLean (1986).

Whether pollutant loadings are higher or lower for snowmelt than for rainfall depends on the particular pollutant and its seasonal prevalence in the environment. For example, the high concentrations of dissolved solids found in snowmelt are usually caused by high chloride concentrations that stem from the amount of de-icing salt used. Figure 3-37 is a plot of the chloride concentrations in the influent to the Monroe Street detention pond in Madison, Wisconsin. Chloride levels are negligible in the non-winter months but increase dramatically when road salting begins in the fall, and remain high through the snow melting period, even extending another month or so after the snowpack in the area has melted. Bennett et al. (1981) found that suspended solids and COD loadings for snowmelt runoff were about one-half of those for rainfall. Nutrients were much lower for snowmelt, while the loadings for lead were about the same for both forms of precipitation. Oberts (1994) reports that much of the annual pollutant yields from event flows in Minneapolis is accounted for by end-of-winter major melts. End-of-winter melts yielded 8 to 20 percent of the total phosphorous and total lead annual load in Minnesota. Small midwinter melts accounted for less than 5 percent of the total loads. Box 3-8 shows mass pollutant discharges for a study site in Toronto and emphasizes the significance of snowmelt discharges on the total annual storm drainage discharges.

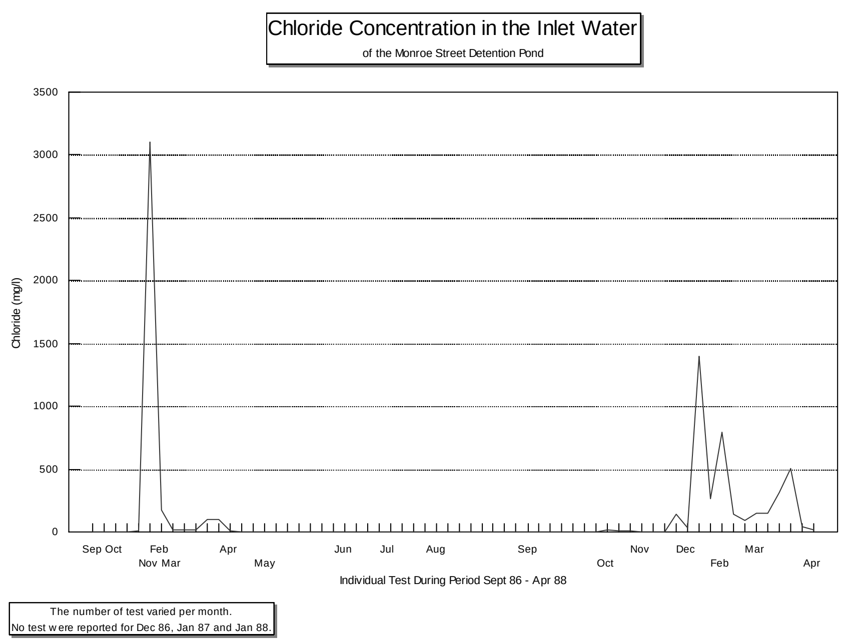

FIGURE 3-37 Monroe Street detention pond chloride concentration of influent (1986–1988). SOURCE: House et al. (1993).

BOX 3-8
The Contribution of Dry Weather Discharges and Snowmelt to Overall Runoff in Toronto, Ontario

An extensive analysis of all types of stormwater flow—for both dry and wet weather—was conducted in Toronto in the mid-1980s (Pitt and McLean, 1986). The Toronto Area Watershed Management Strategy study included comprehensive monitoring in a residential/commercial area and an industrial area for summer stormwater, warm season dry weather flows, snowmelt, and cold season dry weather flows. In addition to the outfall monitoring, detailed source area sheet flow monitoring was also conducted during rain and snowmelt events to determine the relative magnitude of pollutant sources. Particulate accumulation and wash-off tests were also conducted for a variety of streets in order to better determine their role in contaminant contributions.

Tables 3-9 and 3-10 summarize Toronto residential/commercial and industrial urban runoff median concentrations during both warm and cold weather, respectively. These tables show the relative volumes and concentrations of wet weather and dry weather flows coming from the different land uses. The bacteria densities during cold weather are substantially less than during warm weather, but are still relatively high; similar findings were noted during the NURP studies (EPA, 1983). However, chloride concentrations and dissolved solids are much higher during cold weather. Early spring stormwater events also contain high dissolved solids concentrations. Cold weather runoff accounted for more than half of the heavy metal discharges in the residential/commercial area, while warm weather discharges of zinc were much greater than the cold weather discharges for the industrial area. Warm weather flows were also the predominant sources of phosphorus for the industrial area.

One of the interesting observations is that, at these monitoring locations, warm weather stormwater runoff only contributed about 20 to 30 percent of the total annual flows being discharged from the separate stormwater outfalls. The magnitudes of the base flows were especially surprising, as these monitoring locations were research sites to investigate stormwater processes and were carefully investigated to ensure that they did not have significant inappropriate discharges before they were selected for the monitoring programs.

In comparing runoff from the industrial and residential catchments, Pitt and McLean (1986) observed that concentrations of most constituents in runoff from the industrial watershed were typically greater than the concentrations of the same constituents in the residential runoff. The only constituents with a unit-area yield that were lower in the industrial area were chlorides and total dissolved solids, which was attributed to the use of road deicing salts in residential areas. Annual yields of several constituents (total solids, total dissolved solids, chlorides, ammonia nitrogen, and phenolics) were dominated by cold weather flows, irrespective of the land use.

A comparison of the Toronto sheet flow data from the different land-use areas indicated that the highest concentrations of lead and zinc were found in samples collected from paved areas and roads during both rain runoff and snowmelt (Pitt and McLean, 1986). Fecal coliform values were significantly higher on sidewalks and on, or near, roads during snowmelt sampling, likely because these areas are where dogs would be walked in winter conditions. In warm weather, dog walking would be less concentrated into these areas. The concentrations for total solids from grass or bare open areas were reduced dramatically during snowmelt compared to rain runoff, an indication of the reduced erosion and the

continues next page

BOX 3-8 Continued

poor delivery of particulate pollutants during snowmelt periods. Cold weather sheet flow median concentrations of particulate solids for the grass and open areas (80 mg/L) were much less than the TSS concentrations observed during warm weather runoff (250 mg/L) for these same areas. Snowmelt total solids concentrations also increased in areas located near roads due to the influence of road salting on dissolved solids concentrations. In the residential areas, streets were the most significant source of snowmelt solids, while yards and open areas were the major sources of nutrients. Parking and storage areas contrib-

TABLE 3-9 Median Pollutant Concentrations Observed at Toronto Outfalls during Warm Weather[1]

Measured Parameter	Baseflow		Stormwater	
	Residential	*Industrial*	*Residential*	*Industrial*
Stormwater volume (m^3/ha/season)	—	—	950	1500
Baseflow volume (m^3/ha/season)	1700	2100	—	—
Total residue	979	554	256	371
Total dissolved solids	973	454	230	208
Suspended solids	<5	43	22	117
Chlorides	281	78	34	17
Total phosphorus	0.09	0.73	0.28	0.75
Phosphates	<0.06	0.12	0.02	0.16
Total Kjeldahl nitrogen (organic N plus NH_3)	0.9	2.4	2.5	2.0
Ammonia nitrogen	<0.1	<0.1	<0.1	<0.1
Chemical oxygen demand	22	108	55	106
Fecal coliform bacteria (#/100 mL)	33,000	7,000	40,000	49,000
Fecal strep. bacteria (#/100 mL)	2,300	8,800	20,000	39,000
Pseudomonas aeruginosa bacteria (#/100 mL)	2,900	2,380	2,700	11,000
Cadmium	<0.01	<0.01	<0.01	<0.01
Chromium	<0.06	0.42	<0.06	0.32
Copper	0.02	0.05	0.03	0.06
Lead	<0.04	<0.04	<0.06	0.08
Zinc	0.04	0.18	0.06	0.19
Phenolics (μg/L)	<1.5	2.0	1.2	5.1
α-BHC (ng/L)	17	<1	1	3.5
γ-BHC (lindane) (ng/L)	5	<2	<1	<1
Chlordane (ng/L)	4	<2	<2	<2
Dieldrin (ng/L)	4	<5	<2	<2
Pentachlorophenol (ng/L)	280	50	70	705

[1]Values are in mg/L unless otherwise indicated. Warm weather samples were obtained during the late spring, summer, and early fall months when the air temperatures were above freezing and no snow was present.
SOURCE: Pitt and McLean (1986).

uted the most snowmelt pollutants in the industrial area. An analysis of snow samples taken along a transect of a snowpack adjacent to an industrial road showed that the pollutant levels decreased as a function of distance from the roadway. At distances greater than 3 to 5 meters from the edge of the snowpack, the concentrations were relatively constant. Novotny et al. (1986) sampled along a transect of a snowpack by a freeway in Milwaukee. They also found that the concentration of constituents decreased as the distance from the road increased. Most of the measured constituents, including total solids and lead, were at or near background levels at 30 meters or more from the road.

TABLE 3-10 Median Pollutant Concentrations Observed at Toronto Outfalls during Cold Weather[1]

	Baseflow		**Snowmelt**	
Measured Parameter	*Residential*	*Industrial*	*Residential*	*Industrial*
Stormwater volume (m^3/ha/season)	—	—	1800	830
Base flow volume (m^3/ha/season)	1100	660	—	—
Total residue	2230	1080	1580	1340
Total dissolved solids	2210	1020	1530	1240
Suspended solids	21	50	30	95
Chlorides	1080	470	660	620
Total phosphorus	0.18	0.34	0.23	0.50
Phosphates	<0.05	<0.02	<0.06	0.14
Total Kjeldahl nitrogen (organic N plus NH_3)	1.4	2.0	1.7	2.5
Ammonia nitrogen	<0.1	<0.1	0.2	0.4
Chemical oxygen demand	48	68	40	94
Fecal coliform bacteria (#/100 mL)	9800	400	2320	300
Fecal strep bacteria (#/100 mL)	1400	2400	1900	2500
Pseudomonas aeruginosa bacteria (#/100 mL)	85	55	20	30
Cadmium	<0.01	<0.01	<0.01	0.01
Chromium	<0.01	0.24	<0.01	0.35
Copper	0.02	0.04	0.04	0.07
Lead	<0.06	<0.04	0.09	0.08
Zinc	0.07	0.15	0.12	0.31
Phenolics (mg/L)	2.0	7.3	2.5	15
α-BHC (ng/L)	NA	3	4	5
γ-BHC (lindane) (ng/L)	NA	NA	2	1
Chlordane (ng/L)	NA	NA	11	2
Dieldrin (ng/L)	NA	NA	2	NA
Pentachlorophenol (ng/L)	NA	NA	NA	40

[1]Values are in mg/L unless otherwise indicated. Cold weather samples were obtained during the winter months when the air temperatures were commonly below freezing. Snowmelt samples were obtained during snowmelt episodes and when rain fell on snow.
NA, not analyzed
SOURCE: Pitt and McLean (1986).

Atmospheric Deposition

The atmosphere contains a diverse array of contaminants, including metals (e.g., copper, chromium, lead, mercury, zinc), nutrients (nitrogen, phosphorus), and organic compounds (e.g., PAHs, polychlorinated biphenyls, pesticides). These contaminants are introduced to the atmosphere by a variety of sources, including local point sources (e.g., power plant stacks) and mobile sources (e.g., motor vehicles), local fugitive emissions (e.g., street dust and wind-eroded materials), and transport from non-local areas. These emissions, composed of gases, small particles (aerosols), and larger particles, become entrained in the atmosphere and subject to a complex series of physical and chemical reactions (Schueler, 1983).

Atmospheric contaminants are deposited on land and water in two ways—termed wet deposition and dry deposition. Wet deposition (or wetfall) involves the sorption and condensation of pollutants to water drops and snowflakes followed by deposition with precipitation. This mechanism dominates the deposition of gases and aerosol particles. Dry deposition (or dryfall) is the direct transfer of contaminants to land or water by gravity (particles) or by diffusion (vapor and particles). Dry deposition occurs when atmospheric turbulence is not sufficient to counteract the tendency of particles to fall out at a rate governed, but not exclusively determined, by gravity (Schueler, 1983).

As atmospheric contaminants deposit, they can exert an influence on stormwater in several ways. Contaminants deposited by wetfall are directly conveyed to stormwater while those in dryfall can be washed off the land surface. For both processes, the atmospheric load of contaminants is strongly influenced by-characteristics such as the amount of impervious surface, the magnitude and proximity of emission sources, wind speed and direction, and precipitation magnitude and frequency (Schueler, 1983). Deposition rates can depend on the type of contaminant and can be site-specific. The relationships between atmospheric deposition and stormwater quality are, however, not well understood and difficult to determine. Following are a few illustrative examples.

Southern California

Several studies have addressed atmospheric deposition in Southern California (e.g., Lu et al., 2003; Harris and Davidson, 2005; Stolzenbach et al., 2007). Stolzenbach et al. and Lu et al. conclude the following *for this region:*

- the major source of contaminants to the atmosphere in this region is associated with resuspended dust, primarily from roads,
- contaminants in resuspended dust may reflect historical as well as current sources and distant as well as local sources,
- atmospheric loadings to the receiving water are primarily the result of chronic daily dry deposition of large particles greater than 10 μm in size on the

watershed rather than directly on a waterbody,

- significant spatial variability occurs in trace metal mass loadings and deposition fluxes, particularly along transportation corridors along the coast and the mountain slopes of the airshed,
- significant diurnal and seasonal variations occur in the deposition of trace metals, and
- atmospheric deposition of metals is a significant component of contaminant loading to waterbodies in the region relative to other point and non-point sources.

Harris and Davidson (2005) have reported that traditional sources of lead to the south coast air basin of California accounted for less than 15 percent of the lead exiting the basin each year. They resolve this difference by considering that lead particles deposited during the years of leaded gasoline use are resuspended as airborne lead at this time, some decades after their original deposition. This result indicates that lead levels in the soil will remain elevated for decades and that resuspension of this lead will remain a major source of atmospheric lead well into the future.

Sabin et al. (2005) assessed the contribution of trace metals (chromium, copper, lead, nickel, and zinc) from atmospheric deposition to stormwater runoff in a small impervious urban catchment in the Los Angeles area. Dry deposition contributed 90 percent or more of the total deposition inside the catchment, indicating the dominance of dry deposition in semi-arid regions such as Los Angeles. Deposition potentially accounted for from 57 to 90 percent of the total trace metals in stormwater in the study area, demonstrating that atmospheric deposition can be an important source of trace metals in stormwater near urban centers.

San Francisco

Dissolved copper is toxic to phytoplankton, the base of the aquatic food chain. Copper and other metals are released in small quantities when drivers depress their brakes. The Brake Pad Partnership (*http://www.suscon.org/brakepad/index/asp*) has conducted studies to determine how much copper is released as wear debris, and how it travels through the air and streets to surface waters. A comprehensive and complex model of copper loads to and of transport and reactions in San Francisco Bay was developed (Yee and Franz, 2005). Objectives were to provide daily loadings of flow, TSS, and copper to the bay and to estimate the relative contribution of brake pad wear debris to copper in the bay. The modeling results (Rosselot, 2006a) indicated that an estimated 47,000 kg of copper was released to the atmosphere in the Bay Area in 2003. Of this amount, 17,000 kg Cu/yr was dry-deposited in subwatersheds; 3,200 kg Cu/yr was wet-deposited in subwatersheds; 1,200 kg Cu/yr was dry-deposited directly to bay waters; and 1,300 kg Cu/yr was wet-deposited directly to bay waters. The remaining 24,000 kg Cu/yr remained airborne until it left the Bay

Area. The contribution of copper from brake pads to the bay is estimated to range from 10 to 35 percent of the total copper input, with the best estimate being 23 percent (Rosselot, 2006a,b).

Washington, D.C., Metropolitan Area

Schueler (1983) investigated the atmospheric deposition of several contaminants in Washington, D.C., and its surrounding areas in the early 1980s. The contaminants assessed included trace metals (cadmium, copper, iron, lead, nickel, and zinc), nutrients (nitrogen and phosphorus), solids, and organics as measured collectively by BOD and COD. Dryfall solids loading increased progressively from rural to urban sites. A similar trend was observed for total phosphorus, total nitrogen, and trace metal dry deposition rates. Wet deposition rates exhibited few consistent regional patterns.

The relative importance of wet and dry deposition varied considerably with each contaminant and each site. For example, most of the nitrogen was supplied by wet deposition while most of the phosphorus was delivered via dry deposition. If a contaminant is deposited primarily by wet deposition, it is likely that a major fraction of it will be rapidly entrained in urban runoff.

Atmospheric sources were estimated to contribute from 70 to 95 percent of the total nitrogen load to urban runoff and 20 to 35 percent of the total phosphorus load. Overall, atmospheric deposition appeared to be a moderate source of pollutants in urban runoff. However, with the exception of nitrogen, atmospheric deposition was not the major source.

Average annual atmospheric deposition rates suggested a general trend toward greater deposition rates from rural to suburban to urban sites. This pattern was most pronounced for dry deposition. Wet deposition was the most important deposition mechanism for total nitrogen, nitrate, organic nitrogen, COD, copper, and zinc. Dry deposition was most important for most soil-related constituents, such as total solids, iron, lead, total phosphorus, and orthophosphate.

Measurements of rainfall pH showed median values between 4.0 and 4.1 at all stations and during all seasons. Increased mobilization of trace metals from urban surfaces caused by acid rain was noted at several monitoring sites.

***

Relationships between atmospheric deposition rates and the quality of urban stormwater are complex and cannot be generalized regionally or temporally. Site-specific measurements or reliable estimates of (1) contaminant sources, (2) atmospheric particle size and contaminant concentrations, (3) deposition rates and mechanisms, (4) land surface characteristics, (5) local and regional hydrology and meteorology, and (6) contaminant concentrations in stormwater are needed to assess management decisions to improve stormwater quality. Transportation is a major source of metals (lead in gasoline, zinc in tires, copper in brake pads). The results of the modeling of copper in San Francisco and its watershed demonstrate the feasibility of modeling the impact of a source, in this case copper input by atmospheric deposition, on water quality in a receiving waterbody.

BIOLOGICAL RESPONSES TO URBANIZATION

As discussed in Chapter 1, the biological integrity of aquatic ecosystems is influenced by five major categories of environmental stressors: (1) chemical, (2) hydrologic, (3) physical (e.g., habitat), (4) biological (e.g., disease, alien species), and (5) energy-related factors (e.g., nutrient dynamics). Recent studies on biological assemblages in urban or urbanizing waters have begun to examine how stormwater stressors limit biological potential along various urban gradients (Horner et al., 2003; Carter and Fend, 2005; Meador et al., 2005; Barbour et al., 2008; Purcell et al., 2009). Advances in biological monitoring and assessment over the past two decades have enabled much of this research. Today, many states and tribes use biological data to directly measure their aquatic life beneficial uses and have developed numeric biocriteria that are institutionalized in their water quality standards. Most of these approaches compare biology and stressors to suites of reference sites (Hughes, 1995; Stoddard et al., 2006), which can vary from near-pristine areas to agricultural landscapes. While this section focuses on streams because of the wealth of data, similar work is being performed on other waterbody types such as wetlands (Mack and Micacchion, 2007) and estuaries, both of which are susceptible to stormwater pollutants such as metals because of their depositional nature (Morrisey et al., 2000).

Aquatic life beneficial uses are based on achieving aquatic *potential* given feasible restorative actions. Because such potential may vary substantially across a region depending on land use and other factors, some states have adopted tiered aquatic life uses (see Box 2-1). The potential of many urban streams is likely to be something less than "biological integrity" (the ultimate goal of the CWA) or even "fishable–swimmable" goals, which are the interim goals of the CWA. Indeed, there is a near-universal, negative association between biological assemblages in streams and increasing urbanization, to the extent that it has been termed the "Urban Stream Syndrome" (Walsh et al., 2005). Recent investigations that have quantified the responses of macroinvertebrates and other biological assemblages along multiple measures of urban/stormwater stressors have discussed how best to set aquatic life goals for urban streams (Booth and Jackson, 1997; Bernhardt and Palmer, 2007). One of the most important contributions to this debate has been the development of the Biological Condition Gradient (BCG) concept by EPA. The BCG is an attempt to anchor and standardize interpretations of biological conditions and to unify biological monitoring results across the United States in order to advance the use of tiered aquatic life beneficial uses. This section summarizes the characteristic biological responses to urban gradients, within the framework of the BCG, and it reviews evidence of biological responses within the aforementioned five major categories of environmental stressors.

Biological Condition Gradient

The BCG framework is an ecological model of how structural and functional components of biological assemblages change along gradients of increasing stressors of many kinds (Davies and Jackson, 2006). Ecological systems have some common general attributes related to their structure and function that form the basis for how biological organisms respond to stressors in the environment. Over the past 20 years, development of biological indicators nationwide has taken advantage of these repeatable biological responses to stress; however, state benchmarks often have varied substantially, even between adjacent states. To gain consistency, the EPA convened a national workgroup of EPA Regions, States, and Tribes to develop the BCG—a standardized, nationally applicable model that defines important attributes of biological assemblages and describes how these attributes change along a gradient of increasing stress from pristine environments to severely impaired conditions (Figure 3-38; Davies and Jackson, 2006). The goals of this work were to improve national consistency in the rating and application of biological assessment tools for all types of waterbodies and to provide a baseline for the development of tiered aquatic life uses.

To date, the BCG has been applied to assemblages including aquatic macroinvertebrates, fish, Unionid mussels, and algae in streams, but it could be applied to any organism group in any type of waterbody. The BCG is derived by applying a suite of ten ecological attributes that allows biological condition to be interpreted independently of assessment method (Table 3-11; Davies and Jackson, 2006). The first five attributes focus on taxa sensitivity, an important component of tools such as multimetric indices (e.g., the Index of Biotic Integrity [IBI], the Invertebrate Community Index [ICI]; see Box 2-3) used in the United States and Europe. Many indicator taxa have been widely studied, and, for groups such as fish, historical data often exist. Most states have established lists of tolerant and intolerant species as part of their use of biological indices (Simon and Lyons, 1995). The relatively large literature on species population and distribution changes in response to stressors and landscape condition offers insight into the mechanisms for population shifts, some of which are summarized in this section.

The first two attributes of the BCG relate to those streams that are closest to natural or pristine, with most taxa "as naturally occur." Attribute 1 and 2 taxa are the most sensitive species that typically disappear with even minor stress. Table 3-12 lists some example attribute 1 taxa for four different regions of the United States. Attribute 3 reflects more ubiquitous, but still sensitive, species that can provide information as human influence on the landscape becomes more obvious, but is not yet severe. Attributes 5 and 6 are taxa that increase in abundance and distribution with increasing stress. The organism condition at-

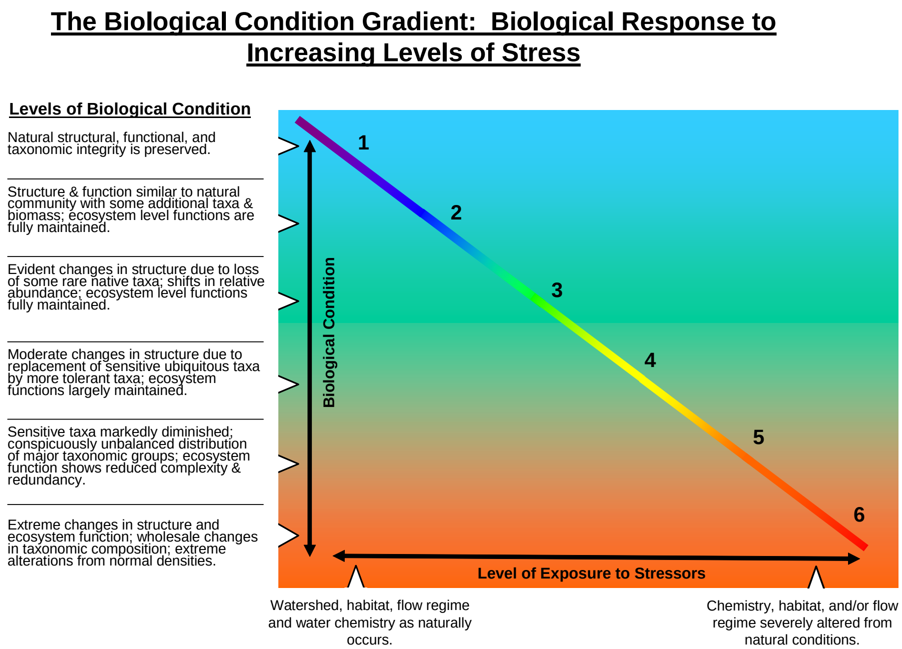

FIGURE 3-38 The Biological Condition Gradient (BCG) and summaries of biological condition along tiers of this gradient. SOURCE: Modified from Davies and Jackson (2006) by EPA.

TABLE 3-11 Ecological attributes that comprise the basis for the BCG

1.	Historically documented, sensitive, long-lived or regionally endemic taxa
2.	Sensitive-rare taxa
3.	Sensitive-ubiquitous taxa
4.	Taxa of intermediate tolerance
5.	Tolerant taxa
6.	Non-native or introduced taxa
7.	Organism condition
8.	Ecosystem functions
9.	Spatial and temporal extent of detrimental effects
10.	Ecosystem connectance

SOURCE: EPA (2005).

TABLE 3-12 Example of Taxa that *Might Serve* as Attribute 1: "Historically Documented, Sensitive, Long-Lived, Regionally Endemic Taxa for Streams in Four Regions of the United States"

State and Taxon	Taxa Representative of Attribute I
Maine	
Mollusks	brook floater (*Alasmodonta varicosa*), triangle floater (*Alasmodonta undulata*), yellow lampmussel (*Lampsilis cariosa*)
Fishes	brook stickleback (*Culaea inconstans*), swamp darter (*Etheostoma fusiforme*)
Washington	
Fishes	steelhead (*Oncorhynchus mykiss*)
Amphibians	spotted frog (*Rana pretiosa*)
Arizona	
Mollusks	spring snails (*Pyrgulopsis* spp.)
Fishes	Gila trout (*Oncorhynchus gilae*), Apache trout (*Oncorhynchus apache*), cutthroat trout (endemic strains) (*Oncorhynchus clarki*)
Amphibians	Chihuahua leopard frog (*Rana chiricahuensis*)
Kansas	
Mollusks†	hickorynut (*Obovaria olivaria*), black sandshell (*Ligumia recta*), ponderous campeloma (*Campeloma crassulum*)
Fishes	Arkansas River shiner (*Notropis girardi*), Topeka shiner (*Notropis topeka*), Arkansas darter (*Etheostoma cragini*), Neosho madtom (*Noturus placidus*), flathead chub (*Platygobio gracilisa*)
Other invertebrates	ringed crayfish (*Orconectes neglectus neglectus*), Plains sand-burrowing mayfly (*Homoeoneuria ammophila*)
Amphibians	Plains spadefood toad (*Spea bombifrans*), Great Plains toad (*Bugo cognatus*), Great Plains narrowmouth toad (*Gastrophryne olivaceae*), Plains leopard frog (*Rana blairi*)

†Although not truly endemic to the central plains, these regionally extirpated mollusks were widely distributed in eastern Kansas prior to the onset of intensive agriculture.
SOURCE: Table 7 from Davies and Jackson (2006). Reprinted, with permission, from Davies and Jackson (2006). Copyright 2006 by Ecological Society of America.

tribute (7) includes the presence of anomalies (e.g., tumors, lesions, eroded fins, etc.) or the presence of large or long-lived individuals in a population. Most natural streams typically have few or incidental rates of "anomalies" associated with disease and stress. Natural waterbodies typically also have the entire range of life stages present, as would be expected. However, as stress is increased, larger individuals may disappear or emigrate, or reproductive failure may occur. Ecosystem function (attribute 8) is very difficult to measure directly (Davies and Jackson, 2006). However, certain functions can be inferred from structural measures common to various multimetric indices, examples of which are listed in Table 3-13. The last two attributes (9 and 10) may be of particular importance with regard to stormwater and urban impacts. Cumulative impacts are a characteristic of urbanization, and biological organisms typically integrate the effects of many small insults to the landscape. Additionally, most natural systems often have strong "connectance," such that aquatic life often has stages that rely on migrating across multiple types or sizes of waterbodies. Urbanized streams can decrease connectance by creating migration blocks, including vertical barriers at road crossings and small dams (Warren and Pardew, 1998).

TABLE 3-13 Function Ecological Attributes or Process Rates and Their Structural Indicators

Biotic Level and Function or Process	**Structural Indicator**
Individual level	
Fecundity	Maximum individual size, number of eggs
Growth and metabolism	Length/mass (condition)
Morbidity	Percentage anomalies
Population Level	
Growth and fecundity	Density
Mortality	Size- or age-class distribution
Production	Biomass, standing crop, catch per unit effort
Sustainability	Size- or age-class distribution
Migration, reproduction	Presence or absence, density
Community or assemblage level	
Production/respiration ratio, autotrophy vs heterotrophy	Trophic guilds, indicator species
Primary production	Biomass, ash-free dry mass
Ecosystem level	
Connectivity	Degree of aquatic and riparian fragmentation longitudinally, vertically, and horizontally; presence or absence of diadromous and potadromous species

SOURCE: Table 4 from Davies and Jackson (2006). Reprinted, with permission, from Davies and Jackson (2006). Copyright 2006 by Ecological Society of America.

Construction of a BCG creates a conceptual framework for developing stressor–response gradients for particular urban areas. The initial work done to develop the BCG derived a series of six tiers to describe a gradient of biological condition that is anchored in pristine conditions (“as naturally occurs”) and that extends to severely degraded conditions (see Figure 3-38). Exercises done by the national work group to derive such a gradient for macroinvertebrates in wadeable streams showed strong consistency in assigning tiers to datasets using the descriptions of taxa for each attribute along these gradients (Davies and Jackson, 2006). Substantial data already exist to populate many of the attributes of the BCG and to provide mechanistic underpinning for the expected directions of change.

The BCG is not a replacement for assessment tools such as the IBI or multivariate predictive models (e.g., RIVPACS approach), but rather a conceptual overlay for characterizing the anchor point-of-reference conditions and a consistent way to communicate biological condition along gradients of stress. As such, it has strong application to understanding stormwater impacts and to communicating where a goal is located along the gradient of biological condition. While most urban goals may be distant from “pristine” or “natural,” the BCG process can dispel misconceptions that alternate urban goals are “dead streams” or unsafe in some manner.

Factors Limiting Aquatic Assemblages in Urban Waters

A slew of recent investigations have quantified the responses of macroinvertebrates and other biological assemblages to multiple measures of urbanization and to stormwater in particular. One important conclusion of some of this work is that declines in the highest biological condition start with low levels of anthropogenic change (e.g., 5 to 25 percent impervious surface); higher levels of urbanization severely alter aquatic conditions (Horner et al., 2003). This has important consequences for protecting sites with the highest biological integrity, as they may be among the most vulnerable. The non-threshold nature of this aquatic response and the typical wedge-shaped response to multiple stressors by aquatic assemblages are discussed in Box 3-9.

BOX 3-9
Non-threshold Nature of the Decline of Biological Assemblages Along Urban Stressor Gradients

Several recent surveys have demonstrated that biological assemblages begin to decline in condition with even low levels of urban disturbance as measured by various gradients of urbanization (e.g., May, 1996; Horner et al., 1997; May et al., 1997; Horner et al., 2003; Moore and Palmer, 2005; Barbour et al., 2008). This box summarizes the work of Horner et al. (2003) in small streams in three regions: Montgomery County, Maryland; Austin, Texas; and the Puget Sound area of Washington. Geographic Information System (GIS) analyses using information such as land use, total impervious area, and riparian land use were used to develop multi-metric Watershed Condition Indices (WCIs) for each region. These in turn were related to fish and macroinvertebrate indices, e.g., benthic IBIs, (B-IBI, all three regions), a fish IBI (F-IBI for Maryland) and an index that was the ratio of the sensitive coho salmon to the more tolerant cutthroat trout in collections for the Puget Sound lowland area.

In each of these areas, no or extremely low urban development, substantial forest cover, and minimal disturbance of riparian zones characterized sites with the highest biological scores, but these conditions did not guarantee high scores because other impacts could limit biology even with these "natural" characteristics. In all three regions, high urbanization and loss of natural cover always led to biological degradation (Figures 3-39 and 3-40). The results of this study were similar to other recent studies such as Barbour et al. (2008) that identify a "wedge-shaped" relationship or a "polygonal" relationship (Carter and Fend, 2005) between urban gradients and biological condition. These types of relationships have also been termed "factor-ceiling" relationships (Thomson et al., 1996). The outer surface of these wedges or polygons reflects where the urban gradients limit biological assemblages, such that points below this surface typically represent sites affected by other stressors (e.g., combined sewer overflows, discharges, etc.). In all of these studies it is easier to predict loss of biological conditions as the urban gradients (e.g., WCI) worsen than it is to ensure high biological integrity at low proportions of urban stress (because some other stressor may still limit aquatic condition).

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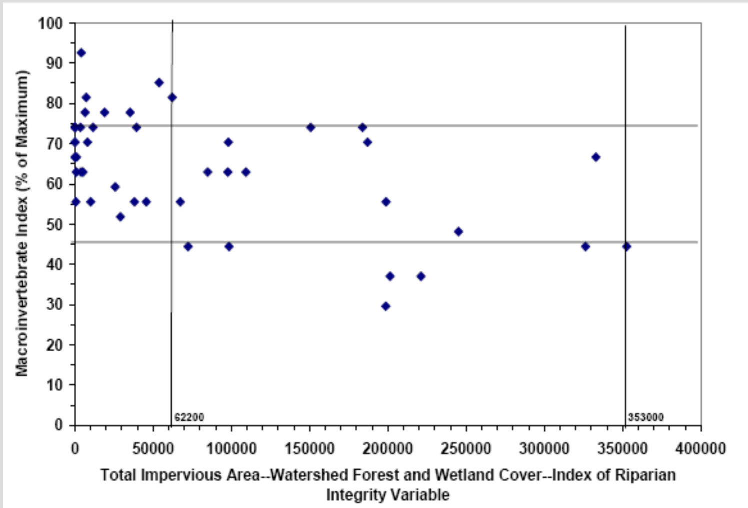
BOX 3-9 Continued



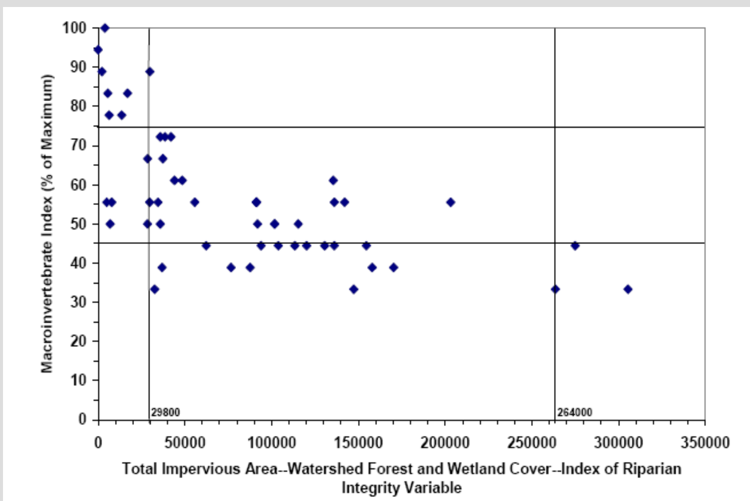


FIGURE 3-39 Plots of a measure of urbanization (TIA + Wetland & Forest Cover + IRI) versus B-IBIs for Austin, Texas (top), and Montgomery County, Maryland (bottom). SOURCE: Horner et al. (2003).

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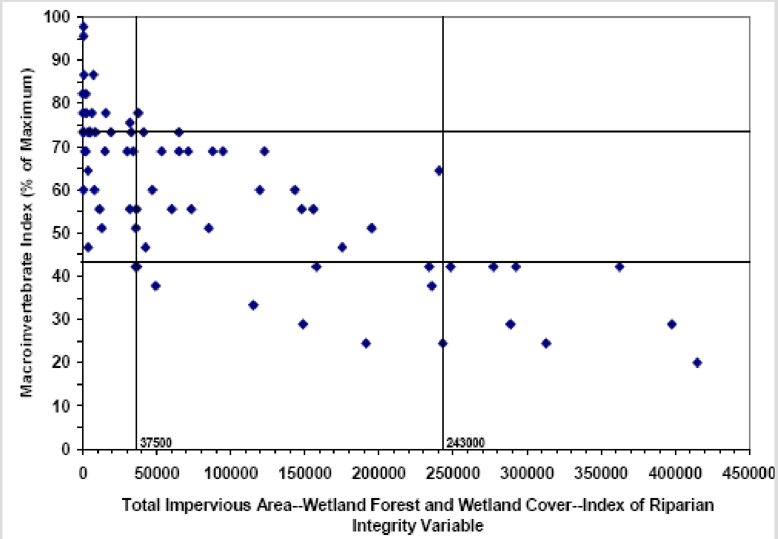
BOX 3-9 Continued



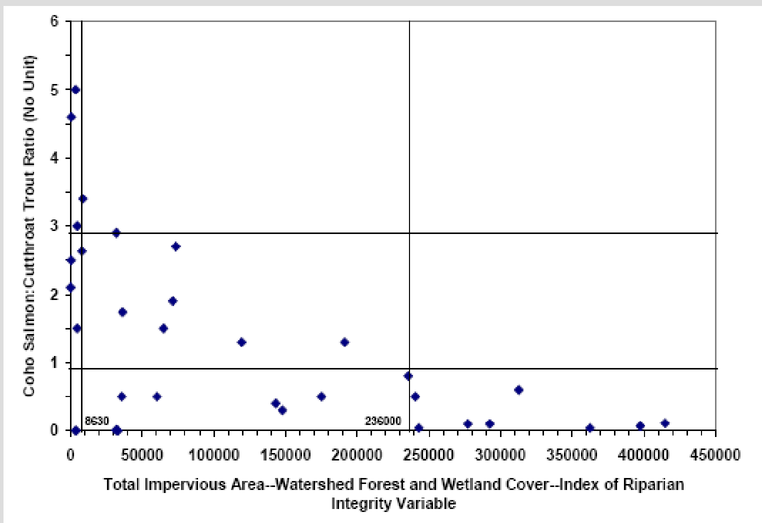


FIGURE 3-40 Plots of a measure of urbanization (TIA + Wetland & Forest Cover + IRI) versus B-IBIs for Puget Sound (top) and versus the ratio of coho salmon to cutthroat trout for Puget Sound (bottom). SOURCE: Horner et al. (2003).

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BOX 3-9 Continued

Horner et al. (2003) also focused on whether structural SCMs could moderate the effects of urbanization on biological assemblages. They made detailed observations of two subbasins in the Puget Sound lowland area, one with a greater degree of stormwater management than the other (although neither had what would be considered comprehensive stormwater management with a focus on water quality issues). As shown in Figure 3-41, at the highest levels of urbanization (triangles), the subbasin with the more extensive use of structural SCMs did have better biological conditions. There was less evidence of biological benefit in the watershed that used SCMs but it had only moderate urbanization and more natural land cover (squares and diamonds). There were no circumstances where high biological condition was observed along with the use of SCMs because high biological condition only occurred where little human alteration was present, and thus SCMs were not used.

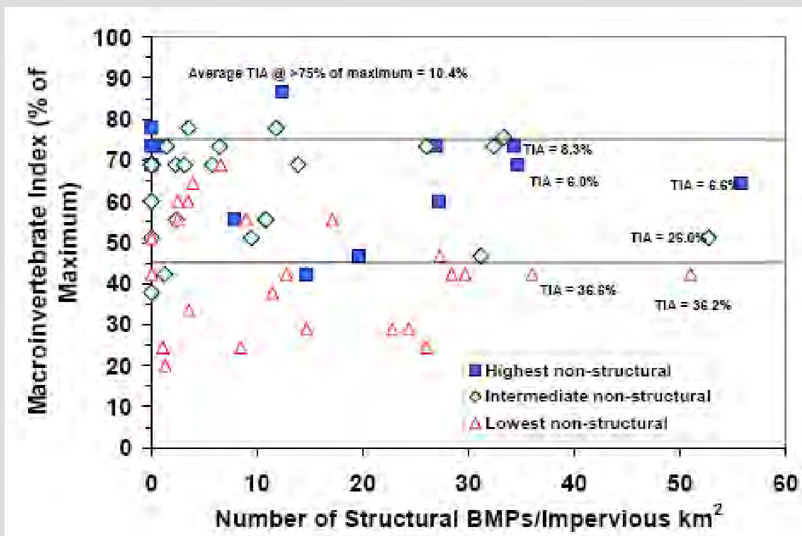

FIGURE 3-41 Macroinvertebrate community index versus structural SCM density with the highest, intermediate, and lowest one-third of natural watershed and riparian cover. The upper and lower horizontal lines represent indices considered to define relatively high and low levels of biological integrity, respectively. SOURCE: Horner et al. (2003).

The sections that follow review the evidence underlying biological responses to each of the major categories of stressors: chemical, hydrologic, physical habitat, biological, and energy-related factors. As will be evident in some of the examples, the stressors themselves can interact (e.g., flow can influence habitat, habitat can influence energy processing, etc.), which increases the complexity of understanding how stormwater affects aquatic ecosystems.

Biological Responses to Toxic Pollutants

The chemical constituents of natural streams vary widely with climatic region, stream size, soil types, and geological setting. Most small natural streams, outside of unique areas wth naturally occurring toxicants, have very low levels of chemicals considered to be toxicants and have relatively low levels of dissolved and particulate materials in general. This applies to chemicals in the water column and in sediments. Increasing amounts of impervious surface in the watershed typically increase the concentrations of many chemical parameters in runoff derived from urban surfaces (e.g., Porcella and Sorenson, 1980; Sprague et al., 2007).

Stormwater concentrations of these pollutants can be variable and sometimes extreme or "toxic" depending on the timing of flows (e.g., first flush), although concentrations at base flows may not routinely exceed water quality benchmarks (Sprague et al., 2007). Historical deposition of toxics in sediments can also be responsible for extremely high pollutant concentrations within waterbodies, even though the stormwater discharges may no longer be active. These situations have been termed "legacy pollution" and are most commonly associated with urban centers that have a history of industrial production.

Natural constituents such as dissolved materials (e.g., chlorides), particulate material (e.g., fine sediments), nutrients (e.g., phosphorus and nitrogen compounds), as well as a myriad of man-made parameters such as heavy metals and organic chemicals (e.g., hydrocarbons, pesticides and herbicides) have been documented to be increased and at times pervasive in stormwater (Heany and Huber, 1984; Paul and Meyer, 2001; Roy et al., 2003; Gilliom et al., 2006) although specific patterns of concentrations can vary with region and ecological setting (Sprague et al., 2007). Water chemistry impacts can also arise from a complex array of permitted discharges, storm sewer discharges, and combined sewer overflows that are treated to certain limits but at times fail to remove all constituents from flows, especially when associated with storm events (Paul and Meyer, 2001).

Streams in urban settings can have increases in toxicant levels compared to background concentrations. In many instances these cases have been associated with loss of aquatic species and impairment of aquatic life goals (EPA, 2002), which are usually explained in terms of typical lethal responses. The complexity of urban systems with regard to pathways, magnitude, duration, and timing of toxicity as well as possible synergistic or antagonistic effects of mixtures of pollutants argues for a broad approach to characterizing effects including not only toxicity testing, but also novel approaches and direct monitoring of biological assemblages (Burton et al., 1999). What is problematic from a traditional management perspective is that aquatic communities may decline before exceedances of water quality criteria are evident (May et al., 1997; Horner et al., 2003).

The first three BCG attributes focus on populations of species of high to very high sensitivity, most of which are uncommon or absent in waters with any substantial level of urbanization. Multi-metric indices such as IBI, which reflect loss of these species, decline at least linearly with increasing urbanization (e.g., Miltner et al., 2004; Meador et al., 2005; Walters et al., 2005). Although toxicity to compounds varies with species, many species of federal and state endangered and threatened aquatic species are more sensitive than "commonly" used test species (Dwyer et al., 2005), such that the loss of aquatic species when toxicant levels exceed criteria are readily explained.

The mechanisms of species population declines in response to chemical contaminants are likely complex and not just limited to direct lethality of the pollutant. Indeed, initial chemical changes may have no "toxic" effects, but rather could change competitive and trophic dynamics by changing primary production and energy dynamics in streams. For example, exposures to aromatic and chlorinated organic compounds from sediments derived from urban areas have been found to increase the susceptibility of salmonids to the bacterial pathogen *Vibrio anguillarum* (Arkoosh et al., 2001). Recent work has found that salmonids show substantial behavioral changes from olfactory degradation related to copper at concentrations as low as 2 μg/L, well below copper water quality criteria and above levels measured in most stormwater-affected streams (Hecht et al., 2007; Sandahl et al., 2007). Salmonid and other fish depend extensively on olfactory cues for feeding, emigration, responding to prey and predators, social and spawning interactions, and other behaviors, such that loss or diminution of such cues may have population-level effects on these species (Sandahl et al., 2007). Copper has been shown to cause olfactory effects on other species (Beyers et al., 2001) and to impair the sensory ability of the fish lateral line (Hernandez et al., 2006), which is nearly ubiquitous in fishes and important for most freshwater species in feeding, schooling, spawning, and other behaviors.

Whole effluent toxicity testing or sediment toxicity testing may misclassify the effects of runoff and effluents in urban settings (Burton et al., 1999). Short-term toxicity tests of stormwater often result in no identified toxicity. However, longer studies (e.g., 30 days) have shown increasing toxicity with time (Masterson and Bannerman, 1994; Ramcheck and Crunkilton, 1995). This suggests that the mechanism of toxicity could be through an ingestion pathway, for example, rather than gill uptake. Metals are often in high concentrations where fine sediments accumulate, and their legacy can extend past the time period of active discharge. Metal concentrations in urban stream sediments have been associated with high rates of fish and invertebrate anomalies such as tumors, lesions, and deformities (Burton, 1992; Ingersoll et al., 1997; Smith et al., 2003).

Biological Responses to Non-Toxicant Chemicals

Non-toxic chemical compounds that occur in stormwater such as nutrients, dissolved oxygen (DO), pH, and dissolved solids as well as physical factors such as temperature can have impacts on aquatic life. The effects of some of these compounds (e.g., DO, pH) have been well documented from other impacts (e.g., wastewater, mining), such that nearly all states have developed water quality criteria for these parameters. For example, nutrient enrichment in stormwater runoff has been associated with declines of biological condition in streams (Miltner and Rankin, 1998). Chloride, sulfate, and other dissolved ions that are often elevated in urban areas can have effects on osmoregulation of aquatic organisms and have been associated with loss of species sensitive to dissolved materials such as mayflies (Kennedy et al., 2004). The concentrations of these compounds can vary regionally (Sprague et al., 2007) and with the degree of urbanization.

Water quality criteria for temperature were spurred by the need for thermal permits for industrial and power plant cooling water discharges. There is a very large literature on the importance of water temperature to aquatic organisms; preference, avoidance, and lethal temperature ranges have been derived for many aquatic species (e.g., Brungs and Jones, 1977; Coutant, 1977; Eaton et al., 1995). In addition, temperature is one of the key classification strata for aquatic life, in that streams are routinely classified as cold water, cool water, or warm water based on the geographic and natural settings of waters. The removal of catchment and riparian vegetation and the general increase in surface runoff from impervious, man-made, and heat-capturing surfaces has been associated with increasing water temperatures in urban waterbodies (Wang and Kanehl, 2003; Nelson and Palmer, 2007). A number of researchers have created models to predict in-stream temperatures based on urban characteristics (Krause et al., 2004; Herb et al., 2008).

Hydrologic Influences on Aquatic Life

The importance of "natural" flow regimes on aquatic life has been well documented (Poff et al., 1997; Richter et al., 1997a, 2003). As watersheds urbanize, flow regimes change from little runoff to over 40 to 90 percent of the rainfall becoming surface runoff (Roesner and Bledsoe, 2003). Flow regimes in urban streams typically are very "flashy," with higher and more frequent peak events, compared to undisturbed systems (Poff et al., 1997; Baker et al., 2004) and well as reduced base flows and more frequent desiccation (Bernhardt and Palmer, 2007). Richter et al. (1996) proposed a series of indicators that could be used to measure hydrologic disturbance, many of which have been used in the recent studies identifying the hydrologic effects of stormwater on aquatic biota (Barbour et al., 2008). Pomeroy et al. (2008) did an extensive review of which flow characteristics appear to have the greatest influence on biological metrics and biological integrity. No single measure of flow was found to be significant in all studies; however, important attributes included flow variability and flashiness, flood frequency, flow volume, flow variability, flow timing, and flow duration.

There are a number of mechanisms that may be responsible for the influence of flow characteristics on aquatic assemblages. Aquatic species vary dramatically in their swimming performance and behaviors, and species are generally adapted to undisturbed flow regimes in an area. Many low- to moderate-gradient small streams in the United States, for example, have strong connections with their flood-prone areas and often possess habitat features that insulate poor swimming species from episodic natural high flows. Undercut banks, rootwads, oxbows, and backwater habitats all can act as refugia from high flows. Some aquatic species are more or less mobile within the sediments, like certain macroinvertebrates (meiofauna or hyporheos) and fish species such as sculpins and madtoms. Secondary impacts from hydrologic changes such as bank erosion and aggradation of fines can render substrates embedded and prohibit organisms, particularly the meiofauna, from moving vertically within the bottom substrates (Schmid-Araya, 2000). Substrate fining has been documented to occur with increasing urbanization, especially in the early stages of development, which can embed spawning habitats and eliminate or reduce spawning success of fish such as salmonids and minnows (Waters, 1995).

Flood flows can cause mortality in the absence of urbanization. For example, flood flows in streams under natural conditions have been documented as a cause of substantial mortality in young or larval fish such as smallmouth bass (Funk and Fleener, 1974; Lorantas and Kristine, 2004). Increased flashiness from urbanization is likely to exacerbate this effect. Thus, increases in the frequency of peak flows during spring will increase the probability of spawning failure, such that sensitive species may eventually be locally extirpated. In urban areas, culverts and other flow obstructions can create conditions that may preclude re-colonization of upstream reaches because weak-swimming fishes cannot move past flow constrictions or leap past vertical drops caused by artificial structures.

Hydrologic simplification and stream straightening that occur in urban streams, often as a result of increased peak flows or as a local management response, typically remove habitat used as temporary refuges from high flows, such as backwater areas, undercut banks, and rootwads. There is a large literature relating populations of fish and macroinvertebrates to various habitat features of streams, rivers, and wetlands. The first two attributes of the BCG identify taxa that are historically documented, sensitive, long-lived, or regionally endemic taxa or sensitive-rare taxa. Many of these taxa are endangered because of large-scale changes in flow-influenced habitats; that is, threats of extinction often center on habitat degradation that influence spawning, feeding, or other aspects of a species life history (Rieman et al., 1993). In contrast, many of the fish and macroinvertebrate taxa that compose regional lists of tolerant taxa are tolerant to habitat changes related to flow disturbance as well as chemical parameters. Understanding the life history attributes of certain species and how they may change with multiple stressors (Power, 1997) is an important tool for understanding complex responses of aquatic ecosystems to urban stressors.

Geomorphic and Habitat Influences on Aquatic Life

In natural waters, geomorphic factors and climate, modified by vegetation and land use, constrain the types of physical habitat features likely to occur in streams (Webster and D'Angelo, 1997). For example, very-low-gradient streams may have few riffles and be dominated by woody debris and bank cover, whereas higher gradient waters may have more habitat types formed by rapidly flowing waters (riffles, runs). Aquatic life in streams is influenced directly by the habitat features that are present, such as substrate types, in-stream structures, bank structure, and flow types (e.g., deep-fast vs. shallow-slow).

As discussed previously, human alteration of landscapes, encroachment on riparian areas, and direct channel modifications (e.g., channelization) that accompany urbanization have often resulted in unstable channels, with negative consequences for aquatic habitat. As urbanization has increased, channel density has declined because streams have been piped, dewatered, and straightened (Meyer and Wallace, 2001; Paul and Meyer, 2001). Changes in the magnitude, relative proportions, and timing of sediment and water delivery have resulted in loss of aquatic life and habitat via a wide range of mechanisms, including changes in channel bed materials, increased suspended sediment loads, loss of riparian habitat due to bank erosion, and changes in the variability of flow and sediment transport characteristics relative to aquatic life cycles (Roesner and Bledsoe, 2003). There are still significant gaps in knowledge about how stormwater stressors can affect stream habitat, especially as one moves from the reach scale to the watershed scale. Understanding the stage and trajectory of channel evolution is critical to understanding channel recovery and expected habitat conditions or in choosing effective restoration options (Simon et al., 2007).

Across much of the United States, stream habitats have been altered to the imperilment of aquatic species (Williams et al., 1989; Richter et al., 1997b; Strayer et al., 2004). A study of rapidly urbanizing streams in central Ohio identified the loss of highly and moderately sensitive species as a key factor the decline in the IBI in these streams (Miltner et al., 2004). These streams had historical fish collections when they were primarily influenced by agricultural land use; sampling after the onset of suburban development documented the loss of many of these species attributable to land-use changes and habitat degradation along these urban streams. Along the BCGs that have been developed for streams, most of the species in attributes 1–3 are specialists requiring very specific habitats for spawning, feeding, and refuge. Habitat alteration, either direct or indirect, creates harsh environments that tend to favor tolerant taxa, which would otherwise be in low abundance. Often these tolerant species are characterized by high reproductive potential, generalist feeding behaviors, tolerance to chemical stressors such as low DO, and pioneering strategies that allow rapid recolonization following acute stressful events.

Altered Energy Pathways in Urban Streams

The pathways of energy flow in streams are an important determinant of aquatic species distributions. In most natural temperate streams, headwaters transform and export energy from stream side vegetation and adjacent land uses into aquatic biomass. The types, amount, and timing of delivery of water, organic material, and debris have important consequences for conditions downstream (Dolloff and Webster, 2000). The energy-transforming aspect of stream ecosystems is difficult to capture directly, so most measures are surrogates, such as the trophic characteristics of assemblages and chemical and physical characteristics consistent with natural energy processes.

An increasingly urban landscape can have a complex array of effects on energy dynamics in streams (Allan, 2004). Loss of riparian areas and changes in riparian vegetation can reduce the supply and quality of coarse organic matter that forms the base of aquatic food webs in most small streams. The reduction in the amount of organic matter with riparian loss is obvious; however, changing species of vegetation (e.g., invasion or planting of exotic species) can affect the quality of organic matter and influence higher trophic levels because, for example, exotic species may have different nutrient values (e.g., C/N ratios, trace chemicals) or process nutrients at a different rate (Royer et al., 1999). Furthermore, native invertebrate taxa may not be adapted to utilize the exotic material (Miller and Boulton, 2005). For example, changes in leaf species in a stream may alter the macroinvertebrate community by favoring species that feed on fast-decaying versus slow-decaying leaves (Smock and MacGregor, 1988; Cummins et al., 1989; Gregory et al., 1991).

Other recent work is examining ways that changes in geomorphology with increasing urbanization can influence trophic structure in streams (Doyle, 2006). Groffman et al. (2005) examined nitrogen processing in stream geomorphic structures such as bars, riffles, and debris dams in suburban and forested areas. Although suburban areas had high rates of production in organic-rich debris dams and gravel bars, higher storm flow effects in urban streams may make these features less stable and able to be maintained (Groffman et al., 2005). Changes in habitat and riparian vegetation may greatly alter trophic patterns of energy transport. For example, local nutrient enrichments combined with reduced riparian vegetation can result in nuisance algal growths in waterbodies that are evidence of simpler energy pathways. Corresponding effects are further water chemistry changes from algal decomposition (e.g.., low DO) or very high algal activity (e.g., high pH) (Ehlinger et al., 2004).

The complexity of energy flow through simple ecosystems is illustrated in Figure 3-42, a "simplified" food web of a headwater stream published by Meyer (1994). The forms in which nutrients are delivered to streams may be more important than actual concentrations as well as the availability of carbon sources essential for nutrient transformation. The nutrient components that form the base of the food web in Figure 3-42 are the FPOM and CPOM boxes. In many natural streams, woody and leafy debris are the most common form of nutrient

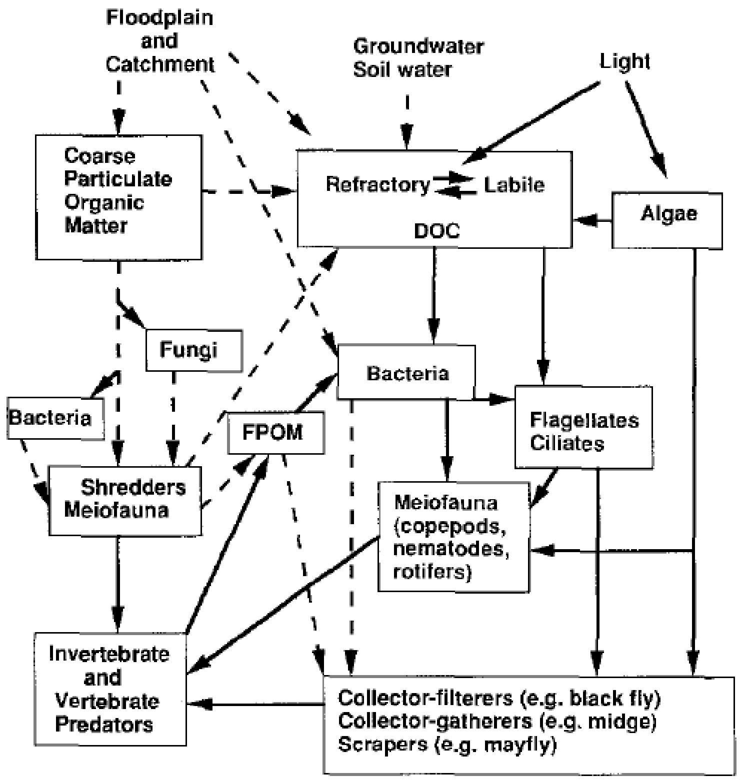

FIGURE 3-42 Simplified diagram of a lotic food web showing sources and major pathways of organic carbon. Dotted lines indicate flows that are a part of the microbial loop in flowing water but not in planktonic systems. SOURCE: Reprinted, with permission, from Meyer (1994). Copyright 1994 by Springer.

input, and changes to urban landscapes often change this to dissolved and finer forms. Urbanization can also reduce the retention of organic debris of streams (Groffman et al., 2005) and the timing of nutrient delivery. Timing can be of crucial importance since species spawning and growth periods may be specifically timed to take advantage of available nutrients.

As important as energy and nutrient dynamics are to stream function, many of the stream characteristics that determine effective energy flow are not typically considered when characterizing stormwater impacts. The best chance for considering these variables and maximizing ecosystem function is through integrated, biologically based monitoring programs that include urban areas (Barbour et al., 2008) and stressor identification procedures (EPA, 2000) to isolate likely causes of impact and to inform the choices of SCMs.

Biological Interactions in Urban Streams

Streams in urbanized environments often are characterized by fewer native and more alien species than natural streams (DeVivo, 1996; Meador et al., 2005). The influence of exotic species is not always predictable and may be most severe in lentic environments (e.g., wetlands, estuaries) and in riparian zones where various exotic aquatic plants can greatly alter natural systems in both structure and function (Hood and Naiman, 2000). Riley et al. (2005) foundthat the presence of alien aquatic amphibians was positively related to degree of urbanization, as was the absence of certain native amphibian species. In a review of possible reasons for this observation, he suggested that altered flow regimes were responsible. In the arid California streams they studied, flow became more constant with urbanization (i.e., natural streams were generally ephemeral), which allowed invasion by exotic species that can prey on, compete with, or hybridize with native species (Riley et al., 2005). The alteration of stream habitat that accompanies urbanization can also lead to predation by domestic cats and dogs or collection by humans, especially where species (e.g., California newts) are large and conspicuous (Riley et al., 2005).

The effects of specific exotic species on aquatic systems has been observed to vary geographically, although recent work has found correlations between total invasion rate and the number of high-impact exotic species (Ricciardi and Kipp, 2008). This suggests that overall efforts to reduce the importation or spread of all alien species should be helpful.

The Role of Biological Monitoring

The preceding sections illustrate the importance of biological data to understanding the complexities associated with urban and stormwater impacts to waterbodies. Although categories of urban stressors have been discussed individually, these stressors routinely, if not universally, co-occur in urban waterbodies. Their cumulative impacts are best measured with biological tools because the biota integrate the influence of all of these stressors.

Many programmatic aspects of the CWA arose as a response to rather obvious impacts of chemical pollutants that were occurring in surface waters during this time. The initial focus of water quality standards was on developing chemical criteria that could serve as engineering endpoints for waste treatment systems (e.g., NPDES permits). Rather general aquatic life goals for streams and rivers that were suitable for the initial focus of the CWA are now considered insufficient to deal with the complex suite of stressors limiting aquatic systems.

To that end, refined aquatic life goals and improved biological monitoring are essential for effective water quality management, including stormwater issues (NRC, 2001). Practical biological and physical monitoring tools have even been developed for very small headwater streams (Ohio EPA, 2002; Fritz et al., 2006), which are particularly affected by stormwater because of their prevalence (greater than 95 percent of channels), their relatively high surface-to-volume ratio, their role in nutrient and material processing, and their vulnerability to direct modification such as channelization and piping (Meyer and Wallace, 2001).

Surrogate indicators of stormwater impacts to aquatic life (such as TSS concentrations) have been widely used because direct biological measures were poorly developed and these surrogates were assumed to be important to pollutant delivery to urban streams. However, biological assessment has rapidly advanced in many states and can be readily applied or if needed modified to be sensitive to stormwater stressors (Barbour et al., 2008). As Karr and Chu (1999) warned, the management of complex systems requires measures that integrate multiple factors. Stormwater permitting is no different, and care must be taken to ensure that permitting and regulatory actions retain ecological relevance. Surrogate measures have an essential role in the assessment of individual SCMs; however, this needs to be kept in context with the entire suite of stressors likely to be important to the aquatic life goals in streams.

Stormwater management programs should not necessarily bear the burden of biological monitoring; rather, well-conceived biological monitoring should be the prevue of state and local government agencies (as discussed more extensively in Chapter 6). Refined aquatic life goals developed for all waters, including urban waters, measured with appropriate biological measures, should be the final endpoint for management. The collection of biological data needs to be closely integrated across multiple disciplines in order to be effective. Pomeroy et al. (2008) describe a multidisciplinary approach to study the effects of stormwater in urban settings, and Scholz and Booth (2001) also propose a monitoring approach for urban watersheds. Such efforts are not necessarily easy, and many institutions find pitfalls when trying to integrate scientific information across disciplines (Benda et al., 2002).

EPA water programs, such as the Total Maximum Daily Load (TMDL) program, have been criticized for having too narrow a focus on a limited number of traditional pollutants to the exclusion of important stressors such as hydrology, habitat alteration, and invasive taxa (Karr and Yoder, 2004)—all serious problems associated with stormwater and urbanization. The science has advanced significantly over the past decade so that biological assessment should be an essential tool for identifying stormwater impacts and informing the choice of SCMs in a region or watershed. Although biological responses to stressors in the ambient environment are by their nature correlative exercises, ecological epidemiology principles or "stressor identification" methods can identify likely causative agents of impairment with relatively high certainty in many instances (Suter, 1993, 2006; EPA, 2000). Coupled with other ambient and source monitoring information, biological information can form the basis for an effective stormwater program. As an example, Box 3-10 introduces the Impervious Cover Model (ICM), which was developed using correlative information on the association between impervious cover and biological metrics. The crux of the ICM is that stormwater management is tailored along a readily measureable gradient (impervious cover) that integrates multiple individual stressor categories that would otherwise be overlooked in the traditional pollutant-based approach to stormwater management. Even the form of the ICM (as conceptualized in Figure 3-43) matches that outlined for the BCG (Figure 3-38). Use of the ICM to improve the MS4 stormwater program is discussed in Chapter 6.

Human Health Impacts

Despite the unequivocal evidence of ecosystem consequences resulting from urban stormwater, a formal risk analysis of the human health effects associated with stormwater runoff is not yet possible. This is because (1) many of the most important waterborne pathogens have not been quantified in stormwater, (2) enumeration methods reported in the current literature are disparate and do not account for particle-bound pathogens, and (3) sampling times during storms have not been standardized nor are known to have occurred during periods of human exposure. Individual studies have investigated the runoff impacts on public health in freshwater (Calderon et al., 1991) and marine waters (Haile et al., 1999; Dwight et al,. 2004; Colford et al., 2007). Although these studies provide ample evidence that stormwater runoff can serve as a vector of pathogens with potential health implications (for example, Ahn et al., 2005, found that fecal indicator bacteria concentrations could exceed California ocean bathing water standards by up to 500 percent in surf zones receiving stormwater runoff), it is difficult to draw conclusive inferences about the specific human health impacts from microbial contamination of stormwater. Calderon et al. (1991) concluded that the currently recommended bacterial indicators are ineffective for predicting potential health effects associated with water contaminated by nonpoint sources of fecal pollution. Furthermore, in a study conducted in Mission Bay, California, which analyzed bacterial indicators using traditional and nontraditional methods (chromogenic substrate and quantitative polymerase chain reaction), as well as a novel bacterial indicator and viruses, traditional fecal indicators were not associated with identified human health risks such as diarrhea and skin rash (Colford et al., 2007).

The Santa Monica Bay study (Haile et al., 1999) indicated that the risks of several health outcomes were higher for people who swam at storm-drain locations compared to those who swam farther from the drain. However, the list of health outcomes that were more statistically significant (fever, chills, ear discharge, cough and phlegm, and significant respiratory) did not include highly

BOX 3-10
The Impervious Cover Model: An Emerging Framework for Urban Stormwater Management

The Impervious Cover Model (ICM) is a management tool that is useful for diagnosing the severity of future stream problems in a subwatershed. The ICM defines four categories of urban streams based on how much impervious cover exists in their subwatershed: *high-quality streams*, *impacted streams, non-supporting streams,* and *urban drainage*. The ICM is then used to develop specific quantitative or narrative predictions for stream indicators within each stream category (see Figure 3-43). These predictions define the severity of current stream impacts and the prospects for their future restoration. Predictions are made for five kinds of urban stream impacts: changes in stream hydrology, alteration of the stream corridor, stream habitat degradation, declining water quality, and loss of aquatic diversity.

The general predictions of the ICM are as follows. Stream segments with less than 10 percent impervious cover (IC) in their contributing drainage area continue to function as **Sensitive Streams**, and are generally able to retain their hydrologic function and support good-to-excellent aquatic diversity. Stream segments that have 10 to 25 percent IC in their contributing drainage area behave as **Impacted Streams** and show clear signs of declining stream health. Most indicators of stream health will fall in the fair range, although some segments may range from fair to good as riparian cover improves. The decline in stream quality is greatest toward the higher end of the IC range. Stream segments that range between 25 and 60 percent subwatershed impervious cover are classified as **Non-Supporting Streams** (i.e., no longer supporting their designated uses in terms of hydrology, channel stability habitat, water quality, or biological diversity). These stream segments become so degraded that any future stream restoration or riparian cover improvements are insufficient to fully recover stream function and diversity (i.e., the streams are so dominated by subwatershed IC that they cannot attain predevelopment conditions). Stream segments whose subwatersheds exceed 60 percent IC are physically altered so that they merely function as a conduit for flood waters. These streams are classified as **Urban Drainage** and consistently have poor water quality, highly unstable channels, and very poor habitat and biodiversity scores. In many cases, these urban stream segments are eliminated altogether by earthworks and/or storm-drain enclosure. Table 3-14 shows in greater detail how stream corridor indicators respond to greater subwatershed impervious cover.

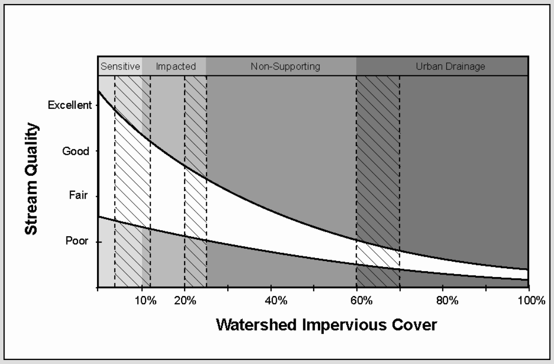

FIGURE 3-43 Changes in Stream Quality with Percent Impervious Cover in the Contributing Watershed. SOURCE: Chesapeake Stormwater Network (2008). Reprinted, with permission, from Chesapeake Stormwater Network (2008). Copyright 2008 by Chesapeake Stormwater Network.

TABLE 3-14 General ICM Predictions Based on Urban Subwatershed Classification (CWP, 2004):

Prediction	Impacted (IC 11 to 25%) [8]	Non-supporting (IC 26 to 60%)	Urban Drainage (IC > 60%)
Runoff as a Fraction of Annual Rainfall [1]	10 to 20%	25 to 60%	60 to 90%
Frequency of Bankfull Flow per Year [2]	1.5 to 3 per year	3 to 7 per year	7 to 10 per year
Fraction of Original Stream Network Remaining	60 to 90%	25 to 60%	10 to 30%
Fraction of Riparian Forest Buffer Intact	50 to 70%	30 to 60%	Less than 30%
Crossings per Stream Mile	1 to 2	2 to 10	None left
Ultimate Channel Enlargement Ration [3]	1.5 to 2.5 larger	2.5 to 6 times larger	6 to 12 times larger
Typical Stream Habitat Score	Fair, but variable	Consistently poor	Poor, often absent
Increased Stream Warming [4]	2 to 4 °F	4 to 8 °F	8+ °F
Annual Nutrient Load [5]	1 to 2 times higher	2 to 4 times higher	4 to 6 times higher
Wet Weather Violations of Bacteria Standards	Frequent	Continuous	Ubiquitous
Fish Advisories	Rare	Potential risk of accumulation	Should be presumed
Aquatic Insect Diversity [6]	Fair to good	Fair	Very poor
Fish Diversity [7]	Fair to good	Poor	Very poor

[1] Based on annual storm runoff coefficient; ranges from 2 to 5% for undeveloped streams.
[2] Predevelopment bankfull flood frequency is about 0.5 per year, or about one bankfull flood every two years.
[3] Ultimate stream-channel cross-section compared to typical predevelopment channel cross section.
[4] Typical increase in mean summer stream temperature in degrees Fahrenheit, compared with shaded rural stream.
[5] Annual unit-area stormwater phosphorus and/or nitrogen load produced from a rural subwatershed.
[6] As measured by benthic index of biotic integrity. Scores for rural streams range from good to very good.
[7] As measured by fish index of biotic integrity. Scores for rural streams range from good to very good.
[8] IC is not the strongest indicator of stream health below 10% IC, so the sensitive streams category is omitted from this table.
SOURCE: Adapted from Schueler (2004).

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BOX 3-10 Continued

Scientific Support for the ICM

The ICM predicts that hydrological, habitat, water quality, and biotic indicators of stream health first begin to decline sharply at around 10 percent total IC in smaller catchments (Schueler, 1994). The ICM has since been extensively tested in ecoregions around the United States and elsewhere, with more than 200 different studies confirming the basic model for single stream indicators or groups of stream indicators (CWP, 2003; Schueler, 2004). Several recent research studies have reinforced the ICM as it is applied to first- to third-order streams (Coles et al., 2004; Horner et al., 2004; Deacon et al., 2005; Fitzpatrick et al., 2005; King et al., 2005; McBride and Booth, 2005; Cianfrina et al., 2006; Urban et al., 2006; Schueler et al., 2008).

Researchers have focused their efforts to define the specific thresholds where urban stream degradation first begins. There is robust debate as to whether there is a sharp initial threshold or merely a continuum of degradation as IC increases, although the latter is more favored. There is much less debate, however, about the dominant role of IC in defining the hydrologic, habitat, water quality, and biodiversity expectations for streams with higher levels of IC (15 to 60 percent).

Caveats to the ICM

The ICM is a powerful predictor of urban stream quality when used appropriately. The first caveat is that subwatershed IC is defined as total impervious area (TIA) and not effective impervious area (EIA). Second, the ICM should be restricted to first- to third-order alluvial streams with moderate gradient and no major point sources of pollutant discharge. The ICM is most useful in projecting the behavior of numerous stream health indicators, and it is not intended to be accurate for every individual stream indicator. In addition, management practices in the contributing catchment or subwatershed must not be poor (e.g., no deforestation, acid mine drainage, intensive row crops, etc.); just because a subwatershed has less than 10 percent IC does not automatically mean that it will have good or excellent stream quality if past catchment management practices were poor.

ICM predictions are general and may not apply to every stream within the proposed classifications. Urban streams are notoriously variable, and factors such as gradient, stream order, stream type, age of subwatershed development, and past land use can and will make some streams depart from these predictions. Indeed, these “outlier” streams are extremely interesting from the standpoint of restoration. In general, subwatershed IC causes a continuous but variable decline in most stream corridor indicators. Consequently, the severity of individual indicator impacts tends to be greater at the upper end of the IC range for each stream category.

Effects of Catchment Treatment on the ICM

Most studies that investigated the ICM were done in communities with some degree of catchment treatment (e.g., stormwater management or stream buffers). Detecting the effect of catchment treatment on the ICM involves a very complex and difficult paired watershed design. Very few catchments meet the criteria for either full treatment or the lack of it, no two catchments are ever really identical, and individual catchments exhibit great variability from year to year. Not surprisingly, the first generation of research studies has produced ambiguous results. For example, seven research studies showed that ponds and wetlands are unable to prevent the degradation of aquatic life in downstream channels associated with higher levels of IC (Galli, 1990; Jones et al., 1996; Horner and May, 1999; Maxted, 1999; MNCPPC, 2000; Horner et al., 2001; Stribling et al., 2001). The primary reasons cited are stream warming (amplified by ponds), changes in organic matter processing, the increased runoff volumes delivered to downstream channels, and habitat degradation caused by channel enlargement.

Riparian forest cover is defined as canopy cover within 100 meters of the stream, and is measured as the percentage of the upstream network in this condition. Numerous researchers have evaluated the relative impact of riparian forest cover and IC on stream geomorphology, aquatic insects, fish assemblages, and various indices of biotic integrity. As a group, the studies suggest that indicator values for urban streams improve when riparian forest cover is retained over at least 50 to 75 percent of the length of the upstream network (Booth et al., 2002; Morley and Karr, 2002; Wang et al., 2003; Allan, 2004; Sweeney et al., 2004; Moore and Palmer, 2005; Cianfrina et al., 2006; Urban et al., 2006).

Application of the ICM to other Receiving Waters

Recent research has focused on the potential value of the ICM in predicting the future quality of receiving waters such as tidal coves, lakes, wetlands and small estuaries. The primary work on small estuaries by Holland et al. (2004) [references cited in CWP (2003), Lerberg et al. (2000)] indicates that adverse changes in physical, sediment, and water quality variables can be detected at 10 to 20 percent subwatershed IC, with a clear biological response observed in the range of 20 to 30 percent IC. The primary physical changes involve greater salinity fluctuations, greater sedimentation, and greater pollutant contamination of sediments. The biological response includes declines in diversity of benthic macroinvertebrates, shrimp, and finfish.

More recent work by King et al. (2005) reported a biological response for coastal plain streams at around 21 to 32 percent urban development (which is usually about twice as high as IC). The thresholds for important water quality indicators such as bacterial exceedances in shellfish beds and beaches appears to begin at about 10 percent subwatershed IC, with chronic violations observed at 20 percent IC (Mallin et al., 2001). Algal blooms and anoxia resulting from nutrient enrichment by stormwater runoff also are routinely noted at 10 to 20 percent subwatershed IC (Mallin et al., 2004).

The primary conclusion to be drawn from the existing science is that the ICM does apply to tidal coves and streams, but that the impervious levels associated with particular biological responses appear to be higher (20 to 30 percent IC for significant declines) than for freshwater streams, presumably due to their greater tidal mixing and inputs from nearshore ecosystems. The ICM may also apply to lakes (CWP, 2003) and freshwater wetlands (Wright et al., 2007) under carefully defined conditions. The initial conclusion is that the application of the ICM shows promise under special conditions, but more controlled research is needed to determine if IC (or other watershed metrics) is useful in forecasting receiving water quality conditions.

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BOX 3-10 Continued

Utility of the ICM in Urban Stream Classification and Watershed Management

The ICM is best used as an urban stream classification tool to set reasonable expectations for the range of likely stream quality indicators (e.g., physical, hydrologic, water quality, habitat, and biological diversity) over broad ranges of subwatershed IC. In particular, it helps define general thresholds where water quality standards or biological narrative conditions cannot be consistently met during wet weather conditions (see Table 6-2). These predictions help stormwater managers and regulators to devise appropriate and geographically explicit stormwater management and subwatershed restoration strategies for their catchments as part of MS4 permit compliance. More specifically, assuming that local monitoring data are available to confirm the general predictions of the ICM, it enables managers to manage stormwater within the context of current and future watershed conditions.

credible gastrointestinal illness, which is curious because the vast majority of epidemiological studies worldwide suggests a causal dose-related relationship between gastrointestinal symptoms and recreational water quality measured by bacterial indicator counts (Pruss, 1998). Dwight et al. (2004) found that surfers in an urban environment reported more symptoms than their rural counterparts; however, water quality was not specifically evaluated in that study.

To better assess the relationship between swimming in waters contaminated by stormwater, which have not been influenced by human sewage, and the risk of related illness, the California Water Boards and the City of Dana Point have initiated an epidemiological study. This study will be conducted at Doheny Beach, Orange County, California, which is a beach known to have high fecal indicator bacteria concentrations with no known human source. The project will examine new techniques for measuring traditional fecal indicator bacteria, new species of bacteria, and viruses to determine whether they yield a better relationship to human health outcomes than the indicators presently used in California. The study is expected to be completed in 2010. In addition, the State of California is researching new methods for rapid detection of beach bacterial indicators and ways to bring these methods into regular use by the environmental monitoring and public health communities to better protect human health.

CONCLUSIONS AND RECOMMENDATIONS

The present state of the science of stormwater reflects both the strengths and weaknesses of historic, monodisciplinary investigations. Each of the component disciplines—hydrology, geomorphology, aquatic chemistry, ecology, land use, and population dynamics—have well-tested theoretical foundations and useful predictive models. In particular, there are many correlative studies showing how parameters co-vary in important but complex and poorly understood ways (e.g., changes in fish community associated with watershed road density or the percentage of IC). Nonetheless, efforts to create mechanistic links between population growth, land-use change, hydrologic alteration, geomorphic adjustments, chemical contamination in stormwater, disrupted energy flows, and biotic interactions, to changes in ecological communities are still in development. Despite this assessment, there are a number of overarching truths that remain poorly integrated into stormwater management decision making, although they have been robustly characterized and have a strong scientific basis. These are expanded upon below.

There is a direct relationship between land cover and the biological condition of downstream receiving waters. The possibility for the highest levels of aquatic biological condition exists only with very light urban transformation of the landscape. Even then, alterations to biological communities have been documented at such low levels of imperviousness, typically associated with roads and the clearing of native vegetation, that there has been no real "urban development" at all. Conversely, the lowest levels of biological condition are inevitable with extensive urban transformation of the landscape, commonly seen after conversion of about one-third to one-half of a contributing watershed into impervious area. Although not every degraded waterbody is a product of intense urban development, all highly urban watersheds produce severely degraded receiving waters. Because of the close and, to date, inexorable linkage between land cover and the health of downstream waters, stormwater management is an unavoidable offshoot of watershed-based land-use planning (or, more commonly, its absence).

The protection of aquatic life in urban streams requires an approach that incorporates all stressors. Urban Stream Syndrome reflects a multitude of effects caused by altered hydrology in urban streams, altered habitat, and polluted runoff. Focusing on only one of these factors is not an effective management strategy. For example, even without noticeably elevated pollutant concentrations in receiving waters, alterations in their hydrologic regimes are associated with impaired biological condition. Achieving the articulated goals for stormwater management under the CWA will require a balanced approach that incorporates hydrology, water quality, and habitat considerations.

The full distribution and sequence of flows (i.e., the flow regime) should be taken into consideration when assessing the impacts of stormwater on streams. Permanently increased stormwater volume is only one aspect of an urban-altered storm hydrograph. It contributes to high in-stream velocities, which in turn increase streambank erosion and accompanying sediment pollution of surface water. Other hydrologic changes, however, include changes in the sequence and frequency of high flows, the rate of rise and fall of the hydrograph, and the season of the year in which high flows can occur. These all can affect both the physical and biological conditions of streams, lakes, and wetlands. Thus, effective hydrologic mitigation for urban development cannot just aim to reduce post-development peak flows to predevelopment peak flows.

A single design storm cannot adequately capture the variability of rain and how that translates into runoff or pollutant loadings, and thus is not suitable for addressing the multiple objectives of stormwater management. Of particular importance to the types of problems associated with urbanization is the size of rain events. The largest and most infrequent rains cause near-bank-full conditions and may be most responsible for habitat destruction; these are the traditional "design storms" used to design safe drainage systems. However, moderate-sized rains are more likely to be associated with most of the annual mass discharges of stormwater pollutants, and these can be very important to the eutrophication of lakes and nearshore waters. Water quality standards for bacterial indicators and total recoverable heavy metals are exceeded for almost *every* rain in urban areas. Therefore, the whole distribution of storm size needs to be evaluated for most urban receiving waters because many of these problems co-exist.

Roads and parking lots can be the most significant type of land cover with respect to stormwater. They constitute as much as 70 percent of total impervious cover in ultra-urban landscapes, and as much as 80 percent of the directly connected impervious cover. Roads tend to capture and export more stormwater pollutants than other land covers in these highly impervious areas because of their close proximity to the variety of pollutants associated with automobiles. This is especially true in areas of the country having mostly small rainfall events (as in the Pacific Northwest). As rainfall amounts become larger, pervious areas in most residential land uses become more significant sources of runoff, sediment, nutrients, and landscaping chemicals. In all cases, directly connected impervious surfaces (roads, parking lots, and roofs that are directly connected to the drainage system) produce the first runoff observed at a storm-drain inlet and outfall because their travel times are the quickest.

Generally, the quality of stormwater from urbanized areas is well characterized, with the common pollutants being sediment, metals, bacteria, nutrients, pesticides, trash, and polycyclic aromatic hydrocarbons. These results come from many thousands of storm events from across the nation, systematically compiled and widely accessible; they form a robust data set of utility to theoreticians and practitioners alike. These data make it possible to accurately estimate pollutant concentrations, which have been shown to vary by land cover and by region across the country. However, characterization data are relatively sparse for individual industrial operations, which makes these sources less amenable to generalized approaches based on reliable assumptions of pollutant types and loads. In addition, industrial operations vary greatly from site to site, such that it may be necessary to separate them into different categories in order to better understand industrial stormwater quality.

Nontraditional sources of stormwater pollution must be taken into consideration when assessing the overall impact of urbanization on receiving waterbodies. These nontraditional sources include atmospheric deposition, snowmelt, and dry weather discharges, which can constitute a significant portion of annual pollutant loadings from storm systems in urban areas (such as metals in Los Angeles). For example, atmospheric deposition of metals is a very significant component of contaminant loading to waterbodies in the Los Angeles region relative to other point and nonpoint sources. Similarly, much of the sediment found in receiving waters following watershed urbanization can come from streambank erosion as opposed to being contributed by polluted stormwater.

Biological monitoring of waterbodies is critical to better understanding the cumulative impacts of urbanization on stream condition. Over 25 years ago, individual states developed the concept of regional reference sites and developed multi-metric indices to identify and characterize degraded aquatic assemblages in urban streams. Biological assessments respond to the range of non-chemical stressors identified as being important in urban waterways including habitat degradation, hydrological alterations, and sediment and siltation impacts, as well as to the influence of nutrients and other chemical stressors where chemical criteria do not exist or where their effects are difficult to measure directly (e.g., episodic stressors). The increase in biological monitoring has also helped to frame issues related to exotic species, which are locally of critical importance but completely unrecognized by traditional physical monitoring programs.

Epidemiological studies on the human health risks of swimming in freshwater and marine waters contaminated by urban stormwater discharges in temperate and warm climates are needed. Unlike with aquatic organisms, there is little information on the health risks of urban stormwater to humans. Standardized watershed assessment methods to identify the sources of human pathogens and indicator organisms in receiving waters need to be developed, especially for those waters with a contact-recreation use designation that have had multiple exceedances of pathogen or indicator criteria in a relatively short period of time. Given their difficulty and expense, epidemiological studies should be undertaken only after careful characterization of water quality and stormwater flows in the study area.

REFERENCES

Abrahams, A. 1984. Channel networks: a geomorphological perspective. Water Resources Research 20:161–168.

Adeniyi, I. F., and I. O. Olabanji. 2005. The physico-chemical and bacteriological quality of rainwater collected over different roofing materials in Ile-Ife, southwestern Nigeria. Chemistry and Ecology 21(3):149–166.

Ahn, J. H., S. B. Grant, C. Q. Surbeck, P. M. DiGiacomo, N. P. Nezlin, and S. Jiang. 2005. Coastal water quality impact of stormwater runoff from an urban watershed in Southern California. Environ. Sci. Technol. 39(16):5940–5953.

Allan, J. D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics 35:257–284.

Anonymous. 2000. Fish kill at Pinch Gut Creek. The Birmingham News (AL). April 18.

Arkoosh, M. R., E. Clemons, P. Huffman, and A. N. Kagley. 2001. Increased susceptibility of juvenile chinook salmon to *Vibriosis* after exposure to chlorinated and aromatic compounds found in contaminated urban estuaries. Journal of Aquatic and Animal Health 13:257–268.

Athansiadis, K., B. Helmreich, and P. A. Wilderer. 2006. Infiltration of a copper roof runoff through artificial barriers. Water Science and Technology 54(6–7):281–289.

Bailey, H. C., J. R. Elphick, A. Potter, and B. Zak. 1999. Zinc toxicity in stormwater runoff from sawmills in British Columbia. Water Research 33(11):2721–2725.

Baker, D. B., R. P. Richards, T. T. Loftus, and J. W. Kramer. 2004. A new flashiness index: Characteristics and applications to midwestern rivers and streams. Journal of the American Water Resources Association 40(2):503–522.

Bannerman, R., K. Baun, M. Bohn, P. E. Hughes, and D. A. Graczyk. 1983. Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin, Vol. I. PB 84-114164. EPA, Water Planning Division.

Bannerman, R. T., D. W. Owens, R. B. Dodds, and N. J. Hornewer. 1993. Sources of pollutants in wisconsin stormwater. Water Science and Technology 28(3–5):241–259.

Barbour, M. T., M. J. Paul, D. W. Bressler, A. H. Purcell, V. H. Resh, and E. T. Rankin. 2008. Bioassessment: a tool for managing aquatic life uses for urban streams. Water Environment Research Foundation Research Digest 01-WSM-3.

Barrie, L. A. 1991. Snow formation and processes in the atmosphere that influence its chemical composition. Pp. 1–20 *In:* Seasonal Snowpacks, NATO ASI Series G, Ecological Sciences, Vol. 28. T. D. Davies, M. Tranter, and H. G. Jones (eds.). Springer: Berlin.

Beck, R., L. Kolankiewicz, and S. A. Camarota. 2003. Outsmarting Smart Growth: Population Growth, Immigration, and the Problem of Sprawl. Washington, DC: Center for Immigration Studies. Available at *http://www.cis.org/articles/2003/SprawlPaper.pdf*. Last accessed October 31, 2007.

Benda, L. E., N. L. Poff, C. Tague, M. A. Palmer, J. Pizzuto, S. Cooper, E. Stanley, and G. Moglen. 2002. How to avoid train wrecks when using science in environmental problem solving. BioScience 52(12):1127–1136.

Bennett, E. R., K. D. Linstedt, V. Nilsgard, G. M. Battaglia, and F. W. Pontius. 1981. Urban snowmelt—characteristics and treatment. Journal Water Pollution Control Federation 53(1):119–125.

Bernhardt, E. S., and M. A. Palmer. 2007. Restoring streams in an urbanizing world. Freshwater Biology 52:738–751.

Beyers, D. W., and M. S. Farmer. 2001. Effects of copper on olfaction of Colorado pikeminnow. Environmental Toxicology and Chemistry 20:907–912.

Bochis, C. 2007. The Magnitude of Impervious Surfaces in Urban Areas. Master Thesis. The University of Alabama at Tuscaloosa.

Bochis, C., R. Pitt, and P. Johnson. 2008. Land development characteristics in Jefferson County, Alabama. Pp. 249–281 *In:* Reliable Modeling of Urban Water Systems, Monograph 16. W. James, K. N. Irvine, E. A. McBean, R. E. Pitt, and S.J. Wright (eds.). Guelph, Ontario, Canada: CHI.

Bochis-Micu, C., and R. Pitt. 2005. Impervious Surfaces in Urban Watersheds. Proceedings of the 78thAnnual Water Environment Federation Technical Exposition and Conference in Washington, D.C., October 29–November 2, 2005.

Boller, M. 1997. Tracking heavy metals reveals sustainability deficits of urban drainage systems. Water Science and Technology 35(9):77–87.

Bonnin, G. M., D. Todd, B. Lin, T. Parzybok, M.Yekta, and D. Riley. 2003. Precipitation-Frequency Atlas of the United States. NOAA Atlas 14, Volume 2, Version 2. Silver Spring, MD: NOAA, National Weather Service. Available at *http://hdsc.nws.noaa.gov/hdsc/pfds/*. Last accessed October 19, 2008.

Bonnin, G. M., Martin, D., Lin, B., Parzybok, T., Yekta,M., Riley, D. 2006. NOAA Atlas 14. Precipitation-Frequency Atlas of the United States Volume 3 Version 4.0: Puerto Rico and the U.S. Virgin Islands U.S. Department of Commerce National Oceanic and Atmospheric Administration National Weather Service Silver Spring, Maryland.

Booth, D. 2000. Forest cover, impervious-surface area, and the mitigation of urbanization impacts in King County, Washington. Center for Urban Water Resources Management, Seattle, WA. Available at *http://www.metrokc.gov/ddes/cao/PDFs04ExecProp/BAS-AppendixB-04.pdf*. Last accessed February 14, 2006.

Booth, D. B., and P. C. Henshaw. 2001. Rates of channel erosion in small urban streams. Pp. 17–38 *In*: Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas. AGU Monograph Series, Water Science and Application, Vol. 2.

Booth, D. B., and C. R. Jackson. 1997. Urbanization of aquatic systems—degradation thresholds, stormwater detention, and limits of mitigation. Journal of the American Water Resources Association 33:1077–1090.

Booth, D. B., D. Hartley, and C. R. Jackson. 2002. Forest cover, impervious-surface area, and the mitigation of stormwater impacts. Journal of the American Water Resources Association 38:835–845.

Brantley, A. S., and T. G. Townsend. 1999. Leaching of pollutants from reclaimed asphalt pavement. Environmental Engineering Science 16(2):105–116.

Brattebo, B. O., and D. B. Booth. 2003. Long-term stormwater quantity and quality performance of permeable pavement systems. Water Research 37:4369–4376.

Brown, J. N., and B. M. Peake. 2006. Sources of heavy metals and polycyclic aromatic hydrocarbons in urban stormwater runoff. Science of the Total Environment 359(1–3):145–155.

Brungs, W. A., and B. R. Jones. 1977. Temperature Criteria for Freshwater Fish: Protocol and Procedures. EPA-600-3-77-061. Duluth, MN: EPA Office of Research and Development.

Burges, S. J., M. S. Wigmosta, and J. M. Meena. 1998. Hydrological effects of land-use change in a zero-order catchment. Journal of Hydraulic Engineering 3(2):86-97.

Burns, D., A. T. Vitvar, J. McDonnell, J. Hassett, J. Duncan, and C. Kendall. 2005. Effects of suburban development on runoff generation in the Croton River Basin, New York USA. Journal of Hydrology 311:266–281.

Burton, G. A., Jr., ed. 1992. Sediment Toxicity Assessment. Chelsea, MI: Lewis Publishers.

Burton, G. A., Jr., and R. Pitt. 2002. Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers. Boca Raton, FL: CRC Press, 911 pp.

Burton, G. A., Jr., R. Pitt, and S. Clark. 1999. The role of traditional and novel toxicity test methods in assessing stormwater and sediment contamination. Critical Reviews in Environmental Science and Technology 30(4):413–447.

Cadle, S. H. 1991. Dry deposition to snowpacks. Pp. 21–66 *In*: Seasaonal Snowpacks, NATO ASI Series G, Ecological Sciences, Vol. 28. T. D. Davies, M. Tranter, and H. G. Jones (eds.). Berlin: Springer.

Calderon, R., E. Mood, and A. Dufour. 1991. Health effects of swimmers and nonpoint sources of contaminated water. International Journal of Environmental Health Research 1:21–31.

Carter, J. L., and S. V. Fend. 2005. Setting limits: the development and use of factor-ceiling distributions for an urban assessment using macroinvertebrates. Pp. 179–192 *In*: Effects of Urbanization on Stream Ecosystems. L. R. Brown, R. H. Gray, R. M. Hughes, and M. R. Meador (eds.). Bethesda, MD: American Fisheries Society.

Chesapeake Stormwater Network. 2008. CSN Technical Bulletin No. 3. Implications of the Impervious Cover Model: Stream Classification, Urban Subwatershed Management and Permitting. Version 1.0. Baltimore, MD: Chesapeake Stormwater Network.

Chesters, G., J. Konrad, and G. Simsiman. 1979. Menomonee River Pilot Watershed Study—Summary and Recommendations. EPA-905/4-79-029. Chicago: EPA.

Chow, V. T., D. R. Maidment, and L. W. Mays. 1988. Applied Hydrology. McGraw-Hill.

Cianfrani, C. M., W. C. Hession, and D. M. Rizzo. 2006. Watershed imperviousness impacts on stream channel condition in southeastern Pennsylvania. Journal of the American Water Resources Association 42(4):941–956.

Clark, S. 2000. Urban Stormwater Filtration: Optimization of Design Parameters and a Pilot-Scale Evaluation. Ph.D. Dissertation. University of Alabama at Birmingham, 450 pp.

Clark, S. E., K. A. Steeke, J. Spicher, C. Y. S. Siu, M. M. Lalor, R. Pitt, and J. Kirby. 2008. Roofing materials' contributions to stormwater runoff pollution. Journal of Irrigation and Drainage Engineering 134(5):638 - 645.

Claytor, R., and T. Schueler. 1996. Design of stormwater filtering systems. Prepared for Chesapeake Research Consortium, Center for Watershed Protection, Ellicott City, MD.

Cochran, J. W. 2008. Evaluation of the Effect of Canopy Cover on the Volume and Intensity of Rain Throughfall. MSCE Thesis. University of Alabama at Birmingham. 56 pp.

Colbeck, S. C. 1981. A simulation of the enrichment of atmospheric pollutants in snowcover runoff. Water Resources Research 17:1383–1388.

Coles, J. F., T. F. Cuffney, G. McMahon, and K. M. Beaulieu. 2004. The Effects of Urbanization on the Biological, Physical, and Chemical Characteristics of Coastal New England Streams: U.S. Geological Survey Professional Paper 1695, 47 pp.

Colford, J. M., Jr, T. J. Wade, K. C. Schiff, C. C. Wright, J. F. Griffith, S. K. Sandhu, S. Burns, J. Hayes, M. Sobsey, G. Lovelace, and S. Weisberg. 2007. Water quality indicators and the risk of illness at non-point source beaches in Mission Bay, California. Epidemiology 18(1):27–35.

Coutant, C. C. 1977. Compilation of temperature preference data. Journal of Fisheries Research Board of Canada 34:739–745.

Cummins, K. W., M. A.Wilzbach, D. M. Gates, J. B. Perry, and W.B. Taliaferro. 1989. Shredders and riparian vegetation. Bioscience 39:24–30.

CWP (Center for Watershed Protection). 2003. Impacts of impervious cover on aquatic ecosystems. Watershed Protection Techniques Monograph No. 1. Ellicott City, MD: Center for Watershed Protection.

CWP and R. Pitt. 2004. Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments. EPA Cooperative Agreement X-82907801-0. Washington, DC: EPA Office of Water.

CWP and R. Pitt. 2008. Monitoring to Demonstrate Environmental Results: Guidance to Develop Local Stormwater Monitoring Studies Using Six Example Study Designs. EPA Cooperative Agreement CP-83282201-0. Washington, DC: EPA Office of Water.

Davies, S. P., and S. K. Jackson. 2006. The biological condition gradient: a descriptive model for interpreting change in aquatic ecosystems. Ecological Applications 16(4):1251–1266.

Deacon, J., S. Soule, and T. Smith. 2005. Effects of urbanization on stream quality at selected sites in the seacoast region in New Hampshire, 2001-

2003. USGS Scientific Investigations Report 2005-5103.

de Sherbinin, A. 2002. A Guide to Land-Use and Land-Cover Change (LUCC). A collaborative effort of SEDAC and the IGBP/IHDP LUCC Project. Center for International Earth Science Information Network, Columbia University, New York. Available at *http://sedac.ciesin.org/tg/guide_frame.jsp?rd=LU&ds=1*. Last accessed October 31, 2007.

DeVivo, J. C. 1996. Fish assemblages as indicators of water quality within the Apalachicola-Chattahoochee-Flint (ACF) River basin. Master's Thesis. University of Georgia, Athens.

Dolloff, C. A., and J. R. Webster. 2000. Particulate organic contributions from forests to streams: debris isn't so bad. Pp. 125–138 *In:* Riparian Management in Forests of the Continental Eastern United States. E. S. Verry, J. W. Hornbeck, and C. A. Dolloff (eds.). Boca Raton, FL: Lewis Publishers.

Doyle, M. W. 2006. A heuristic model for potential geomorphic influences on trophic interactions in streams. Geomorphology 77:235–248.

Dunne, T., and L. B. Leopold. 1978. Water in Environmental Planning. New York: W.H. Freeman.

Dwight, R. H., D. B. Baker, J. C. Semenza, and B. H. Olson. 2004. Health effects associated with recreational coastal water use: urban vs. rural California. American Journal of Public Health 94(4):565–567.

Dwyer, F. J., F. L. Mayer, L. C. Sappington, D. R. Buckler, C. M. Bridges, I. E. Greer, D. K. Hardesty, C. E. Henke, C. G. Ingersoll, J. L. Kunz, D. W. Whites, T. Augspurger, D. R. Mount, K. Hattala, and G. N. Neuderfer. 2005. Assessing contaminant sensitivity of endangered and threatened aquatic species: Part I. Acute toxicity of five chemicals. Archives of Environmental Contamination and Toxicology 48:143–154.

Eaton, J. G., J. H. McCormick, B. E. Goodno, D. G. O'Brien, H. G. Stefan, M. Hondzo, and R. M. Scheller. 1995. A field information-based system for estimating fish temperature tolerances. Fisheries 20(4):10–18.

Ebisemiju, F. S. 1989. The response of headwater stream channels to urbanization in the humid tropics. Hydrological Processes 3:237–253.

Ehlinger, T. J., C. D. Sandgren, and L. Schacht-DeThorne. 2004. Degradation and recovery in urban watersheds: Executive Summary Narrative and Recommendations, February 2004. Submitted to Great Lakes Protection Fund, Grant WR539.

EPA (U.S. Environmental Protection Agency). 1983. Results of the Nationwide Urban Runoff Program. PB 84-185552. Washington, DC: Water Planning Division.

EPA. 2000. Stressor Identification Guidance Document. EPA 822-B-00-025. Washington, DC: EPA, Offices of Water and Research and Development.

EPA. 2002. Summary of Biological Assessment Programs and Biocriteria Development for States, Tribes, Territories, and Interstate Commissions: Streams and Wadeable Rivers. EPA-822-R-02-048. Washington, DC: EPA.

EPA. 2005. Draft: Use of Biological Information to Better Define Designated Aquatic Life Uses in State and Tribal Water Quality Standards: Tiered Aquatic Life Uses—August 10, 2005. EPA-822-E-05-001. Washington, DC: EPA Office of Water.

FISRWG (Federal Interagency Stream Restoration Working Group). 2000. Stream Corridor Restoration: Principles, Processes and Practices. Washington, DC: USDA Natural Resource Conservation Service.

Fitzpatrick, F. A., M. W. Diebel, M. A. Harris, T. L. Arnold, M. A. Lutz, and K. D. Richards. 2005. Effects of urbanization on the geomorphology, habitat, hydrology, and fish index of biotic integrity of streams in the Chicago area, Illinois and Wisconsin. American Fisheries Society Symposium 47:87–115.

Fritz, K. M., B. R. Johnson, and D. M. Walters. 2006. Field Operations Manual for Assessing the Hydrologic Permanence and Ecological Condition of Headwater Streams. EPA/600/R-06/126. Washington, DC: EPA Office of Research and Development.

Funk, J. L., and G. G. Fleener. 1974. The fishery of a Missouri Ozark stream, Big Piney River, and the effects of stocking fingerling smallmouth bass. Transactions of the American Fisheries Society 103(4):757–771.

Galli, J. 1990. Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices. Washington, DC: Metropolitan Washington Council of Governments.

GAO (General Accounting Office). 2003. Water Quality: Improved EPA Guidance and Support Can Help States Develop Standards that Better Target Cleanup Efforts. GAO-03-308. Washington, DC: GAO.

Gilliom, R. J., J. E. Barbash, C. G. Crawford, P. A. Hamilton, J. D. Martin, N. Nakagaki, L. H. Nowell, J. C. Scott, P. E. Stackelberg, G. P. Thelin, and D. M. Wolock. 2006. The Quality of our Nation's Water—Pesticides in the Nation's Streams and Ground Water, 1992–2001. U.S. Geological Survey Circular 1291, 169 pp.

Goetz, S., R. Wright, A. Smith, E. Zinecker, and E. Schaub. 2003. IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. Remote Sensing in the Environment 88:195–208.

Good, J. C. 1993. Roof runoff as a diffuse source of metals and aquatic toxicity in stormwater. Water Science and Technology 28(3–5):317–321.

Gregory, M., J. Aldrich, A. Holtshouse, and K. Dreyfuss-Wells. 2005. Evaluation of imperviousness impacts in large, developing watersheds. Pp. 115–150 *In:* Efficient Modeling for Urban Water Systems, Monograph 14. W. James, E. A. McBean, R. E. Pitt, and S. J. Wright (eds.). Guelph, Ontario, Canada: CHI.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. Bioscience 41:540–551.

Groffman, P. M., N. L. Law, K. T. Belt, L. E. Band, and G. T. Fisher. 2004. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems

7:393–403.

Groffman, P. M., A. M. Dorsey, and P. M. Mayer. 2005. N processing within geomorphic structures in urban streams. Journal of the North American Benthological Society 24(3):613–625.

Haile, R.W., J. S. Witte, M. Gold, R. Cressey, C. McGee, R. C. Millikan, A. Glasser, N. Harawa, C. Ervin, P. Harmon, J. Harper, J. Dermand, J. Alamillo, K. Barrett, M. Nides, and G. Wang. 1999. The health effects of swimming in ocean water contaminated by storm drain runoff. Epidemiology 10(4):355–363.

Hammer, T. R. 1972. Stream and channel enlargement due to urbanization. Water Resources Research 8:1530–1540.

Harris, A. R., and C. I. Davidson. 2005. The role of resuspended soil in lead flows in the California South Coast Air Basin. Environmental Science and Technology 39:7410–7415.

Heany, J. P., and W. C. Huber. 1984. Nationwide assessment of urban runoff impact on receiving water quality. Water Resources Bulletin 20:35–42.

Heaney, J. 2000. Principles of integrated urban water management. Pp. 36–73 *In*: Innovative Urban Wet-Weather Flow Management Systems. Lancaster, PA: Technomic Publishing.

Hecht, S. A., D. H. Baldwin, C. A. Mebane, T. Hawkes, S. J. Gross, and N. L. Scholz. 2007. An Overview of Sensory Effects on Juvenile Salmonids Exposed to Dissolved Copper: Applying a Benchmark Concentration Approach to Evaluate Sublethal Neurobehavioral Toxicity. NOAA Tech. Memo. NMFS-NWFSC-83. Washington, DC: U.S. Department of Commerce.

Herb, W. R., B. Janke, O. Mohseni, and H. G. Stefan. 2008. Thermal pollution of streams by runoff from paved surfaces. Hydrological Processes 22(7):987–999.

Hernandez, P. P, V. Moreno, F. A. Olivari, and M. L. Allende. 2006. Sublethal concentrations of waterborne copper are toxic to lateral line neuromasts in zebrafish (Danio rerio). Hearing Research 213:1–10.

Hoblit, B., S. Zelinka, C. Castello, and D. Curtis. 2004. Spatial Analysis of Storms Using GIS. Paper 1891. 24th Annual ESRI International User Conference, San Diego, August 9–13, 2004. Available at *http://gis.esri.com/library/userconf/proc04/docs/pap1891.pdf*. Last accessed October 19, 2008.

Holland, F., D. Sanger, C. Gawle, S. Lerberg, M. Santiago, G. Riekerk, L. Zimmerman, and G. Scott. 2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. Journal of Experimental Marine Biology and Ecology 298:151–178.

Hollis, G. E., and J. K. Luckett. 1976. The response of natural river channels to urbanization: two case studies from southeast England. Journal of Hydrology 30:351–363.

Hood, W. G., and R. J. Naiman. 2000. Vulnerability of riparian zones to invasion by exotic vascular plants. Plant Ecology 148:105–114.

Horner, R., and C. May. 1999. Regional study supports natural land cover protection as leading management practice for maintaining stream ecological integrity. Pp. 233–247 *In:* Comprehensive Stormwater and Aquatic Ecosystem Management. First South Pacific Conference, February 22–26, Auckland, New Zealand.

Horner, R. R., D. B. Booth, A. Azous, and C. W. May. 1997. Watershed determinants of ecosystem functioning. Pp. 251–274 *In:* Effects of Watershed Development and Management on Aquatic Ecosystems. L.A. Roesner (ed.). New York: American Society of Civil Engineers.

Horner, R., C. May, E. Livingston, D. Blaha, M. Scoggins, J. Tims, and J. Maxted. 2001. Structural and non-structural BMPs for protecting streams. L inking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation. Pp. 60–77 *In:* Proceedings Engineering Research Foundation Conference, American Society of Civil Engineers.

Horner, R. R., C. W. May, and E. H. Livingston. 2003. Ecological Effects of Stormwater and Stormwater Controls on Small Streams. Prepared for EPA, Office of Water, Office of Science and Technology by Watershed Management Institute, Inc., Cooperative Agreement CX824446.

Horner, R. R., H. Lim, and S. J. Burges. 2004. Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects: Summary of the 2000-2003 Water Years. Water Resources Series Technical Report Number 181. Department of Civil and Environmental Engineering, University of Washington, Seattle, WA.

Horton, R. E. 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geological Society of America Bulletin 56:275–370.

House, L. B., R. J. Waschbusch, and P. E. Hughes. 1993. Water Quality of an Urban Wet Detention Pond in Madison, Wisconsin, 1987-1988. USGS, in cooperation with the Wisconsin Department of Natural Resources. USGS Open File Report 93-172.

Huff, F. A., and S. A. Changnon. 1973. Precipitation modification by major urban areas. Bulletin of the American Meteorological Society 54:1220–1232.

Hughes, R. M. 1995. Defining acceptable biological status by comparing with reference conditions. Pp. 31–47 *In:* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making for Rivers and Streams. W. Davis and T. Simon (eds.). Boca Raton, FL: Lewis Publishers.

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: A method for assessing stream potentials. Environmental Management 10:629–635.

Hunt, C. L., and J. K. Grow. 2001. Impacts of Sedimentation to a Stream by a Non-compliant Construction Site. Proc. ASCE EWRI Conf. - Bridging the Gap: Meeting the World’s Water and Environmental Resources Challenges.

Ingersoll, C. G., T. Dillon, and G. R. Biddinger, eds. 1997. Ecological Risk

Assessment of Contaminated Sediments. SETAC Pellston Workshop on Sediment Ecological Risk Assessment. Pensacola, FL: SETAC Press.

Intergovernmental Panel on Climate Change (IPCC). 2007. Summary for Policymakers. Pp. 7-22 *In:* Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.). Cambridge, UK: Cambridge University Press.

Johnson, P. D., R. Pitt, S. R. Durrans, M. Urrutia, and S. Clark. 2003. Metals Removal Technologies for Urban Stormwater. WERF 97-IRM-2. ISBN: 1-94339-682-3. Alexandria, VA: Water Environment Research Foundation.

Jokela, B. 1990. Water quality considerations. Pp. 349–369 *In:* Cold Regions Hydrology and Hydraulics. W. L. Ryan and R. D. Crissman (eds.). New York: ASCE.

Jones, R. C., A. Via-Norton, and D. R. Morgan. 1996. Bioassessment of BMP effectiveness in mitigating stormwater impacts on aquatic biota. Pp. 402–417 *In:* Effects of Watershed Development and Management on Aquatic Ecosystems. L. A. Roesner (ed.). New York: American Society of Civil Engineers.

Karr, J. R. 1995. Protecting aquatic ecosystems: clean water is not enough. Pp. 7–13 *In:* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. W. S. Davis and T. P. Thomas (eds.). Boca Raton, FL: CRC Press, Inc.

Karr, J., and E. Chu. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Island Press. ISBN 1559636742, 9781559636742. 206 pages

Karr, J. R., and C. O. Yoder. 2004. Biological assessment and criteria improve total maximum daily load decision making. Journal of Environmental Engineering 130(6):594–604.

Kennedy, A. J., D. S. Cherry1, and R. J. Currie. 2004. Evaluation of ecologically relevant bioassays for a lotic system impacted by a coal-mine effluent, using Isonychia. Environmental Monitoring and Assessment 95(1–3):37–55.

Khan, B. I., H. M. Solo-Gabriele, T. G. Townsend, and Y. Cai. 2006. Release of arsenic to the environment from CCA-treated wood. 1. Leaching and speciation during service. Environmental Science and Technology 40:988–993.

King, R. M. Baker, D. Whigham, D. Weller and K. Hurd. 2005. Spatial considerations for linking watershed land cover to ecological indicators in streams. Ecological Applications 15:137–153.

Kline, M. 2002. Storm water official plans to send $2,000 bill to sealing company. The Tennessean (Nashville). October 2.

Konrad, C. P., and D. B. Booth. 2005. Ecological significance of hydrologic changes in urban streams. Pp. 157–177 *In:* Effects of Urbanization on Stream Ecosystems. L. R. Brown, R. H. Gray, R. M. Hughes, and M. R.

Meador (eds.). American Fisheries Society, Symposium 47.

Konrad, C. P., D. B. Booth, and S. J. Burges. 2005. Effects of urban development in the Puget Lowland, Washington, on interannual streamflow patterns: consequences for channel form and streambed disturbance. Water Resources Research 41(7):1–15.

Krajeswki, W. F., and J. A. Smith. 2002. Radar hydrology: rainfall estimation. Advances in Water Resources 25:1387–1394.

Krause, C.W., B. Lockard, T. J. Newcomb, D. Kibler, V. Lohani, and D. J. Orth. 2004. Predicting influences of urban development on thermal habitat in a warm water stream. Journal of the American Water Resources Association 40:1645–1658.

Kunkel, K. E., K, Amdsager, and D. R. Easterling. 1999. Long-term trends in extreme precipitation events over the coterminous United States and Canada. Journal of Climate 12:2515–2527.

LAC DPW (Los Angeles County, Department of Public Works). 1985. Plan for Flood Control and Water Conservation, Maps 2, 3, 7, 16, and 17. LAC DPW, Los Angeles, CA.

Lee, J., and J. Heaney. 2003. Estimation of urban imperviousness and its impacts on storm water systems. Journal of Water Resources Planning and Management 129(5):419–426.

Leopold, L., and Maddock. 1953. The hydraulic geometry of stream channels and some physiographic implications. USGS Professional Paper 252. Washington, DC: U.S. Department of the Interior.

Leopold, L. B. 1968. Hydrology for Urban Planning—A Guidebook on the Hydrologic Effects of Urban Land Use. USGS Circular 554. Washington, DC: USGS.

Leopold, L. B. 1973. River channel change with time—an example. Geological Society of America Bulletin 84:1845–1860.

Lerberg, S., F. Holland, and D. Singer. 2000. Responses of tidal creek macrobenthic communities to the effects of watershed development. Estuaries 23(6):838–853.

Line, D., and N. White. 2007. Effect of development on runoff and pollutant export. Water Environment Research 75(2):184–194.

Lorantas, R. M., and D. P. Kristine. 2004. Annual monitoring of young of the year abundance of smallmouth bass in rivers in Pennsylvania: relationships between abundance, river characteristics, and spring fishing. Pennsylvania Fish & Boat Commission, Bellefonte.

Lowrance, R., L. S. Altier, J. D. Newbold, R. R. Schnabel, P. M. Groffman, J. M. Denver, D. L. Correll, J. W. Gilliam, J. L. Robinson, R. B. Brinsfield, K. W. Staver, W. Lucas, and A. H. Todd. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. Environmental Management 21:687–712.

Lu, R., R. P. Turco, K. Stolzenbach, S. K. Friendlander, C. Xiong, K. Schiff, and L. Tiefenthaler. 2003. Dry deposition of airborne trace metals on the Los Angeles Basin and adjacent coastal waters. Journal of Geophysical Research 102(D2):4074.

Mack, J. J., and M. Micacchion. 2007. An Ecological and Functional Assessment of Urban Wetlands in Central Ohio. Volume 1: Condition of Urban Wetlands Using Rapid (Level 2) and Intensive (Level 3) Assessment Methods. Ohio EPA Technical Report WET/2007-3A. Columbus, OH: Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water.

MacRae, C. R. 1997. Experience from morphological research on Canadian streams: is control of the two-year frequency runoff event the best basis for stream channel protection? *In:* Proceedings of the Effects of Watershed Developments and Management on Aquatic Ecosystems Conference, Snowbird, UT, August 4–9, 1996. L. A. Roesner (ed.). New York: ASCE.

Madsen, T., and E. Figdor. 2007. When It Rains, It Pours: Global Warming and the Rising Frequency of Extreme Precipitation in the United States. Penn Environment Research & Policy Center, Philadelphia, PA. Available at *http://www.pennenvironment.org*.

Maestre, A., Pitt, R. E., and Derek Williamson. 2004. Nonparametric statistical tests comparing first flush with composite samples from the NPDES Phase 1 municipal stormwater monitoring data. Stormwater and Urban Water Systems Modeling. Pp. 317–338 *In:* Models and Applications to Urban Water Systems, Vol. 12. W. James (ed.). Guelph, Ontario: CHI.

Maestre, A., and R. Pitt. 2005. The National Stormwater Quality Database, Version 1.1, A Compilation and Analysis of NPDES Stormwater Monitoring Information. Final Draft Report. Washington, DC: EPA Office of Water.

Maestre, A., and R. Pitt. 2006. Identification of significant factors affecting stormwater quality using the National Stormwater Quality Database. Pp. 287–326 *In:* Stormwater and Urban Water Systems Modeling, Monograph 14. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Mahler, B. J., P. C. VanMetre, T. J. Bashara, J. T. Wilson, and D. A. Johns. 2005. Parking lot sealcoat: an unrecognized source of urban polycyclic aromatic hydrocarbons. Environmental Science and Technology 39:5560–5566.

Mallin, M., S. Ensign, M. McIver, C. Shank, and P. Fowler. 2001. Demographic, landscape and meteorological factors controlling the microbial pollution of coastal waters. Hydrobiologia 460:185–193.

Mallin, M., D. Parsons, V. Johnson, M. McIver, and H. Covan. 2004. Nutrient limitation and algal blooms in urbanizing tidal creeks. Journal of Experimental Marine Biology and Ecology 298:211–231.

Masterson, J. P., and R. T. Bannerman. 1994. Impacts of stormwater runoff on urban streams in Milwaukee County, Wisconsin. In National Symposium on Water Quality, American Water Resources Association.

Maxted, J. R. 1999. The effectiveness of retention basins to protect aquatic life and physical habitat in three regions of the United States. Pp. 215–222 *In:*

Proceedings of the Comprehensive Stormwater and Aquatic Ecosystem Management Conference, Auckland, New Zealand, February 1999.

May, C. W. 1996. Assessment of Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion: Implications for Salmonid Resource Management. Ph.D. dissertation, University of Washington, Seattle, WA.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, and E. B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques 2(4):483–494.

McBride, M., and D. Booth. 2005. Urban impacts on physical stream condition: effects on spatial scale, connectivity, and longitudinal trends. Journal of the American Water Resources Association 6:565–580.

McClain, M. E., E. W. Boyer, C. L. Dent, S. E. Gergel, N. B. Grimm, P. M. Groffman, S. C. Hart, J. W. Harvey, C. A. Johnston, E. Mayorga, W. H. McDowell, and G. Pinay. 2003. Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. Ecosystems 6:301–312.

McPherson, T. N., S. J. Burian, H. J. Turin, M. K. Stenstrom, and I. H. Suffet. 2002. Comparison of the pollutant loads in dry and wet weather runoff in a southern California urban watershed. Water Science and Technology 45:255–261.

Meador, M. R., J. F. Coles, and H. Zappia. 2005. Fish assemblage responses to urban intensity gradients in contrasting metropolitan areas: Birmingham, Alabama and Boston, Massachusetts. American Fisheries Society Symposium 47:409–423.

Meierdiercks, K. J., J. A. Smith, A. J. Miller, and M. L. Baeck. 2004. The urban drainage network and its control on extreme floods. Transactions of the American Geophysical Union 85(47), Abstract H11F-0370.

Meyer, J. L. 1994. Sources of carbon for the microbial loop. Microbial Ecology 28:195–199.

Meyer, J. L., and J. B. Wallace. 2001. Lost linkages and lotic ecology: rediscovering small streams. Pp. 295–317 *In:* Proceedings of the 41st Symposium of the British Ecological Society jointly sponsored by the Ecological Society of America. M. C. Press, N. J. Huntly, and S. Levin (eds.). Orlando, FL: Blackwell Science.

Meyer, J. L., G. C. Poole, and K. L. Jones. 2005a. Buried alive: potential consequences of burying headwater streams in drainage pipes. Proceedings of the 2005 Georgia Water Resources Conference, held April 25–27, 2005, at the University of Georgia. K. J. Hatcher (ed.). Athens, GA: Institute of Ecology, The University of Georgia.

Meyer, J. L., M. J. Paul, and W. K. Taulbee. 2005b. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society 24(3):602–612.

Meyer, S. C. 2005. Analysis of base flow trends in urban streams, northeastern Illinois, USA. Hydrogeology Journal 13(5–6):871–885.

Miller, W., and A. J. Boulton. 2005. Managing and rehabilitating ecosystem processes in regional urban streams in Australia. Hydrobiologia 552.

Miltner, R. J., and E. T. Rankin. 1998. Primary nutrients and the biotic integrity of rivers and streams. Freshwater Biology 40(1):145–158.

Miltner, R. J., D. White, and C. O. Yoder. 2004. The biotic integrity of streams in urban and suburbanizing landscapes. Landscape and Urban Planning 69:87–100.

MNCPPC (Maryland National Capital Park and Planning Commission). 2000. Stream Condition Cumulative Impact Models for the Potomac Subregion. Silver Spring, MD.

Moore, A. A., and M. A. Palmer. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: Implications for conservation and management. Ecological Applications 15(4):1169–1177.

Morisawa, M., and E. LaFlure. 1982. Hydraulic geometry, stream equilibrium and urbanization. Pp. 333350 *In:* Adjustments of the Fluvial System. D. D. Rhodes and G. P. Williams (eds.). London: Allen and Unwin.

Morley, S., and J. Karr. 2002. Assessing and restoring the health of urban streams in the Puget Sound Basin. Conservation Biology 16(6):1498–1509.

Morquecho, R. 2005. Pollutant Associations with Particulates in Stormwater. PhD dissertation. University of Alabama.

Morrisey, D. J., R. B. Williamson, L. Van Dam, and D. J. Lee. 2000. Stormwater-contamination of urban estuaries. 2. Testing a predictive model of the build-up of heavy metals in sediments. Estuaries 23(1):67–79.

Moscrip, A. L., and D. R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Puget Lowland streams. Journal of the American Water Resources Association 33:1289–1297.

Nadeau, T. L., and M. C. Rains. 2007. Hydrological connectivity of headwaters to downstream waters: how science can inform policy. Journal of the American Water Resources Association 43:118–133.

Nanson, G. C., and R. W. Young. 1981. Downstream reduction of rural channel size with contrasting urban effects in small coastal streams of southeastern Australia. Journal of Hydrology 52:239–255.

Neller, R. J. 1988. A comparison of channel erosion in small urban and rural catchments, Armidale, New South Wales. Earth Surface Processes and Landforms 13:1–7.

Nelson, E. J., and D. B. Booth. 2002. Sediment budget of a mixed-land use, urbanizing watershed. Journal of Hydrology 264:51–68.

Nelson, K. C., and M. A. Palmer. 2007. Stream temperature surges under urbanization and climate change: Data, models, and responses. Journal of the American Water Resources Association 43(2):440–452.

Ng, E., and P. C. Miller. 1980. Soil Moisture Relations in the Southern California Chaparral. Ecology 61(1):98-107.

Novotny, V., and G. Chesters. 1981. Handbook of Nonpoint Pollution. New York: VanNostrand Reinhold.

Novotny, V., et al. 1986. Effect of Pollution from Snow and Ice on Quality of

Water from Drainage Basins. Technical report, Marquette University.

NRC (National Research Council). 1984. Wastewater characteristics. Chapter 2 in Ocean Disposal Systems for Sewage Sludge and Effluent. Washington, DC: National Academy Press.

NRC. 2001. Assessing the TMDL Approach to Water Quality Management. Washington, DC: National Academies Press.

NRC. 2002. Riparian Areas: Functions and Strategies for Management. Washington, DC: National Academy Press.

NRC. 2004. Assessing the National Streamflow Information Program. Washington, DC: National Academy Press.

Oberts, G. L. 1994. Influence of snowmelt dynamics on stormwater runoff quality. Watershed Protection Techniques 1(2).

Odemerho, F. O. 1992. Limited downstream response of stream channel size to urbanization in a humid tropical basin. Professional Geographer 44:332–339.

Ohio EPA (Ohio Environmental Protection Agency). 1992. Biological and Habitat Investigation of Greater Cincinnati Area Streams (Hamilton and Clermont Counties, Ohio). Ohio EPA Tech. Rept. 1992-1-1. Columbus, OH: Division of Water Quality Planning and Assessment.

Ohio EPA. 2002. Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams, Final Version 1.0. Columbus, OH: Ohio Environmental Protection Agency, Division of Surface Water.

Oliver, B., J. B. Milne, and N. LaBarre. 1974. Chloride and lead in urban snow. Journal of Water Pollution Control Federation 46(4).

Paul, M. J., and J. L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333–365.

Perez-Rivas, M. 2000. Asphalt sealer kills 1,000 fish in Montgomery. The Washington Post (Washington, DC), July 29.

Pierstorff, B. W., and P. L. Bishop. 1980. Water pollution from snow removal operations. Journal of the Environmental Engineering Division 106(2):377-388.

Pitt, R. 1987. Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges. Ph.D. Dissertation. Department of Civil and Environmental Engineering, University of Wisconsin–Madison.

Pitt, R., and J. McLean. 1986. Toronto Area Watershed Management Strategy Study. Humber River Pilot Watershed Project. Toronto, Ontario: Ontario Ministry of the Environment.

Pitt, R., and J. Voorhees. 1995. Source loading and management model (SLAMM). Pp. 225–243 *In:* National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels, March 30–April 2, 1993. EPA/625/R-95/003. Cincinnati, OH: EPA Center for Environmental Research Information.

Pitt, R., and J. Voorhees. 2002. SLAMM, the Source Loading and Management Model. Pp. 79–101 *In:* Wet-Weather Flow in the Urban Watershed: Technology and Management. R. Field and D. Sullivan (eds.). Boca Raton, FL:

Lewis Publishers.

Pitt, R., M. Lalor, R. Field, D. D. Adrian, and D. Barbe'. 1993. Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems. EPA/600/R-92/238. Cincinnati, OH: EPA Office of Research and Development.

Pitt, R. E., R. Field, M. Lalor, and M. Brown. 1995. Urban stormwater toxic pollutants: assessment, sources, and treatability. Water Environment Research 67(3):260–275.

Pitt, R., B. Robertson, P. Barron, A. Ayyoubi, and S. Clark. 1999. Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT). EPA/600/R-99/017. Cincinnati, OH: EPA Wet Weather Flow Management Program, National Risk Management Research Laboratory.

Pitt, R., R. Bannerman, S. Clark, and D. Williamson. 2005a. Sources of pollutants in urban areas (Part 1)—Older monitoring projects. Pp. 465–484 and 507–530 *In:* Effective Modeling of Urban Water Systems, Monograph 13. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Pitt, R., R. Bannerman, S. Clark, and D. Williamson. 2005b. Sources of pollutants in urban areas (part 2)—recent sheetflow monitoring results. Pp. 485–530 *In:* Effective Modeling of Urban Water Systems, Monograph 13. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Pitt, R., D. Williamson, and J. Voorhees. 2005c. Review of historical street dust and dirt accumulation and washoff data. Pp. 203–246 *In:* Effective Modeling of Urban Water Systems, Monograph 13. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Pitt, R., S. Clark, and D. Lake. 2007. Construction Site Erosion and Sediment Controls: Planning, Design, and Performance. Lancaster, PA: DEStech Publications.

Pitt, R., A. Maestre, H. Hyche, and N. Togawa. 2008. The updated National Stormwater Quality Database (NSQD), Version 3. Conference CD. 2008 Water Environment Federation Technical Exposition and Conference, Chicago, October 2008.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. Bioscience 47(11):769–784.

Poff, N. L., B. P. Bledsoe, and C. O. Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: geomorphic and ecological consequences for stream ecosystems. Geomorphology 79(3–4):264–285.

Pomeroy, C. A., L. A. Roesner, J. C. Coleman II, and E. Rankin. 2008. Protocols for Studying Wet Weather Impacts and Urbanization Patterns. Report No. 03WSM3. Alexandria, VA: Water Environment Research Foundation.

Porcella, D. B., and D. L. Sorenson. 1980. Characteristics of Non-point Source Urban Runoff and Its Effects on Stream Ecosystems. EPA-600/3-80-032. Washington, DC: EPA.

Power, M. 1997. Assessing the effects of environmental stressors on fish populations. Aquatic Toxicology 39(2):151–169.

Prince Georges County, Maryland. 2000. Low-Impact Development Design Strategies. EPA 841-B-00-003.

Pruss, A. 1998. Review of epidemiological studies on health effects from exposure to recreational water. International Journal of Epidemiology 27(1):1–9.

Purcell, A. H., D. W. Bressler, M. J. Paul, M. T. Barbour, E. T. Rankin, J. L. Carter, and V. H. Resh. 2009. Assessment Tools for Urban Catchments: Developing Biological Indicators. Journal of the American Water Resources Association.

Ramcheck, J. M., and R. L. Crunkilton. 1995. Toxicity Evaluation of Urban Stormwater Runoff in Lincoln Creek, Milwaukee, Wisconsin. College of Natural Resources, University of Wisconsin, Stevens Point, WI.

Ricciardi, A., and R. Kipp. 2008. Predicting the number of ecologically harmful exotic species in an aquatic system. Diversity and Distributions 14:374–380.

Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10(1):163–174.

Richter, B. D., J. V. Baumgartner, R. Wigington, and D. P. Braun. 1997a. How much water does a river need? Freshwater Biology 37(1):231–249.

Richter, B. D., D. P. Braun, M. A. Mendelson, and L. L. Master. 1997b. Threats to imperiled freshwater fauna. Conservation Biology 11:1081–1093.

Richter, B. D., R. Mathews, and R. Wigington. 2003. Ecologically sustainable water management: Managing river flows for ecological integrity. Ecological Applications 13(1):206–224.

Rieman, B., D. Lee, J. McIntyre, K. Ovetton, and R. Thurow. 1993. Consideration of Extinction Risks for Salmonids. Fish Habitat Relationships Technical Bulletin Number 14. USDA Forest Service, Intermountain Research Station.

Riley, S. P. D., G. T. Busteed, L. B. Kats, T. L. Vandergon, L. F. S. Lee, R. G. Dagit, J. L. Kerby, R. N. Fisher, and R. M. Sauvajot. 2005. Effects of urbanization on the distribution and abundance of amphibians and invasive species in Southern California streams. Conservation Biology 19(6):1894–1907.

Rodríguez-Iturbe, I., A. Rinaldo, R. Rigon, R. L. Bras, A. Marani, and E. J. Ijjasz-Vásquez. 1992. Energy dissipation, runoff production, and the 3-dimensional structure of river basins. Water Resources Research 28(4):1095–1103.

Roesner, L. A., and B. P. Bledsoe. 2003. Physical effects of wet weather flows on aquatic habitats: present knowledge and research needs. Water Environment Research Foundation Rept. No. 00-WSM-4.

Rogge, W. F., L. M. Hildemann, M. A. Mazurek, G. R. Cass, and B. R. T. Simoneit. 1997. Sources of fine organic aerosol. 7. Hot asphalt roofing tar pot fumes. Environmental Science and Technology 31(10):2726–2730.

Rose, S., and N. E. Peters. 2001. Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach. Hydrological Processes 18:1441–1457.

Rosselot, K. S. 2006a. Copper Released from Brake Lining Wear in the San Francisco Bay Area, Final Report, Brake Pad Partnership, January.

Rosselot, K. S. 2006b. Copper Released from Non-Brake Sources in the San Francisco Bay Area, Final Report, Brake Pad Partnership, January.

Roy, A., B. Freeman, and M. Freeman. 2006. Riparian influences on stream fish assemblage structure on urbanizing streams. Landscape Ecology 22(3):385–402.

Roy, A. H., A. D. Rosemond, M. J. Paul, D. S. Leigh, and J. B. Wallace. 2003. Stream macroinvertebrate response to catchment urbanization (Georgia, U.S.A.). Freshwater Biology 48:329–346.

Roy, A. H., M. C. Freeman, B. J. Freeman, S. J. Wenger, W. E. Ensign, and J. L. Meyer. 2005. Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams. Journal of the North American Benthological Society 24(3):656–678.

Royer, T. V., M. T. Monaghan, and G. W. Minshall. 1999. Processing of native and exotic leaf litter in two Idaho (U.S.A.) streams. Hydrobiologia 400:123–128.

Sabin, L.D., J.H. Lim, K.D. Stolzenbach, and K.C. Schiff. 2005. Contributions of trace metals from atmospheric deposition to stormwater runoff in a small impervious urban catchment. Water Research 39(16):3929-3937.

Salaita, G. N., and P. H. Tate. 1998. Spectroscopic and microscopic charaterization of Portland cement based unleached and leached solidified waste. Applied Surface Science 133(1–2):33–46.

Sandahl, J. F., D. H. Baldwin, J. J. Jenkins, and N. Scholz. 2007. A sensory system at the interface between urban stormwater runoff and salmon survival. Environmental Science and Technology 41:2998–3004.

Schmid-Araya, J. M. 2000. Invertebrate recolonization patterns in the hyporheic zone of a gravel stream. Limnology and Oceanography 45(4):1000–1005.

Scholz, J. G., and D. B. Booth. 2001. Monitoring urban streams: strategies and protocols for humid-region lowland systems. Environmental Monitoring and Assessment 71:143–164.

Schueler, T. 1983. Atmospheric loading sources. Chapter IV in Urban Runoff in the Washington Metropolitan Area, Final Report. Washington, DC.

Schueler, T. R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Department of Environmental Programs, Metropolitan Washington Council of Governments, Water Resources Planning Board.

Schueler, T. 1994. The importance of imperviousness. Watershed Protection Techniques 1(1):1–15.

Schueler, T. 2004. An integrated framework to restore small urban watersheds. Urban Subwatershed Restoration Manual Series. Ellicott City, MD: Center for Watershed Protection.

Schwarz, G. E., A. B. Hoos, R. B. Alexander, and R. A. Smith. 2006. The SPARROW Surface Water-Quality Model—Theory, Application, and User Documentation: U.S. Geological Survey Techniques and Methods, Book 6, Section B, Chapter 3. Available at *http://pubs.usgs.gov/tm/2006/tm6b3*. Last accessed August 6, 2007.

SEWRPC (Southeastern Wisconsin Planning Commission). 1978. Sources of Water Pollution in Southeastern Wisconsin: 1975. Technical Rept. No. 21. Waukesha, WI.

Sharp, J. M., L. N. Christian, B. Garcia-Fresca, S. A. Pierce, and T. J. Wiles. 2006. Changing recharge and hydrogeology in an urbanizing area—Example of Austin, Texas, USA. Philadelphia Annual Meeting (October 22–25, 2006), Geological Society of America. Abstracts with Programs 38(7):289.

Shields, C.A., L. E. Band, N. Law, P. M. Groffman, S. S. Kaushal, K. Savvas, G. T. Fisher, K. T. Belt. 2008. Streamflow distribution of non-point source nitrogen export from urban-rural catchments in the Chesapeake Bay watershed. Water Resources Research 44. W09416, doi:10.1029/2007 WR006360.

Shreve, R. L. 1966. Statistical law of stream numbers. Journal of Geology 74:17–37.

Shreve, R. L. 1967. Infinite topologically *random* channel networks. Journal of Geology 75:179–186.

Shreve, R. L. 1969. Stream lengths and basin areas in topologically random channel networks. Journal of Geology 77:397–414.

Simmons, D. L., and R. J. Reynolds. 1982. Effects of urbanization on base flow of selected South-Shore streams, Long Island, New York. Journal of the American Water Resources Association 18(5):797–805.

Simon, A., and C. R. Hupp. 1986. Channel evolution in modified Tennessee streams. Pp. 71–82 *In:* Proceedings of the Fourth Federal Interagency Sedimentation Conference, March, Las Vegas, NV, Vol. 2.

Simon, T. P., and J. Lyons. 1995. Application of the Index of Biotic Integrity to evaluate water resource integrity in freshwater ecosystems. Pp. 245–262 *In:* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. W. S. Davis and T. P. Simon (eds.). CRC Press.

Simon, A., M. Doyle, M. Kondolf, F. D. Shields, Jr., B. Rhoads, and M. McPhillips. 2007. Critical evaluation of how the Rosgen classification and associated "natural channel design" methods fail to integrate and quantify fluvial processes and channel response. Journal of the American Water Resources Association 43(5):1117–1131.

Smart, J. S. 1968. Statistical properties of stream lengths. Water Resources Research 4:1001–1014.

SMBRP (Santa Monica Bay Restoration Project). 1994. Characterization Study of the Santa Monica Bay Restoration Plan. Santa Monica Bay Restoration Project, Monterey Park, CA.

Smith, S. B., D. R. P. Reader, P. C. Baumann, S. R. Nelson, J. A. Adams, K. A. Smith, M. M. Powers, P. L. Hudson, A. J. Rosolofson, M. Rowan, D. Peterson, V. S. Blazer, J. T. Hickey, and K. Karwowski. 2003. Lake Erie Ecological Investigation; Summary of findings: Part 1; Sediments, Invertebrate Communities, and Fish Communities: Part 2; Indicators, Anomalies, Histopathology, and Ecological Risk Assessment. USGS, Mimeo.

Smock, L. A., and C. M. MacGregor. 1988. Impact of the America chestnut blight on aquatic shredding macroinvertebrates. Journal of the North American Benthological Society 7:212–221.

Sprague, L. A., D. A. Harned, D. W. Hall, L. H. Nowell, N. J. Bauch, and K. D. Richards. 2007. Response of stream chemistry during base flow to gradients of urbanization in selected locations across the conterminous United States, 2002–04. U.S. Geological Survey Scientific Investigations Report 2007–5083, 132 pp.

Stein, E. D., and L. L. Tiefenthaler. 2005. Dry-weather metals and bacteria loading in an arid, urban watershed: Ballona Creek, California. Water, Air, Soil Pollution 164(1–4):367–382.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16(4):1267–1276.

Stolzenbach, K. D., S. K. Friedlander, R. Turco, A. Winer, R. Lu, C. Xiong, J.-H. Lim, L. Sabin, K. Schiff, and L. Tiefenthaler. 2007. Atmospheric Deposition as a Source of Contaminants in Stormwater Runoff. Presentation to NRC Committee on Reducing Stormwater Discharge Contributions to Water Pollution, May 2, 2007, Austin, TX.

Stone, B. 2004. Paving over paradise: how land use regulations promote residential imperviousness. Landscape and Urban Planning (69):101–113.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union (38):913–920.

Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks. Pp. 4-39–4-76 *In:* Handbook of Applied Hydrology. Ven Te Chow (ed.). New York: McGraw-Hill.

Strayer, D. L., J. A. Downing, W. R. Haag, T. L. King, J. B. Layzer, T. J. Newton, and S. Nichols. 2004. Changing Perspectives on Pearly Mussels, North America's Most Imperiled Animals. BioScience 54(5):429–439.

Stribling, J. B., E. W. Leppo, J. D. Cummins, J. Galli, S. Meigs, L. Coffman, M. Cheng. 2001. Relating instream biological condition to BMPs in watershed. Pp. 287–304 *In:* Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation. B. R. Urbonas (ed.). Proceedings of an Engineering Foundation Conference, Snowmass Village, CO, August 19–24, 2001. United Engineering Foundation, Environmental and Water Resources Institute of ASCE.

Suter, G. 2006. Ecological risk assessment and ecological epidemiology for

contaminated sites. Human and Ecological Risk Assessment 12(1):31–38.
Suter, G. W., II. 1993. Ecological Risk Assessment. Boca Raton, FL: Lewis Publishers.
Sutherland, R. 2000. Methods for estimating the effective impervious area of urban watersheds. Pp. 193–195 *In:* The Practice of Watershed Protection. T. R. Schueler and H. K. Holland (eds.). Ellicott City, MD: Center for Watershed Protection.
Sweeney, B., W. Bott, T. Jackson, K. Kaplan, L. Newbold, J. Standley, L. Hession, and R. Horowitz. 2004. Riparian deforestation, stream narrowing and loss of stream ecosystem services. Proceedings of the National Academy of Sciences 101:14132–14137.
Thomson, J. D., G. Weiblen, B. A. Thomson, S. Alfaro, and P. Legendre. 1996. Untangling multiple factors in spatial distributions: lilies, gophers, and rocks. Ecology 77(6):1698–1715.
Tobiason, S. 2004. Stormwater metals removal by media filtration: field assessment case study. Watershed 2004 Conference Proceedings, CD-ROM. Alexandria, VA: Water Environment Federation.
Trimble, S. W. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. Science 278:1442–1444.
Urban, M., D. Skelly, D. Burchsted, W. Price, and S. Lowry. 2006. Stream communities across a rural-urban landscape gradient. Diversity and Distributions 12:337–350.
U.S. Department of Agriculture (USDA). 2000. Summary Report: 1997 National Resources Inventory (revised December 2000). Natural Resources Conservation Service, Washington, DC, and Statistical Laboratory, Iowa State University, Ames, Iowa, 89 pages.
USGS (U. S. Geological Survey). 1998. A New Evaluation of the USGS Streamgaging Network: A Report to Congress dated November 30, 1998. Reston, VA: U.S. Geological Survey.
USGS. 1999. Analyzing Land Use Change in Urban Environments. USGS Fact Sheet 188-99.
Vogel, R. M., J. R. Stedinger, and R. P. Hooper. 2003. Discharge indices for water quality loads. Water Resources Research 39(10), doi:10.1029/2002WR001872.
Wallinder, I. O., B. Bahar, C. Leygraf, and J. Tidblad. 2007. Modelling and mapping of copper runoff for Europe. Journal of Environmental Monitoring 9:66–73.
Walsh, C., K. Waller, J. Gehling, and R. MacNally. 2007. Riverine invertebrate assemblages are degraded more by catchment urbanization than riparian deforestation. Freshwater Biology 52(3):574–587.
Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society 24(3):706–723.
Walters, D. M., M. C. Freeman, D. S. Leigh, B. J. Freeman, and C. M. Pringle.

2005. Urbanization effects on fishes and habitat quality in a southern piedmont river basin. Pp. 69–85 *In:* Effects of Urbanization on Stream Ecosystems. L. R. Brown, R. M. Hughes, R. Gray, and M. R. Meador (eds.). Bethesda, MD: American Fisheries Society.

Wang, L., and P. Kanehl. 2003. Influences of watershed urbanization and instream habitat on macroinvertebrates in cold water streams. Journal of the American Water Resources Association 39(5):1181–1196.

Wang, L., J. Lyons, P. Rasmussen, P. Simons, T. Wiley, and P. Stewart. 2003. Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest Ecoregion. Canadian Journal of Fisheries and Aquatic Science 60:491–505.

Warren, M., and M. G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fishery Society 127:637–644.

Waters, T. F. 1995. Sediment in Streams—Sources, Biological Effects and Control. American Fisheries Society Monograph 7. Bethesda, MD: American Fisheries Society.

Webster, J. R., and D. J. D'Angelo. 1997. A regional analysis of the physical characteristics of streams. Journal of the North American Benthological Society 16(1):87–95.

Wells, C. 1995. Skinny streets and one-sided sidewalks: a strategy for not paving paradise. Watershed Protection Techniques 1(3):135–137.

Whitlow, J. R., and K. J. Gregory. 1989. Changes in urban stream channels in Zimbabwe. Regulated Rivers Research and Management 4:27–42.

Wiebusch, B., M. Ozaki, H. Watanabe, and C. F. Seyfried. 1998. Assessment of leaching tests on construction material made of incinerator ash (sewage sludge): investigations in Japan and Germany. Water Science and Technology 38(7):195–205.

Willett, G. 1980. Urban erosion. In National Conference on Urban Erosion and Sediment Control; Institutions and Technology. EPA 905/9-80-002. Washington, DC: EPA.

Williams, J. E., J. E. Johnson, D. A. Hendrickson, S. Contreras-Balderas, J. D. Williams, M. Navarro Mendoza, D. E. McAllister, J. E. Deacon. 1989. Fishes of North America endangered, threatened, or of special concern: 1989. Fisheries 14:2–20.

Winter, T. 2007. The role of groundwater in generating streamflow in headwater areas in maintaining baseflow. Journal of American Water Resources Association 43(1):15–25.

Wolman, M. G., and W. P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68:54–74.

Wolman, M. G., and A. Schick. 1967. Effects of construction on fluvial sediment, urban and suburban areas of Maryland. Water Resources Research 3:451–464.

Wright, T., J. Tomlinson, T. Schueler, and K. Cappiella. 2007. Direct and indirect impacts of urbanization on wetland quality. Wetlands and Watersheds

Article 1. Washington, DC: EPA Office of Wetlands, Oceans, and Watersheds, and Ellicott City, MD: Center for Watershed Protection.

Xiao, Q. F. 1998. Rainfall Interception of Urban Forest. Ph.D. Dissertation. University of California, Davis.

Yee, D., and A. Franz. 2005. Castro Valley Atmospheric Deposition Monitoring. PowerPoint presentation, Brake Pad Partnership Stakeholder Conference.

4
Monitoring and Modeling

As part of its statement of task, the committee was asked to consider several aspects of stormwater monitoring, including how useful the activity is, what should be monitored and when and where, and how benchmarks should be established. As noted in Chapter 2, the stormwater monitoring requirements under the U.S. Environmental Protection Agency (EPA) stormwater program are variable and generally sparse, which has led to considerable skepticism about their usefulness. This chapter first considers the value of the data collected over the years by municipalities and makes suggestions for improvement. It then does the same for industrial stormwater monitoring, which has lagged behind the municipal separate storm sewer system (MS4) program both in requirements and implementation.

It should be noted upfront that this chapter does not discuss the fine details of MS4 and industrial monitoring that pertain to regulatory compliance—questions such as should the average end of pipe concentrations meet water quality standards, how many exceedances should be allowed per year, or should effluent concentrations be compared to acute or chronic criteria. Individual benchmarks and effluent limits for specific chemicals emanating from specific industries are not provided. The current state of MS4 and industrial stormwater monitoring and the paucity of high quality data are such that it is premature and in many cases impossible to make such determinations. Rather, the chapter suggests both *how* to monitor an individual industry and *how* to determine benchmarks and effluent limits for industrial categories. It suggests how monitoring requirements should be tailored to accommodate the risk level of an individual industrial discharger. Finally, it makes numerous technical suggestions for improving the monitoring of MS4s, building on the data already submitted and analyzed as part of the National Stormwater Quality Database. Policy recommendations about the monitoring of both industries and MS4s are found in Chapter 6.

This chapter's emphasis on monitoring of stormwater should not be interpreted as a disinterest in other types of monitoring, such as biomonitoring of receiving waters, precipitation measurements, or determination of land cover. Indeed, these latter activities are extremely important (they are introduced in the preceding chapter) and they underpin the new permitting program proposed in Chapter 6 (especially biological monitoring). Stormwater management would benefit most substantially from a well-balanced monitoring program that encompasses chemical, biological, and physical parameters from outfalls to receiving waters. Currently, however, decisions about stormwater management are usually made with incomplete information; for example, there are continued recommendations by many that street cleaning will solve a municipality's problems, even when the municipality does not have any information on the sources of the material being removed.

A second charge to the committee was to define the elements of a "protocol" to link pollutants in stormwater discharges to ambient water quality criteria. As described in Chapter 3, many processes connect sources of pollution to an effect observed in a downstream receiving water. More and more, these processes can be represented in watershed models, which are the key to linking stormwater sources to effects observed in receiving waters. The latter half of the chapter explores the current capability of models to make such links, including simple models, statistical and conceptual models, and more involved mechanistic models. At the present time, associating a single discharger with degraded in-stream conditions is generally not possible because of the state of both modeling and monitoring of stormwater.

MONITORING OF MS4s

EPA's regulations for stormwater monitoring of MS4s is very limited, in that only the application requirements are stated [see 40 CFR § 122.26(d)]. The regulations require the MS4 program to identify five to ten stormwater discharge outfalls and to collect representative stormwater data for conventional and priority toxic pollutants from three representative storm events using both grab and composite sampling methods. Each sampled storm event must have a rainfall of at least 0.1 inch, must be preceded by at least 72 hours of a dry period, and the rain event must be within 50 percent of the average or median of the per storm volume and duration for the region. While the measurement of flow is not specifically required, an MS4 must make estimates of the event mean concentrations (EMCs) for pollutants discharged from all outfalls to surface waters, and in order to determine EMCs, flow needs to be measured or calculated.

Other than these requirements, the exact type of MS4 monitoring that is to be conducted during the permit term is left to the discretion of the permitting authority. EPA has not issued any guidance on what would be considered an adequate MS4 monitoring program for permitting authorities to evaluate compliance. Some guidance for MS4 monitoring based on desired management questions has been developed locally (for example, see the SCCWRP Technical Report No. 419, SMC 2004, Model Monitoring Program for MS4s in Southern California).

In the absence of national guidance from EPA, the MS4 monitoring programs for Phase I MS4s vary widely in structure and objectives, and Phase II MS4 programs largely do not perform any monitoring at all. The types of monitoring typically contained in Phase I MS4 permits include the (1) wet weather outfall screening and monitoring to characterize stormwater flows, (2) dry weather outfall screening and monitoring under illicit discharge detection and elimination programs, (3) biological monitoring to determine storm water impacts, (4) ambient water quality monitoring to characterize water quality conditions, and (5) stormwater control measure (SCM) effectiveness monitoring.

The Nationwide Stormwater Quality Database

Stormwater monitoring data collected by a portion of Phase I MS4s has been evaluated for years by the University of Alabama and the Center for Watershed Protection and compiled in a database called the Nationwide Stormwater Quality Database (NSQD). These data were collected in order to describe the characteristics of stormwater on a national level, to provide guidance for future sampling needs, and to enhance local stormwater management activities in areas with limited data. The MS4 monitoring data collected over the past ten years from more than 200 municipalities throughout the country have great potential in characterizing the quality of stormwater runoff and comparing it against historical benchmarks. Version 3 of the NSQD is available online at: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml. It contains data from more than 8,500 events and 100 municipalities throughout the country. About 5,800 events are associated with homogeneous land uses, while the remainder are for mixed land uses.

The general approach to data collection was to contact EPA regional offices to obtain state contacts for the MS4 data, then the individual municipalities with Phase I permits were targeted for data collection. Selected outfall data from the International BMP Database were also included in NSQD version 3, eliminating any source area and any treated stormwater samples. Some of the older National Urban Runoff Program (NURP) (EPA, 1983) data were also included in the NSQD, along with some data from specialized U.S. Geological Survey (USGS) stormwater monitoring activities in order to better represent nationwide conditions and additional land uses. Because there were multiple sources of information, quality assurance and quality control reviews were very important to verify the correctness of data added to the database, and to ensure that no duplicate entries were added.

The NSQD includes sampling location information such as city, state, land use, drainage area, and EPA Rain Zone, as well as date, season, and rain depth. The constituents commonly measured for in stormwater include total suspended solids (TSS), 5-day biological oxygen demand (BOD_5), chemical oxygen demand (COD), total phosphorus (TP), total Kjeldahl nitrogen (TKN), nitrite plus nitrate (NO_2+NO_3), total copper (Cu), total lead (Pb), and total zinc (Zn). Less information is available for many other constituents (including filterable heavy metals and bacteria). Figure 4-1 is a map showing the EPA Rain Zones in the United States, along with the locations of the communities contributing to the NSQD, version 3. Table 4-1 shows the number of samples for each land use and for each Rain Zone. This table does not show the number of mixed land-use site samples. Rain Zones 8 and 9 have very few samples, and institutional and open-space areas are poorly represented. However, residential, commercial, industrial, and freeway data are plentiful, except for the few Rain Zones noted above.

Land use has an important impact on the quality of stormwater. For example, the concentrations of heavy metals are higher for industrial land-use areas

TABLE 4-1 Number of Samples per Land Use and EPA Rain Zone

Single Land Use	1	2	3	4	5	6	7	8	9	Total
Commercial	234	484	131	66	42	37	64	0	22	1080
Freeways	0	241	14	0	262	189	28	0	0	734
Industrial	100	327	90	51	83	74	146	0	22	893
Institutional	9	46	0	0	0	0	0	0	0	55
Open Space	68	37	0	18	0	2	0	0	0	125
Residential	294	1470	290	122	105	32	532	7	81	2933
Total	705	2605	525	257	492	334	770	7	125	5820

Note: there are no mixed-use sites in this table. SOURCE: National Stormwater Quality Database.

due to manufacturing processes and other activities that generate these materials. Fecal coliform concentrations are relatively high for residential and mixed residential land uses, and nitrate concentrations are higher for the freeway land use. Open-space land-use areas show consistently low concentrations for the constituents examined. Seasons could also be a factor in the variation of nutrient concentrations in stormwater due to seasonal uses of fertilizers and leaf drop occurring during the fall season. Most studies also report lower bacteria concentrations in the winter than in the summer. Lead concentrations in stormwater have also significantly decreased since the elimination of lead in gasoline (see Figure 2-6). Most of the statistical tests used are multivariate statistical evaluations that compare different constituent concentrations with land use and geographical location. More detailed discussions of the earlier NSQD results are found in various references, including Maestre et al. (2004, 2005) and Pitt et al. (2003, 2004).

How to use the NSQD to Calculate Representative EMC Values

EMC values were initially used during the NURP to describe typical concentrations of pollutants in stormwater for different monitoring locations and land uses. An EMC is intended to represent the average concentration for a single monitored event, usually based on flow-weighted composite sampling. It can also be calculated from discrete samples taken during an event if flow data are also available. Many individual subsamples should be taken throughout most of the event to calculate the EMC for that event. Being an overall average value, an EMC does not represent possible extremes that may occur during an event.

The NSQD includes individual EMC values from about 8,500 separate events. Stormwater managers typically want a representative single value for a land use for their area. As such, they typically evaluate a series of individual

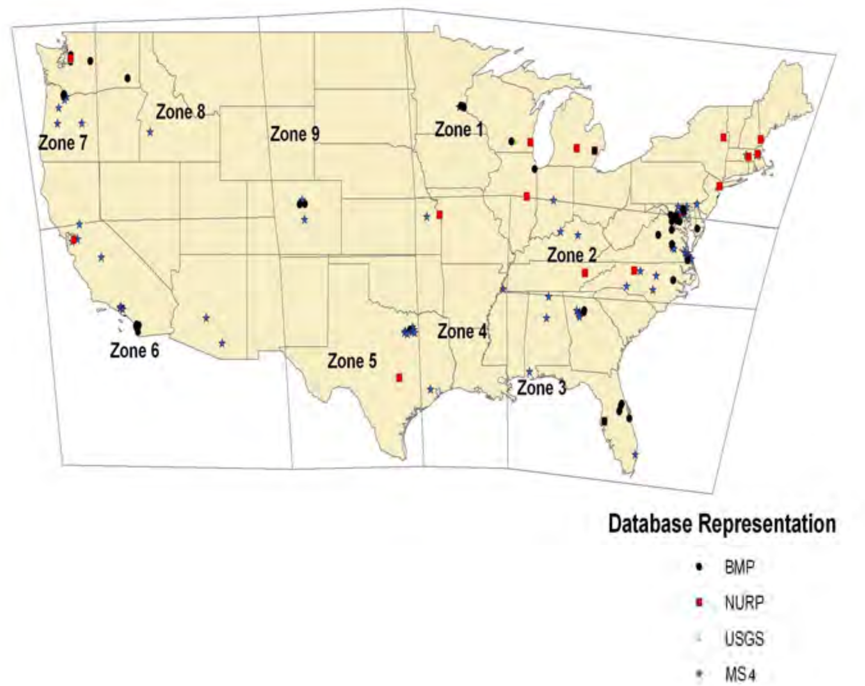

FIGURE 4-1 Sampling Locations for Data Contained in the National Stormwater Quality Database, version 3.

storm EMC values for conditions similar to those representing their site of concern. With the NSQD in a spreadsheet form, it is relatively simple to extract suitable events representing the desired conditions. However, the individual EMC values will likely have a large variability. Maestre and Pitt (2006) reviewed the NSQD data to better explain the variability according to different site and sampling conditions (land use, geographical location, season, rain depth, amount of impervious area, sampling methods, antecedent dry period, etc.). The most common significant factor was land use, with some geographical and fewer seasonal effects observed. As with the original NURP data, EMCs in the NSQD are usually expressed using medians and coefficients of variation to reflect uncertainty, assuming lognormal distributions of the EMC values. Figure 4-2 shows several lognormal probability plots for a few constituents from the NSQD. Probability plots shown as straight lines indicate that the concentrations can be represented by lognormal distributions (see Box 4-1).

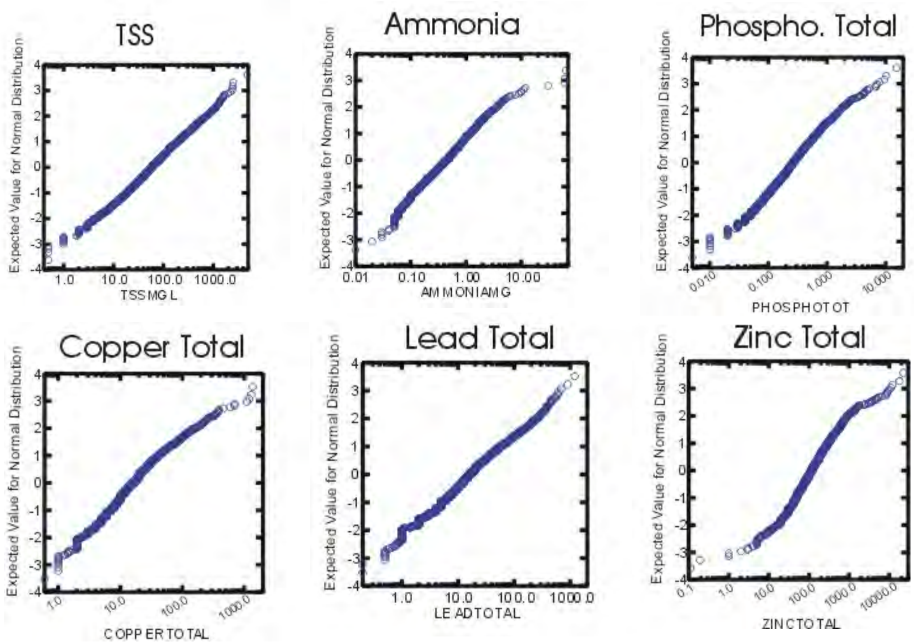

FIGURE 4-2 Lognormal probability plots of stormwater quality data for selected constituents (pooled data from NSQD version 1.1).

Fitting a known distribution is important as it helps indicate the proper statistical tests that may be conducted. Using the *median* EMC value in load calculations, without considering the data variability, will result in smaller mass loads compared to actual monitored conditions. This is due to the medians underrepresenting the larger concentrations that are expected to occur. The use of *average* EMC values will represent the larger values better, although they will still not represent the variability likely to exist. If all of the variability cannot be further explained adequately (such as being affected by rain depth), which would be highly unlikely, then a set of random calculations (such as that obtained using Monte Carlo procedures) reflecting the described probability distribution of the constituents would be the best method to use when calculating loads.

Municipal Monitoring Issues

As described in Chapter 2, typical MS4 monitoring requirements involve sampling during several events per year at the most common land uses in the area. Obviously, a few samples will not result in very useful data due to

BOX 4-1
Probability Distributions of Stormwater Data

The coefficient of variation (COV) values for many constituents in the NSQD range from unusually low values of about 0.1 (for pH) to highs between 1 and 2. One objective of a data analysis procedure is to categorize the data into separate stratifications, each having small variations in the observed concentrations. The only stratification usually applied is for land use. However, further analyses indicated many differences by geographical area and some differences by season. When separated into appropriate stratifications, the COV values are reduced, ranging between about 0.5 to 1.0. With a reasonable confidence of 95 percent (α= 0.05) and power of 80 percent (β= 0.20), and a suitable allowable error goal of 25 percent, the number of samples needed to characterize these conditions would therefore range from about 25 to 50 (Burton and Pitt, 2002). In a continuing monitoring program (such as the Phase I stormwater National Pollutant Discharge Elimination System [NPDES] permit monitoring effort) characterization data will improve over time as more samples are obtained, even with only a few samples collected each year from each site.

Stormwater managers have generally accepted the assumption of lognormality of stormwater constituent concentrations between the 5th and 95th percentiles. Based on this assumption, it is common to use the log-transformed EMC values to evaluate differences between land-use categories and other characteristics. Statistical inference methods, such as estimation and tests of hypothesis, and analysis of variance, require statistical information about the distribution of the EMC values to evaluate these differences. The use of the log-transformed data usually includes the location and scale parameter, but a lower-bound parameter is usually neglected.

Maestre et al. (2005) conducted statistical tests using NSQD data to evaluate the lognormality assumptions of selected common constituents. It was found in almost all cases that the log-transformed data followed a straight line between the 5^{th} and 95^{th} percentile, as illustrated in Figure 4-3 for total dissolved solids (TDS) in residential areas.

For many statistical tests focusing on the central tendency (such as for determining the concentrations that are to be used for mass balance calculations), this may be a suitable fit. As an example, the model WinSLAMM (Pitt, 1986; Pitt and Voorhees, 1995) uses a Monte Carlo component to describe the likely variability of stormwater source flow pollutant concentrations using either lognormal or normal probability distributions for each constituent. However, if the most extreme values are of importance, such as when dealing with the influence of many non-detectable values on the predicted concentrations, or determining the frequency of observations exceeding a numerical standard, a better description of the extreme values may be important.

The NSQD contains many factors for each sampled event that likely affect the observed concentrations. These include such factors as seasons, geographical zones, and rain intensities. These factors may affect the shape of the probability distribution. The only way to evaluate the required number of samples in each category is by using the power of the test, where power is the probability that the test statistic will lead to a rejection of the null hypothesis (Gibbons and Chakraborti, 2003).

In the NSQD, most of the data were from residential land uses. The Kolmogorov-Smirnov test was used to indicate if the cumulative empirical probability distribution of the residential stormwater constituents can be adequately represented with a lognormal distribution. The number of collected samples was sufficient to detect if the empirical distribu-

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BOX 4-1 Continued

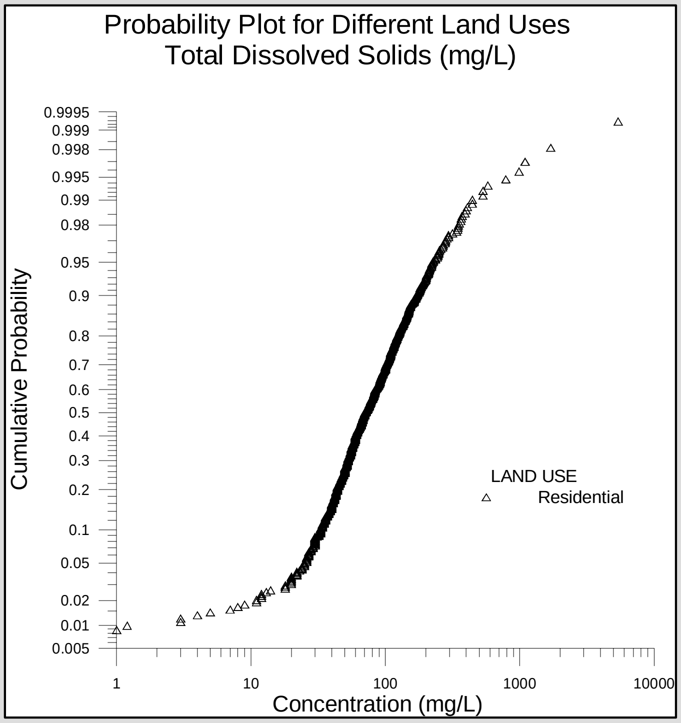


FIGURE 4-3 Probability plot of total dissolved solids in residential land uses (NSQD version 1.1 data).

tion was located inside an interval of width 0.1 above and below the estimated cumulative probability distribution. If the interval was reduced to 0.05, the power varies between 40 and 65 percent. Another factor that must be considered is the importance of relatively small errors in the selected distribution and the problems of false-negative determinations. It may not be practical to collect as many data observations as needed when the distributions are close. Therefore, it is important to understand what types of further statistical and analysis problems may be caused by having fewer samples than optimal. For example, Figure 4-4 (total phosphorus in residential areas) shows that most of the data fall along the straight line (indicating a lognormal fit), with fewer than 10 observations (out of 933) in the tails being outside of the obvious path of the line, or a false-negative rate of about 0.01 (1 percent).

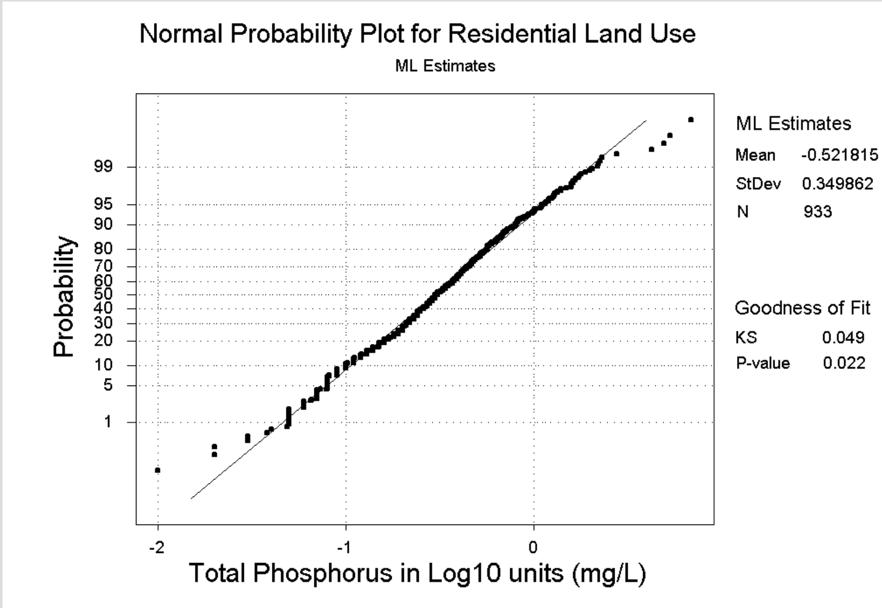


FIGURE 4-4 Normality test for total phosphorus in residential land uses using the NSQD.

Further analyses to compare the constituent concentration distributions to other common probability distributions (normal, lognormal, gamma, and exponential) were also conducted for all land uses by Maestre et al. (2004). Most of the stormwater constituents can be assumed to follow a lognormal distribution with little error. The use of a third parameter in the estimated lognormal distribution may be needed, depending on the number of samples. When the number of samples is large per category (approximately more than 400 samples) the maximum likelihood and the two-parameter lognormal distribution better fit the empirical distribution. For large sample sizes, the L-moments method usually unacceptably truncates the distribution in the lower tail. However, when the sample size is more moderate per category (approximately between 100 and 400 samples), the three-parameter lognormal method, estimated by L-moments, better fits the empirical distribution. When the sample size is small (less than 100 samples, as is common for most stormwater programs), the use of the third parameter does not improve the fit with the empirical distribution and the common two-parameter lognormal distribution produces a better fit than the other two methods. The use of the lognormal distribution also has an advantage over the other distribution types because it can be easily transformed to a normal distribution and the data can then be correctly examined using a wide variety of statistical tests.

the variability of stormwater characteristics. However, during the period of a five-year permit with three samples per year, about 15 events would be sampled for each land use. While still insufficient for many analyses, this number of data points likely allows the confidence limits to be reasonably calculated for the average conditions. When many sites of the same land use are monitored for a region, substantial data may be collected during a permit cycle. This was the premise of the NSQD where MS4 data were collected for many locations throughout the country. These data were evaluated and various findings made. The following comments are partially based on these analyses, along with additional data sources.

Sampling Technique and Compositing

There are a variety of methods for collecting and compositing stormwater samples that can result in different values for the EMC. The first distinction is the mode of sample collection, either as grab samples or automatic sampling. Obviously, grab sampling is limited by the speed and accuracy of the individuals doing the sampling, and it is personnel intensive. It is for this reason that about 80 percent of the NSQD samples are collected using automatic samplers. Manual sampling has been observed to result in slightly lower TSS concentrations compared to automatic sampling procedures. This may occur, for example, if the manual sampling team arrives after the start of runoff and therefore misses an elevated first flush (if it exists for the site), resulting in reduced EMCs.

A second important concept is how and whether the samples are combined following collection. With *time-based discrete sampling*, **s**amplers (people or machines) are programmed to take an aliquot after a set period of time (usually in the range of every 15 minutes) and each aliquot is put into a separate bottle (usually 1 liter). Each bottle is processed separately, so this method can have high laboratory costs. This is the only method, however, that will characterize the changes in pollutant concentrations during the event. *Time-based composite sampling* refers to samplers being programmed to take an aliquot after a set period of time (as short as every 3 minutes), but then the aliquots are combined into one container prior to analysis (compositing). All parts of the event receive equal weight with this method, but the large number of aliquots can produce a reasonably accurate composite concentration. Finally, *flow-weighted composite sampling* refers to samplers being programmed to collect an aliquot (usually 1 liter) for a set volume of discharge. Thus, more samples are collected during the peak of the hydrograph than toward the trailing edge of the hydrograph. All of the aliquots are composited into one container, so the concentration for the event is weighted by flow.

Most communities calculate their EMC values using flow-weighted composite sample analyses for more accurate mass discharge estimates compared to time-based compositing. This is especially important for areas with a first flush of very short duration, because time-composited samples may overly emphasize these higher flows. An automatic sampler with flow-weighted samples, in conjunction with a bed-load sampler, is likely the most accurate sampling method, but only if the sampler can obtain a representative sample at the location (such as sampling at a cascading location, or using an automated depth-integrated sampler) (Clark et al., 2008).

Time- and flow-weighted composite options have been evaluated in residential, commercial, and industrial land uses in EPA Rain Zone 2 and in industrial land uses in EPA Rain Zone 3 for the NSQD data. No significant differences were observed for BOD_5 concentrations using either of the compositing schemes for any of the four categories. TSS and total lead median concentrations in EPA Rain Zone 2 were two to five times higher in concentration when time-based compositing was used instead of flow-based compositing. Nutrients in EPA Rain Zone 2 collected in residential, commercial, and industrial areas showed no significant differences using either compositing method. The only exceptions were for ammonia in residential and commercial land-use areas and total phosphorus in residential areas where time-based composite samples had higher concentrations. Metals were higher when time-based compositing was used in residential and commercial land-use areas. No differences were observed in industrial land-use areas, except for lead. Again, in most cases, mass discharges are of the most importance in order to show compliance with TMDL requirements. Flow-weighted sampling is the most accurate method to obtain these values (assuming sufficient numbers of subsamples are obtained). However, if receiving water effects are associated with short-duration high concentrations, then discrete samples need to be collected and analyzed, with no compositing of the samples during the event. Of course, this is vastly more costly and fewer events are usually monitored if discrete sampling is conducted.

Numbers of Data Observations Needed

The biggest issue associated with most monitoring programs is the number of data points needed. In many cases, insufficient data are collected to address the objectives of the monitoring program with a reasonable amount of confidence and power. Burton and Pitt (2002) present much guidance in determining the amount of data that should be collected. A basic equation that can be used to estimate the number of samples to characterize a set of conditions is as follows:

$$n = [COV(Z_{1-\alpha} + Z_{1-\beta})/(error)]^2$$

where:

n = number of samples needed.

α = false-positive rate (1–α is the degree of confidence; a value of α of 0.05 is usually considered statistically significant, corresponding to a 1–α degree of confidence of 0.95, or 95%).

β = false-negative rate (1–β is the power; if used, a value of β of 0.2 is common, but it is frequently and improperly ignored, corresponding to a β of 0.5).

$Z_{1-\alpha}$ = Z score (associated with area under a normal curve) corresponding to 1–α; if α is 0.05 (95% degree of confidence), then the corresponding $Z_{1-\alpha}$ score is 1.645 (from standard statistical tables).

$Z_{1-\beta}$ = Z score corresponding to 1–β value; if β is 0.2 (power of 80%), then the corresponding $Z_{1-\beta}$ score is 0.85 (from standard statistical tables); however, if power is ignored and β is 0.5, then the corresponding $Z_{1-\beta}$ score is 0.

error = allowable error, as a fraction of the true value of the mean.

COV = coefficient of variation (sometimes noted as CV), the standard deviation divided by the mean (dataset assumed to be normally distributed).

Figures 4-5 and 4-6 can be used to estimate the sampling effort, based on the expected variability of the constituent being monitored, the allowable error in the calculated mean value, and the associated confidence and power. Figure 4-5 can be used for a single sampling point that is being monitored for basic characterization information, while Figure 4-6 is used for paired sampling when two locations are being compared. Confidence and power are needed to control the likelihood of false negatives and false positives. The sample needs increase dramatically as the difference between datasets becomes small when comparing two conditions with a paired analysis, as shown in Figure 4-6 (above and below an outfall, influent vs. effluent, etc.). Typically, being able to detect a difference of at least about 25 percent (requiring about 50 sample pairs with typical sample variabilities) is a reasonable objective for most stormwater projects. This is especially important when monitoring programs attempt to distinguish test and control conditions associated with SCMs. It is easy to confirm significant differences between influent and effluent conditions at wet detention ponds, as they have relatively high removal rates. Less effective controls are much more difficult to verify, as the sampling program requirements become very expensive.

First-Flush Effects

First flush refers to an assumed elevated load of pollutants discharged in the beginning of a runoff event. The first-flush effect has been observed more often in small catchments than in large catchments (Thompson et al., 1995, cited by WEF and ASCE, 1998). Indeed, in large catchments (>162 ha, 400 acres), the

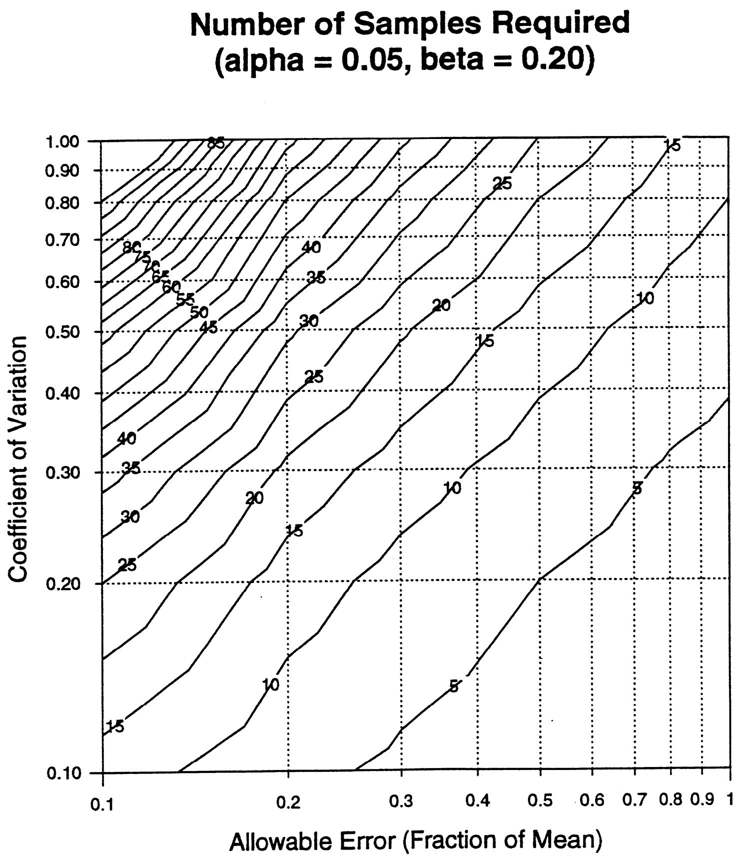


FIGURE 4-5 Number of samples to characterize median (power of 80% and confidence of 95%). SOURCE: Reprinted, with permission from, Burton and Pitt (2002). Copyright 2002 by CRC Press.

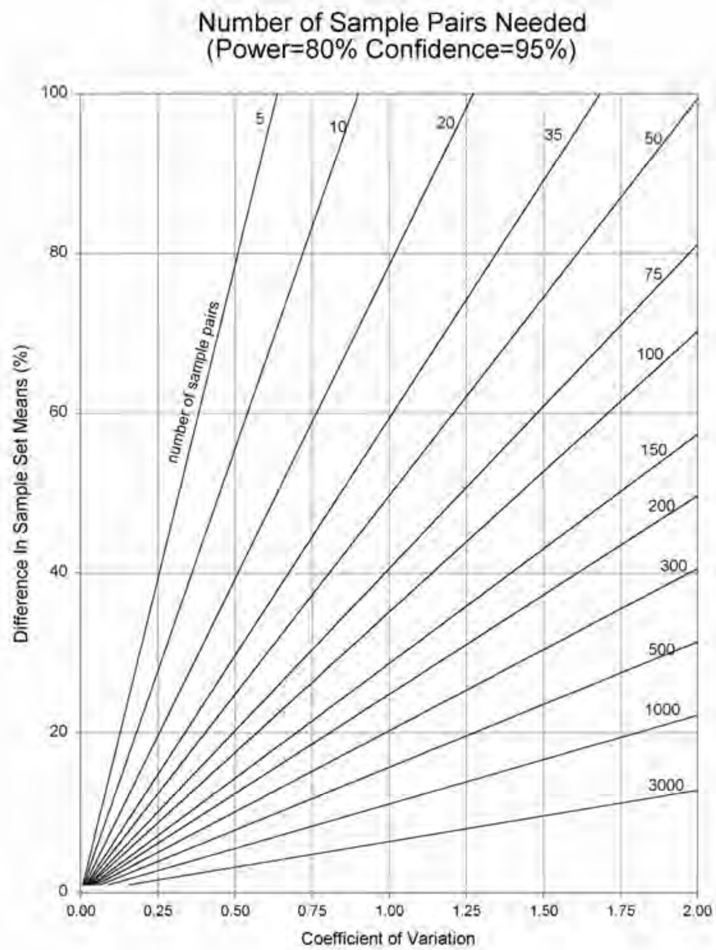


FIGURE 4-6 Number of paired samples needed to distinguish between two sets of observations (power 80% and confidence of 95%). SOURCE: Reprinted, with permission from, Burton and Pitt (2002). Copyright 2002 by CRC Press.

highest concentrations are usually observed at the times of flow peak (Brown et al., 1995; Soeur et al., 1995). Adams and Papa (2000) and Deletic (1998) both concluded that the presence of a first flush depends on numerous site and rainfall characteristics.

Figure 4-7 is a plot of monitoring data from the Villanova first-flush study (Batroney, 2008) showing the flows, rainfall, TSS concentration, TDS concentration, and TDS and TSS event mean concentrations for the inflow to an infiltration trench. Because of the first-flush effect, a grab sample early in the storm would have over-predicted the TSS event mean concentration of the site, and a later sample would have under-predicted this same value, although for TDS the results would have been similar.

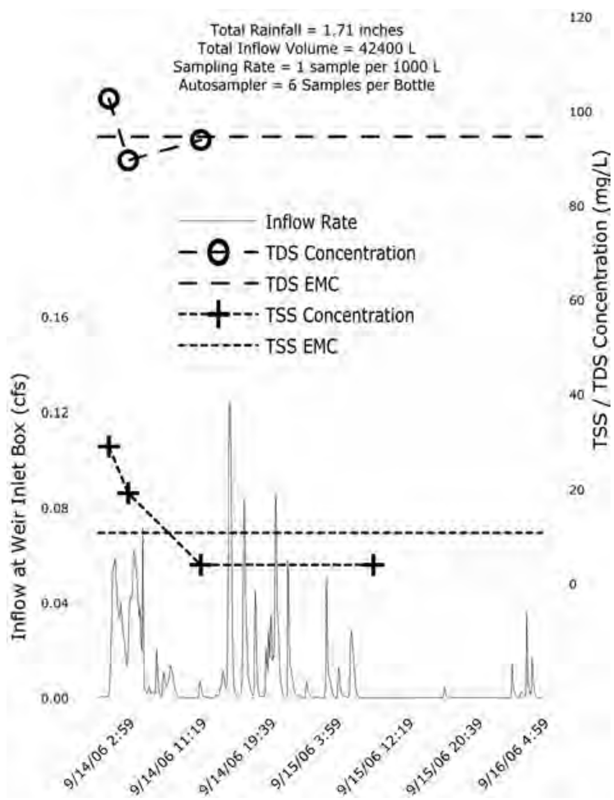


FIGURE 4-7 Villanova first-flush study showing pollutant concentration as a function of inflow rainfall volume. This study collected runoff leaving the top floor of a parking garage. Samples were taken of the runoff in one-quarter-inch increments, up to an inch of rain, and then every inch thereafter. The plot of TSS concentration versus rainfall increment shows a strong first flush for this storm, while the TDS concentration does not. SOURCE: Reprinted, with permission, Batroney (2008). Copyright 2008 by T. Thomas Batroney.

Figure 4-8 shows data for a short-duration, high-intensity rain in Tuscaloosa, Alabama, that had rain intensities as great a 6 inches per hour for a 10-minute period. The drainage area was a 0.4-ha paved parking lot with some landscaping along the edges. The turbidity plot shows a strong first flush for this event, and the particle size distributions indicate larger particles at the beginning of the event, then becoming smaller as the event progresses, and then larger near the end. Most of the other pollutants analyzed had similar first-flush patterns like the turbidity, with the notable exception of bacteria. Both *E. coli* and enterococci concentrations started off moderately low, but then increased substantially near the end of the rain. Several rains have been monitored at this site so far, and most show a similar pattern with decreasing turbidity and increasing bacteria as the rain continues.

Sample collection conducted for some of the NPDES MS4 Phase I permits required both a grab and a composite sample for each event. A grab sample was to be taken during the first 30 minutes of discharge to capture the first flush, and a flow-weighted composite sample was to be taken for the entire time of discharge (every 15 to 20 minutes for at least three hours or until the event ended). Maestre et al. (2004) examined about 400 paired sets of 30-minute and 3-hour samples from the NSQD, as shown in Table 4-2. Generally, a statistically significant first flush is associated with a median concentration ratio of about 1.4 or greater (the exceptions are where the number of samples in a specific category is much smaller). The largest ratios observed were about 2.5, indicating that for these conditions the first 30-minute flush sample concentrations are about 2.5 times greater than the composite sample concentrations. More of the larger ratios are found for the commercial and institutional land-use categories, where larger paved areas are likely to be found. The smallest ratios are associated with the residential, industrial, and open-space land uses—locations where there may be larger areas of unpaved surfaces.

The data in Table 4-2 were from North Carolina (76.2 percent), Alabama (3.1 percent), Kentucky (13.9 percent), and Kansas (6.7 percent) because most other states' stormwater permits did not require this sampling strategy. The NSQD investigation of first-flush conditions for these data locations indicated that a first-flush effect was not present for all the land-use categories and certainly not for all constituents. Commercial and residential areas were more likely to show this phenomenon, especially if the peak rainfall occurred near the beginning of the event. It is expected that this effect will more likely occur in a watershed with a high level of imperviousness, but even so, the data indicated first flushes for less than 50 percent of the samples for the most impervious areas. This reduced frequency of observed first flushes in areas most likely to have first flushes is probably associated with the varying rain conditions during the different events, including composite samples that did not represent the complete runoff duration.

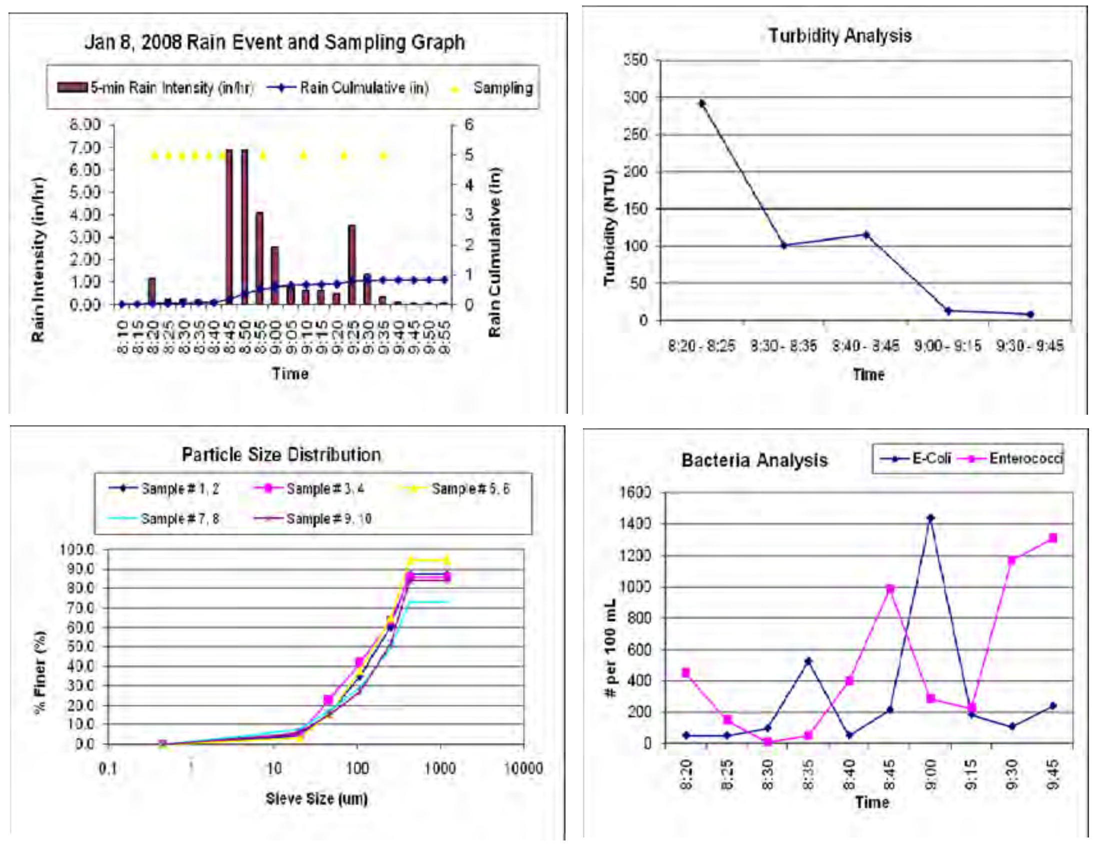


FIGURE 4-8 Pollutant variations during rain period (0.4-ha drainage area, mostly paved parking with small fringe turf area, Tuscaloosa, Alabama). SOURCE: Robert Pitt, University of Alabama.

TABLE 4-2 Significant First Flush Ratios (First Flush to Composite Median Concentration)

Parameter	Commercial				Industrial				Institutional			
	n	sc	R	ratio	n	sc	R	ratio	n	sc	R	ratio
Turbidity, NTU	11	11	=	1.32			X				X	
COD, mg/L	91	91	≠	2.29	84	84	≠	1.43	18	18	≠	2.73
TSS, mg/L	90	90	≠	1.85	83	83	=	0.97	18	18	≠	2.12
Fecal coliform, col/100mL	12	12	=	0.87			X				X	
TKN, mg/L	93	86	≠	1.71	77	76	≠	1.35			X	
Phosphorus total, mg/L	89	77	≠	1.44	84	71	=	1.42	17	17	=	1.24
Copper, total, µg/L	92	82	≠	1.62	84	76	≠	1.24	18	7	=	0.94
Lead, total, µg/L	89	83	≠	1.65	84	71	≠	1.41	18	13	≠	2.28
Zinc, total, µg/L	90	90	≠	1.93	83	83	≠	1.54	18	18	≠	2.48

Parameter	Open Space				Residential				All Combined			
	n	sc	R	ratio	n	sc	R	ratio	n	sc	R	ratio
Turbidity, NTU			X		12	12	=	1.24	26	26	=	1.26
COD, mg/L	28	28	=	0.67	140	140	≠	1.63	363	363	≠	1.71
TSS, mg/L	32	32	=	0.95	144	144	≠	1.84	372	372	≠	1.60
Fecal coliform, col/100mL			X		10	9	=	0.98	22	21	=	1.21
TKN, mg/L	32	14	=	1.28	131	123	≠	1.65	335	301	≠	1.60
Phosphorus, total, mg/L	32	20	=	1.05	140	128	≠	1.46	363	313	≠	1.45
Copper, total, µg/L	30	22	=	0.78	144	108	≠	1.33	368	295	≠	1.33
Lead, total, µg/L	31	16	=	0.90	140	93	≠	1.48	364	278	≠	1.50
Zinc, total, µg/L	21	21	=	1.25	136	136	≠	1.58	350	350	≠	1.59

Note: n, number of total possible events; sc, number of selected events with detected values; R, result; X, not enough data; =, not enough evidence to conclude that median values are different; ≠, median values are different. "Ratio" is the ratio of the first flush to the full-period sample concentrations.
SOURCE: NSQD, as reported by Maestre et al. (2004).

Groups of constituents showed different behaviors for different land uses. All the heavy metals evaluated showed higher concentrations at the beginning of the event in the commercial land-use category. Similarly, all the nutrients showed higher initial concentrations in residential land-use areas, except for total nitrogen and orthophosphorus. This phenomenon was not found in the bacterial analyses. None of the land uses showed a higher population of bacteria at the beginning of the event.

The general conclusion from these data is that, in areas having low and generally even-intensity rains, first-flush observations are more common, especially in small and mostly paved areas. As an area increases in size, multiple routing pathways tend to blend the water, and runoff from the more distant locations reaches the outfall later in the event. SCMs located at outfalls in areas having low levels of impervious cover should be selected and sized to treat the complete event, if possible. Preferential treatment of first flushes may only be justified for small impervious areas, but even then, care needs to be taken to prevent undersizing and missing substantial fractions of the event.

Seasonal first flushes refer to larger portions of the annual runoff and pollutant discharges occurring during a short rain season. Seasonal first flushes may be observed in more arid locations where seasonal rainfalls are predominant. As an example, central and southern California can have dry conditions for extended periods, with the initial rains of the season occurring in the late fall. These rains can be quite large and, since they occur after prolonged dry periods, may carry substantial portions of the annual stormwater pollutant load. This is especially pronounced if later winter rains are more mild in intensity and frequent. For these areas, certain types of seasonally applied SCMs may be effective. As an example, extensive street, channel, and inlet cleaning in the late summer and early fall could be used to remove large quantities of debris and leaves from the streets before the first heavy rains occur. Other seasonal maintenance operations benefiting stormwater quality should also be scheduled before these initial rains.

Rain Depth Effects

An issue related to first flushes pertains to the effects of rain depth on stormwater quality. The NSQD contains much rainfall data along with runoff data for most areas of the country. Figure 4-9 contains scatter plots showing concentrations plotted against rain depth for some NSQD data. Although many might assume a correlation between concentrations and rain depth, in fact there are no obvious trends of concentration associated with rain depth. Rainfall energy determines erosion and wash-off of particulates, but sufficient runoff volume is needed to carry the particulate pollutants to the outfalls. Different travel times from different locations in the drainage areas results in these materials arriving at different times, plus periods of high rainfall intensity (that increase pollutant wash-off and movement) occur randomly throughout the storm. The

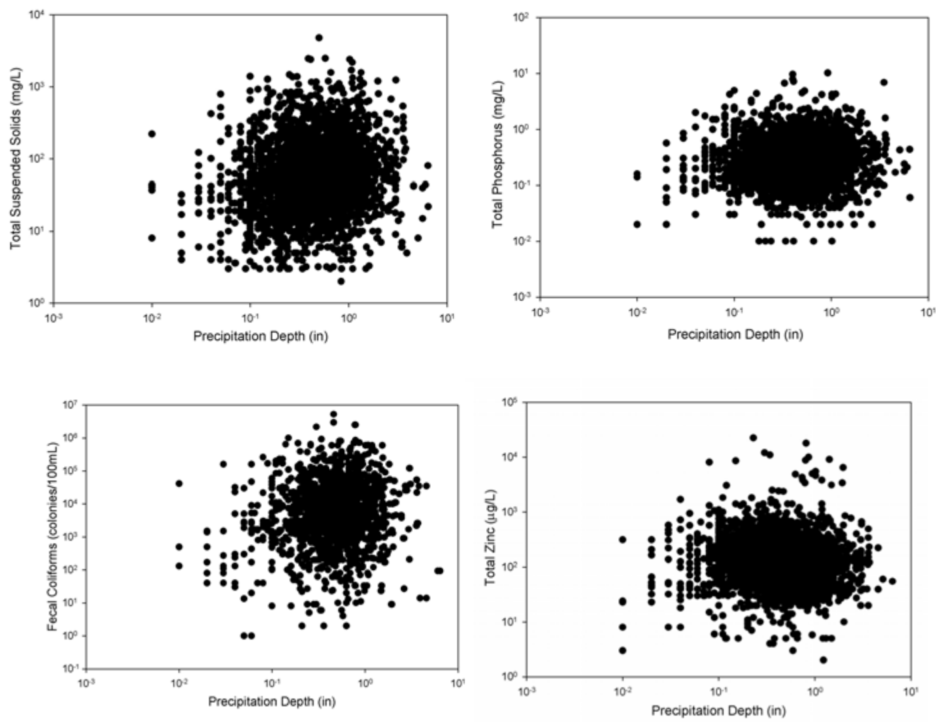


FIGURE 4-9 Examples of scatter plots by precipitation depth. SOURCE: NSQD.

resulting outfall stormwater concentration patterns for a large area having various surfaces is therefore complex and rain depth is just one of the factors involved.

Reported Monitoring Problems

A number of monitoring problems were described in the local Phase I community MS4 annual monitoring reports that were summarized as part of assembling the NSQD. About 58 percent of the communities described monitoring problems. Problems were mostly associated with obtaining reliable data for the targeted events. These problems increased costs because equipment failures had to be corrected and sampling excursions had to be rescheduled. One of the basic sampling requirements was to collect three samples every year for each of the land-use stations. These samples were to be collected at least one month apart during storm events having at least 0.1-inch rains, and with at least 72 hours from the previous 0.1-inch storm event. It was also required (when feasible) that the variance in the duration of the event and the total rainfall not exceed the median rainfall for the area. About 47 percent of the communities reported problems meeting these requirements. In many areas of the country, it was difficult to have three storm events per year with these characteristics. Furthermore, the complete range of site conditions needs to be represented in the data-collection effort; focusing only on a narrow range of conditions limits the representativeness of the data.

The second most frequent problem, reported by 26 percent of the communities, concerned backwater tidal influences during sampling, or that the outfall became submerged during the event. In other cases, it was observed that there was flow under the pipe (flowing outside of the pipe, in the backfill material, likely groundwater), or sometimes there was no flow at all. These circumstances all caused contamination of the collected samples, which had to be discarded, and prevented accurate flow monitoring. Greater care is obviously needed when locating sampling locations to eliminate these problems.

About 12 percent of the communities described errors related to malfunctions of the sampling equipment. When reported, the equipment failures were due to incompatibility between the software and the equipment, clogging of the rain gauges, and obstruction in the sampling or bubbler lines. Memory losses in the equipment recording data were also periodically reported. Other reported problems were associated with lighting, false starts of the automatic sampler before the runoff started, and operator error due to misinterpretation of the equipment configuration manual.

The reported problems suggest that the following changes should be made. First, the rain gauges need to be placed close to the monitored watersheds. Large watersheds cannot be represented with a single rain gauge at the monitoring station. In all cases, a standard rain gauge needs to supplement a tipping bucket rain gauge, and at least three rain gauges should be used in the research watersheds. Second, flow-monitoring instrumentation also needs to be used at all water quality monitoring stations. The lack of flow data greatly hinders the value of the chemical data. Third, monitoring needs to cover the complete storm duration. Automatic samplers need to be properly programmed and maintained to handle very short to very long events. It is unlikely that manual samplers were able to initiate sampling near the beginning of the events, unless they were deployed in anticipation of an event later in the day. A more cost-effective and reliable option would be to have semi-permanent monitoring stations at the various locations with sampling equipment installed in anticipation of a monitored event. Most monitoring agencies operated three to five land-use stations at one time. This number of samplers, and flow equipment, could have been deployed in anticipation of an acceptable event and would not need to be continuously installed in the field at all sampling locations.

Non-Detected Analyses

Left-censored data involve observations that are reported as below the limits of detection, whereas right-censored data involve above-range observations. Unfortunately, many important stormwater measurements (such as for filtered heavy metals) have large fractions of undetected values. These incomplete data greatly hinder many statistical tests. To estimate the problems associated with censored values, it is important to identify the probability distributions of the data in the dataset and the level of censoring. As discussed previously, most of the constituents in the NSQD follow a lognormal distribution. When the frequencies of the censored observations were lower than 5 percent, the means, standard deviations, and COVs were almost identical to the values obtained when the censored observations were replaced by half of the detection limit. As the percentage of nondetected values increases, replacing the censored observation by half of the detection limit instead of estimating them using Cohen's maximum likelihood method produced lower means and larger standard deviations. Replacing the censored observations by half of the detection limit is not recommended for levels of censoring larger than 15 percent. Because the Cohen method uses the detected observations to estimate the nondetected values, it is not very accurate, and therefore not recommended, when the percentage of censored observations is larger than 40 percent (Burton and Pitt, 2002). In this case, summaries should only be presented for the detected observations, with clear notations stating the level of nondetected observations.

The best method to eliminate problems associated with left-censored data is to use an appropriate analytical method. By keeping the nondetectable level below 5 percent, there are many fewer statistical analysis problems and the value of the datasets can be fully realized. Table 4-3 summarizes the recommended minimum detection limits for various stormwater constituents to obtain manageable nondetection frequencies (< 5 percent), based on the NSQD data observations. Some of the open-space stormwater measurements (lead, and oil and grease, for example) would likely have greater than 5 percent nondetections, even with the detection limits shown. The detection limits for filtered heavy metals should also be substantially less than shown on this table.

Seasonal Effects

Another factor that some believe may affect stormwater quality is the season when the sample was obtained. If the few samples collected for a single site were all collected in the same season, the results may not be representative of the whole year. The NPDES sampling protocols were designed to minimize this effect by requiring the three samples per year to be separated by at least one month. The few samples still could be collected within a single season, but not within the same week. Seasonal variations for residential fecal coliform data are shown in Figure 4-10 for NSQD data for all residential areas. These data were

TABLE 4-3 Suggested Analytical Detection Limits for Stormwater Monitoring Programs to Obtain Less Than 5 Percent Nondetections

Parameter	Residential, Commercial, Industrial, Freeway		Open Space	
Conductivity	20	μS/cm	20	μS/cm
Hardness	10	mg/L	10	mg/L
Oil and grease	0.5	mg/L	0.5	mg/L
TDS	10	mg/L	10	mg/L
TSS	5	mg/L	1	mg/L
BOD_5	2	mg/L	1	mg/L
COD	10	mg/L	5	mg/L
Ammonia	0.05	mg/L	0.01	mg/L
$NO_2 + NO_3$	0.1	mg/L	0.05	mg/L
TKN	0.2	mg/L	0.2	mg/L
Dissolved P	0.02	mg/L	0.01	mg/L
Total P	0.05	mg/L	0.02	mg/L
Total Cu	2	μg/L	2	μg/L
Total Pb	3	μg/L (residential μg/L)	1	μg/L
Total Ni	2	μg/L	1	μg/L
Total Zn	20	μg/L (residential 10 μg/L)	5	μg/L

SOURCE: Maestre and Pitt (2005).

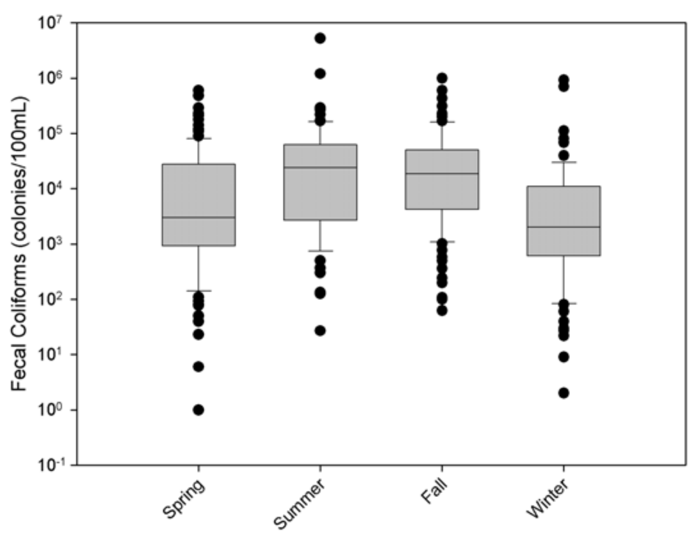


FIGURE 4-10 Fecal coliform concentrations in stormwater by season. SOURCE: NSQD.

the only significant differences in concentration by season for any constituent measured. The bacteria levels are lowest during the winter season and highest during the summer and fall (a similar conclusion was obtained during the NURP data evaluations).

Recommendations for MS4 Monitoring Activities

The NSQD is an important tool for the analysis of stormwater discharges at outfalls. About a fourth of the total existing information from the NPDES Phase I program is included in the database. Most of the statistical analyses in this research were performed for residential, commercial, and industrial land uses in EPA Rain Zone 2 (the area of emphasis according to the terms of the EPA-funded research). Many more data are available from other stormwater permit holders that are not included in this database. Acquiring these additional data for inclusion in the NSQD is a recommended and cost-effective activity and should be accomplished as additional data are also being obtained from ongoing monitoring projects.

The use of automatic samplers, coupled with bed-load samplers, is preferred over manual sampling procedures. In addition, flow monitoring and on-site rainfall monitoring need to be included as part of all stormwater characterization monitoring. The additional information associated with flow and rainfall data will greatly enhance the usefulness of the much more expensive water quality monitoring. Flow monitoring must also be correctly conducted, with adequate verification and correct base-flow subtraction methods applied. A related issue frequently mentioned by the monitoring agencies is the lack of on-site precipitation information for many of the sites. Using regional rainfall data from locations distant from the monitoring location is likely to be a major source of error when rainfall factors are being investigated.

Many of the stormwater permits only required monitoring during the first three hours of the rain event. This may have influenced the EMCs if the rain event continued much beyond this time. Flow-weighted composite monitoring should continue for the complete rain duration. Monitoring only three events per year from each monitoring location requires many years before statistically adequate numbers of observations are obtained. In addition, it is much more difficult to ensure that such a small fraction of the total number of annual events is representative. Also, there is minimal value in obtaining continued data from an area after sufficient information is obtained. It is recommended that a more concentrated monitoring program be conducted for a two- or three-year period, with a total of about 30 events monitored for each site, covering a wide range of rain conditions. Periodic checks can be made in future years, such as repeating concentrated monitoring every 10 years or so (and for only 15 events during the follow-up surveys).

Finally, better watershed area descriptions, especially accurate drainage-area delineations, are needed for all monitored sites. While the data contained in the NSQD are extremely useful, future monitoring information obtained as part of the stormwater permit program would be greatly enhanced with these additional considerations.

MONITORING OF INDUSTRIES INCLUDING CONSTRUCTION

The various industrial stormwater monitoring requirements of the EPA Stormwater Program have come under considerable scrutiny since the program's inception. Input to the committee at its first meeting conveyed the strong sense that monitoring as it is being done is nearly useless, is burdensome, and produces data that are not being utilized. The requirements consist of the following. All industrial sectors covered under the Multi-Sector General Permit (MSGP) must conduct visual monitoring four times a year. This visual monitoring is performed by collecting a grab sample within the first hour of stormwater discharge and observing its characteristics qualitatively (except for construction activities—see below). A subset of MSGP industries are required to perform analytical monitoring for benchmark pollutant parameters (see Table 2-5) four times in year 2 of permit coverage and again in year 4 if benchmarks are exceeded in year 2. A benchmark sample is collected as a grab sample within the first hour of stormwater discharge after a rainfall event of 0.1 inch or greater and with an interceding dry period of at least 72 hours. An even smaller subset of MSGP industries that are subject to numerical effluent guidelines under 40 C.F.R. must, in addition, collect grab samples of their stormwater discharge after every discharge event and analyze it for specific pollutant parameters as specified in the effluent guidelines (see Table 2-6). There is no monitoring requirement for stormwater discharges from construction activity in the Construction General Permit. There is only an elective requirement that the construction site be visually inspected within 24 hours after the end of a storm event that is 0.5 inch or greater, if inspections are not performed weekly.

EPA selected the benchmark analytical parameters for industry subsectors to monitor using data submitted by industrial groups in 1993 as part of their group applications. The industrial groups were required to sample a minimum of 10 percent of facilities within an industry group for pH, TSS, BOD_5, oil and grease, COD, TKN, nitrate plus nitrite nitrogen, and total phosphorous. Each sampling facility within a group collected a minimum of one grab sample within the first 30 minutes of discharge and one flow-weighted composite sample. Other nonconventional pollutants such as fecal coliform bacteria, iron, and cobalt were analyzed only if the industry group expected it to be present. Similarly, toxic pollutants such as lead, copper, and zinc were not sampled but rather self-identified only if expected to be present in the stormwater discharge. As a result of the self-directed nature of these exercises, the data submitted with the group applications were often incomplete, inconsistent, and not representative of the potential risk posed by the stormwater discharge to human health and aquatic life. EPA has not conducted or funded independent investigations and has relied solely on the data submitted by industry groups to determine which pollutant parameters are appropriate for the analytical monitoring of an industry subsector. Thus, there are glaring deficiencies; for example, the only benchmark parameter for asphalt paving and roofing materials is TSS, even though current science shows that the most harmful pollutants in stormwater discharges from the asphalt manufacturing industry are polycyclic aromatic hydrocarbons (compare Table 2-5 with Mahler et al., 2005).

Aside from the suitability of benchmark parameters is the fact the too few samples are collected to sufficiently characterize the variability of pollutant concentrations associated with industrial facilities within a sector. This is discussed in detail in Box 4-2, which describes one of the few efforts to collect and analyze data from the benchmark monitoring of industries done in Southern California. EPA has not requested a nationwide effort to compile these data, as was done for the MS4 program, although this could potentially lead to average effluent concentrations by industrial sector that could be used for a variety of purposes, including more considerate regulations. Finally, the compliance monitoring that is presently being conducted under the MSGP is of limited usefulness because it is being done to comply with effluent guidelines that have not been updated to reflect the best available technology relevant to pollutants of most concern. All of these factors have led to an industrial stormwater monitoring program that is not very useful for the purposes of reducing stormwater pollution from industries or informing operators on which harmful pollutants to expect from their sites.

Industrial-Area Monitoring Issues

Monitoring at industrial sites has some unique issues that must be overcome. The most important aspect for any monitoring program is understanding and specifying the objectives of the monitoring program and developing and following a detained experimental design to allow these objectives to be met. The following discussion is organized around the reasons why monitoring at industrial sites may be conducted.

Regional Monitoring of Many Facilities

An important monitoring objective would be regional monitoring to calibrate and verify stormwater quality models, to randomly verify compliance at facilities not normally requiring monitoring, and to establish benchmarks for compliance. As shown in Box 4-2, haphazard monitoring throughout an area would require a very large effort, and would still likely result in large errors in the expected data. It is recommended that a regional stormwater authority coordinate regional monitoring as part of the MS4 monitoring requirements, possibly

BOX 4-2
The Plight of Industrial Stormwater Data

Unlike the data collected by municipalities and stored in the NSQD, the benchmark monitoring data collected by permitted industries are not compiled or analyzed on a national basis. However, there has been at least one attempt to compile these data on a more local basis. California required that industrial facilities submit their benchmark monitoring data over a nine-year period, and it was subsequently analyzed by Michael Stenstrom and colleagues at UCLA (Stenstrom and Lee, 2005; Lee et al., 2007). The collected data were for such parameters as pH, turbidity, specific conductance, oil and grease (or total organic carbon), and several metals. There are more than 6,000 industries covered under the California general permit, each of which was to have collected two grab samples per year for a limited number of parameters. Whether these data were collected each year and for each industry was highly variable.

The analysis of the data from Los Angeles and Ventura counties revealed that stormwater monitoring data are not similar to the types of data that the environmental engineering field is used to collecting, in particular wastewater data. Indeed, as shown in Figure 4-11, stormwater data are many orders of magnitude more variable than drinking water and wastewater data. The coefficients of variation for municipal and industrial stormwater were almost two orders of magnitude higher than for drinking water and wastewater, with the industrial stormwater data being particularly variable. This variability comes from various sources, including intrinsic variability given the episodic nature of storm events, analytical methods that are more variable when applied to stormwater, and sampling technique problems and error.

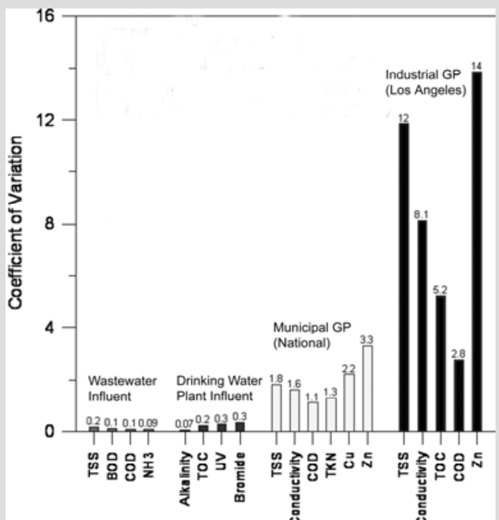


FIGURE 4-11 A comparison of data from four sources: wastewater influent, drinking water plant effluent, municipal stormwater, and industrial stormwater. SOURCE: Reprinted, with permission, from Stenstrom (2007). Copyright 2007 by Michael K. Stenstrom.

continues next page

BOX 4-2 Continued

This enormous variability means that it is extremely difficult to make meaningful statements. For example, it was impossible, using different analyses, to correlate certain chemical pollutants with certain industries. Furthermore, although the data revealed that there are exceedances of benchmark values for certain parameters (Al, Cu, Fe, Pb, and Zn in particular), the data are not of sufficient quantity or quality to identify problem polluters. Finally, there were also large numbers of outliers (that is, samples whose concentrations were well above the 75th percentile range).

Because of these large coefficients of variation, greater numbers of samples are needed to be able to say there is a significant difference between samples. As shown in Figure 4-12 using COD and a 50 percent difference in means as an example, one would need six data points to tell the difference between two wastewater influents, 80 data points if one had municipal stormwater data, and around 1,000 data points for industrial stormwater. These numbers obviously eclipse what is required under all states' MSGPs.

For drinking water treatment, monitoring is done to ensure the quality of the product, while for wastewater, there is a permit that requires the plant to meet a specific quality of water. Unlike these other areas of water resources, there are few incentives that might compel an industry to increase its frequency of stormwater monitoring. As a result, industries are less invested in the process and rarely have the expertise needed to carry out self-monitoring.

Permitted industries are not required to sample flow. However, Stenstrom and colleagues used Los Angeles rainfall data (see Figure 4-13) as a surrogate for flow and demonstrated that there is a seasonal first-flush phenomenon occurring in early fall. That is, samples taken after a prolonged dry spell will have higher pollutant concentrations. There are always high concentrations of contaminants during the first rainfall because contaminants have had time to accumulate since the previous rainfall. This is important because EPA asks the industrial permittees to collect data from the first rainfall, such that they may end up overestimating the mass emissions for the year. Furthermore, it shows that numeric limits for grab samples would be risky because the measured data are highly affected by the timing of the storm.

The controversy about numeric limits for industrial stormwater dischargers has existed for more than ten years in California. A recent expert panel concluded that in some cases, numeric limits are appropriate (for construction, but not for municipalities). Stenstrom's recommendations are that industrial monitoring should be either ended or upgraded (for competent industries). If upgraded, it should include more types of monitored parameters, a sampling method with a lower coefficient of variation, real-time monitoring as opposed to grab samples, more quality assurance/quality control, and web-based reporting. A fee-based program with a subset of randomly selected industries may be better than requiring every industry to sample. Stenstrom and Lee (2005) suggest who might do this monitoring if the industry does not have the necessary trained personnel. There is concern that the California water boards are too understaffed to administer such programs and respond to high emitters.

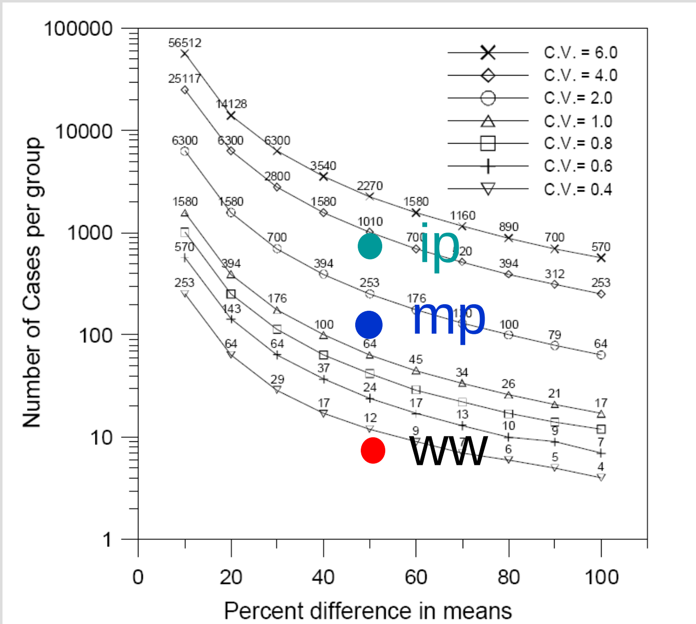
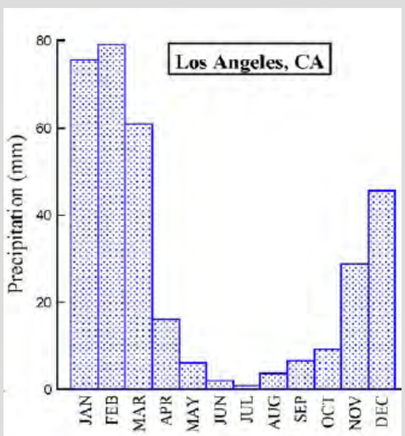


FIGURE 4-12 Number of cases needed to detect a certain percentage difference in the means, using COD as an example. SOURCE: Reprinted, with permission, from Stenstrom (2007). Copyright 2007 by Michael K. Stenstrom.



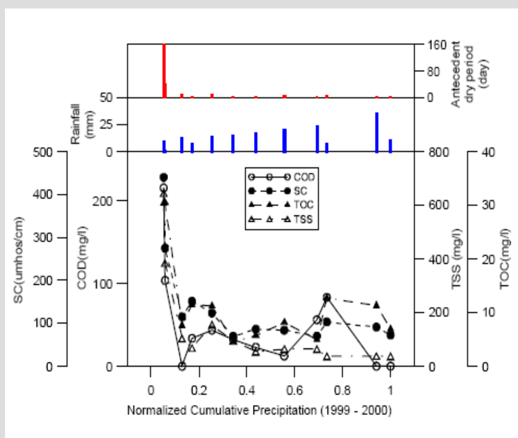


FIGURE 4-13 Annual precipitation in Los Angeles (left) and seasonal first flushes of various contaminants (right). SOURCE: Reprinted, with permission, from Stenstrom (2007). Copyright 2007 by Michael K. Stenstrom.

SOURCES: Stenstrom and Lee (2005), Lee et al. (2007), Stenstrom (2007).

even at the state level covering several Phase I municipalities. A coordinated effort would be most cost-effective with the results compiled for a specific objective. The general steps in this effort would include the following.

(1) Compiling available regional stormwater quality data and comparing the available data to the needs (such as calibration of a regional model; verifying compliance of facilities not requiring monitoring; and establishing regional benchmarks). This may include expanding the NSQD for the region to include all of the collected data, plus examination of data collected as part of other specialized monitoring activities. These objectives will result in different data needs, so it is critical that the uses of the data are identified before sampling plans are established.

(2) Identifying monitoring opportunities as part of other on-going activities that can be expanded to also meet data gaps for these specific objectives. It is important to understand the time frame for the monitoring and ensure that it will meet the needs. As an example, current NPDES stormwater monitoring only requires a few events to be sampled per year at a facility. It may take many years before sufficient data are obtained unless the monitoring effort is accelerated.

(3) Preparing an experimental design that identifies the magnitude of the needed data, considering the allowable errors in the results, and carrying out the sampling program. Different types of data may have varying data quality objectives, depending on their use. It may be possible to truncate some of the monitoring when a sufficient understanding is obtained.

A regionally calibrated and verified model can be used to review development plans and proposed SCMs for new facilities. When suitably integrated with receiving-water modeling tools, a stormwater model can also be used to develop discharge objectives and numeric discharge limits that are expected to meet regulatory requirements. Eventually, it may be possible to couple watershed stormwater models with regional receiving water assessments and beneficial use studies. Haphazard monitoring of a few events each year will be very difficult to correlate with regional receiving water objectives, while a calibrated and verified watershed model, along with receiving water assessments, will result in a much more useful tool and understanding of the local problems.

Regional monitoring can also be targeted to categories of industries that were previously determined to be of low priority. This monitoring activity would randomly target a specific number of these facilities for monitoring to verify the assumption that they are of low priority and are still carrying out the minimum management practices. This activity would also quantify the discharges from these facilities and the performance of the minimum controls. If the discharges are excessive when compared to the initial assumptions, or the management practices being used are not adequate, then corrective actions would be instigated. A single category of specific industries could be selected for any one year, and a team from the regional stormwater management authority could randomly select and monitor a subset of these facilities. An efficient experimental design would need to be developed based on expected conditions, but it is expected that from 10 to 15 such facilities would be monitored for at least a year in a large metropolitan area that has a Phase I stormwater permit, or even state-wide.

Regional monitoring is also necessary to more accurately establish benchmarks for numeric permits. Geographical location, along with land use, is normally an important factor affecting stormwater quality. Receiving water impacts and desired beneficial uses also vary greatly for different locations. It is therefore obvious that compliance benchmarks also be established that consider these regional differences. This could be a single statewide effort if the state agency has the permit authority and if the state has minimal receiving water and stormwater variations. However, in most cases, significant variations occur throughout the state and separate monitoring activities would be needed for each region. In the simplest case, probability distributions of stormwater discharge quality can be developed for different discharge categories and the benchmarks would be associated with a specific probability value. In some cases, an overall distribution may be appropriate, and only the sites having concentrations greater than the benchmark value would need to have additional treatment. In all cases, a basic level of stormwater management should be expected for all sites, but the benchmark values would identify sites where additional controls are necessary. The random monitoring of sites not requiring extensive monitoring could be used to identify and adjust the basic levels of control needed for all categories of stormwater dischargers.

Identification of Critical Source Areas Associated with Specific Industrial Operations

The objective of this monitoring activity would be to identify and characterize critical source areas for specific industries of concern. If critical source areas can be identified, targeted control or treatment can be much more effective than relying only on outfall monitoring. Many of the treatment strategies for industrial sites involve pollution prevention, ranging from covering material or product storage areas to coating galvanized metal. Other treatment strategies involve the use of highly effective treatment devices targeting a small area, such as filters used to treat zinc in roof runoff or lamella plate separators for pretreatment of storage yard runoff before wet pond treatment. Knowledge of the characteristics of the runoff from the different areas at a facility is needed in order to select and design the appropriate treatment methods.

Box 4-3 is a case study of one such group monitoring effort—for a segment of the telecommunications industry targeting a specific maintenance practice. Instead of having each telecommunication company throughout the country conduct a detailed monitoring program for individual stormwater permits associated with maintenance efforts, many of the companies joined together under an

BOX 4-3
Monitoring to Support a General Stormwater Group Permit Application for the Telecommunications Industry

This monitoring program was conducted to support a group permit application for the telecommunications industry, specifically to cover maintenance operations associated with pumping water out of communications manholes that is then discharged into the storm drainage system. Under federal and state environmental statues, the generator (owner or operator) is responsible for determining if the discharged water needs treatment. The work performed under this project covered characterization, prevention, and treatment methods of water found in manholes.

The objective of this project was to develop a test method to quickly evaluate water in manholes and then to recommend on-site treatment and preventative methods. To meet the telecommunication industry needs, the evaluating tests of water found in manholes need to be simple, quick, inexpensive, field applicable, and accurate indicators of contaminated conditions. The on-site treatment methods must be cost-effective and quickly reduce the concentrations of the contaminant of concern to acceptable levels before the water from manholes is discharged, to result in a safe environment for workers.

A sampling effort was conducted by Pitt et al. (1998) to characterize the quality of the water and sediment found in manholes. More than 700 water samples and 300 sediment samples were analyzed over a three-year period, representing major land-use, age, season, and geographical factors from throughout the United States. The samples were analyzed for a wide range of common and toxic constituents. The statistical procedures identified specific relationships between these main factor categories and other manhole characteristics. Part of the project was to evaluate many field analytical methods. Finally, research was also conducted to examine possible water treatment methods for water being pumped from telecommunication manholes.

Summary of Sampling Effort and Strategy

The objective of the monitoring program was to characterize telecommunication manhole water and sediment. Important variables affecting the quality of these materials were also determined. A stratified random sampling design was followed, with the data organized in a full 2^4 factorial design, with repeated sampling of the same manholes for each season. The goal for the minimum number of samples per strata was ten. This sampling effort enabled the determination of errors associated with the results, which was expected to be less than 25 percent. In addition, this level of effort enabled comparison tests to be made outside of the factorial design. Table 4-4 lists the constituents that were evaluated for each of the sample types.

The immense amount of data collected during this project and the adherence to the original experimental design enabled a comprehensive statistical evaluation of the data. Several steps in data analysis were performed, including:

- exploratory data analyses (mainly probability plots and grouped box plots),
- simple correlation analyses (mainly Pearson correlation matrices and associated scatter plots),
- complex correlation analyses (mainly cluster and principal component analyses, plus Kurskal-Wallis comparison tests), and

• model building (based on complete 2^4 factorial analyses of the most important factors).

The toxicity screening tests (using the Azur Microtox® method) conducted on both unfiltered and filtered water samples from telecommunication manholes indicated a wide range of toxicity, with no obvious trends for season, land use, or age. About 60 percent of the samples were not considered toxic (less than an I25 light reduction of 20 percent, the light reduction associated with phosphorescent bacteria after a 25-minute exposure to undiluted samples), about 20 percent were considered moderately toxic, while about 10 percent were considered toxic (light reductions of greater than 40 percent), and 10 percent were considered highly toxic (light reductions of greater than 60 percent). Surprisingly, samples from residential areas generally had greater toxicities than samples from commercial and industrial areas. Samples from newer areas were also more toxic than those from older areas. Further statistical tests of the data indicated that the high toxicity levels were likely associated with periodic high concentrations of salt (in areas using de-icing salt), heavy metals (especially filterable zinc, with high values found in most areas), and pesticides (associated with newer residential areas).

TABLE 4-4 Constituents Examined in Water and Sediment from Telecommunication Manholes

Constituent	Unfiltered Water	Filtered Water	Sediment
Solids, volatile solids, COD, Cu, Pb, and Zn	X	X	X
Turbidity, color, and toxicity (Microtox screening method)	X	X	
pH, conductivity, hardness, phosphate, nitrate, ammonia, boron, fluoride, potassium, and detergents	X		
Odor, color, and texture			X
E. coli, enterococci, particle size, and chromium	Selected		
Metal scan (ICP)			Selected
PAHs, phenols (GC/MSD), and pesticides	X	Selected	Selected

SOURCE: Modified from Pitt et al. (1998).

Concentrations of copper, lead, and zinc were evaluated in almost all of the water samples, and some filtered samples were also analyzed for chromium. From 470 to 548 samples (75 to 100 percent of all unfiltered samples analyzed) had detectable concentrations of these metals. Filterable lead concentrations in the water were as high as 160 μg/L, while total lead concentrations were as high as 810 μg/L. Zinc values in filtered and unfiltered samples were as high as about 3,500 μg/L. Some of the copper concentrations were also high in both filtered and unfiltered samples (as high as 1,400 μg/L). Chromium concentrations as high as 45 μg/L were also detected.

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BOX 4-3 Continued

About 300 sediment samples were analyzed and reviewed for heavy metals. An ICP/MS was used to obtain a broad range of metals with good detection limits. The following list shows the median observed concentrations for some of the constituents found in the sediments (expressed as milligrams of the constituent per kilogram of dry sediment):

Aluminum	14,000 mg/kg
COD	85,000 mg/kg
Chromium	<10 mg/kg
Copper	100 mg/kg
Lead	200 mg/kg
Strontium	35 mg/kg
Zinc	1,330 mg/kg

Geographical area had the largest effect on the data observations, while land use, season, and age influenced many fewer parameters. The most obvious relationship was found for high dissolved solids and conductivity associated with winter samples from snowmelt areas. The high winter concentrations slowly decreased with time, with the lowest concentrations noted in the fall. Another important observation was the common association between zinc and toxicity. Residential-area samples generally had larger zinc concentrations than the samples from commercial and industrial areas. Samples from the newest areas also had higher zinc concentrations compared to samples from older areas. No overall patterns were observed for zinc concentrations in sediment samples obtained from manholes. Other constituents (especially nutrients and pesticides) were also found to have higher concentrations in water collected from manholes in newer residential areas. Very few organic toxicants were found in the water samples, but sediment sample organic toxicant concentrations appeared to be well correlated to sediment texture and color. About 10 to 25 percent of the sediment samples had relatively large concentrations of organics. Bacteria analyses indicated some relatively high bacteria counts in a small percentage of the samples. Bacteria were found in lower amounts during sampling periods that were extremely hot or extremely cold. Pacific Northwest samples also had the lowest bacteria counts.

The data were used to develop and test predictive equations based on site conditions. These models were shown to be valid for most of the data, but the highest concentrations were not well predicted. Therefore, special comparisons of many site conditions were made for the manholes having water with the highest concentrations of critical constituents for comparison to the other locations. It was interesting to note that about half of the problem manholes were repeated samples from the same sites (after complete pumping), but at different seasons, indicating continuous problems and not discrete incidents. In addition, the problem manholes were found for all areas of the country and for most rain conditions. Water clarity and color, along with sediment texture, were found to be significant factors associated with the high concentrations of other constituents, while land use was also noted as a significant factor. These factors can be used to help identify problem manholes, but the rates of false positives and false negatives were found to be high. Therefore, these screening criteria can be used to identify more likely problematic manholes, but other methods (such as confirmation chemical analyses) are also needed to identify those that could not be identified using these simpler methods.

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BOX 4-3 Continued

The field analytical test methods worked reasonably well, but had much higher detection limits than advertised, limiting their usefulness. Due to the complexity and time needs for many of these on-site analyses, it is usually more effective to analyze samples at a central facility. For scheduled maintenance operations, a crew could arrive at the site before the maintenance time to collect samples and have them analyzed before the maintenance crew arrives. For emergency repairs, it is possible to pump the collected water into a tank truck for later analyses, treatment, and disposal.

The treatment scenario developed and tested is relatively rapid and cheap and can be used for all operations, irrespective of screening analyses. Chemical addition (using ferric chloride) to the standing water in the manhole was found to reduce problematic levels of almost all constituents to low levels. Slow pumping from the water surface over about a 15- to 30-minute period, with the discharged water then treated in 20-µm cartridge filters, allows the manhole to be entered and the repairs made relatively rapidly, with the water safely discharged. The remaining several inches of water in the bottom of the manhole, along with the sediment, can be removed at a later time for proper disposal.

SOURCE: Pitt et al. (1998).

industrial trade group to coordinate the monitoring and to apply for a group permit. This was a significant effort that was conducted over several years and involved the participation of many regional facilities throughout the nation. This coordinated effort spread the cost over these different participants, and also allowed significant amounts of data to be collected, control practices to be evaluated, and the development of screening methods that allow emergency maintenance operations of the telecommunication system to proceed in a timely manner. The experimental design of this monitoring program allowed an efficient examination of factors affecting stormwater discharges from these operations. This enabled the efficient implementation of effective control programs that targeted specific site and operational characteristics. Although the total cost for this monitoring program was high, it was much less costly than if each individual company had conducted their own monitoring. In addition, this group effort resulted in much more useful information for the industry as a whole.

Outfall Monitoring at a Single Industrial Facility for Permit Compliance and to Demonstrate Effectiveness of Control Practices

Sampling at an individual facility results in outfall data that can be compared to pre-control conditions and numeric standards. There are many guidance documents and reports available describing how to monitor stormwater at an outfall. Two comprehensive sources that describe stormwater monitoring procedures include the handbook written by Burton and Pitt (2002) and a recent guidance report prepared by Shaver et al. (2007). There are a number of basic components that need to be included for an outfall characterization monitoring effort, many which have been described in this report. These include the following:

- rainfall monitoring in the drainage area (rate and depth, at least at two locations).
- flow monitoring at the outfall (calibrated with known flow or using dye dilution methods).
- flow-weighted composite sampler, with sampler modified to accommodate a wide range of rain events.
- recommended use of water quality sonde to obtain high-resolution and continuous measurements of such parameters as turbidity, conductivity, pH, oxidation reduction potential, dissolved oxygen (DO), and temperature.
- preparation of adequate experimental design that quantifies the needed sampling effort to meet the data quality objectives (adequate numbers of samples in all rain categories and seasons).
- selection of constituents that meet monitoring objectives. In addition, the analytical methods must be appropriately selected to minimize "nondetected" values.
- monitoring station maintenance must also be conducted appropriately to ensure reliable sample collection. Sampling plan must also consider sample retrieval, sample preparation and processing, and delivery to the analytical laboratory to meet quality control requirements.

Burton and Pitt (2002) describe these monitoring components in detail, along with many other monitoring elements of potential interest (e.g., receiving water biological, physical, and chemical monitoring, including sediment and habitat studies), and include many case studies addressing these components, along with basic statistical analyses and interpretation of the collected data. Box 4-4 provides a detailed example of industrial stormwater monitoring at individual sites in Wisconsin.

In general, monitoring of industries should be tailored to their stormwater pollution potential, considering receiving water uses and problems. There are a number of site survey methods that have been developed to rank industry by risk that mostly rely on visual inspections and information readily available from regional agencies. The Center for Watershed Protection developed a hot-spot investigation procedure that is included in the Urban Subwatershed Restoration Manual No. 11 (Wright et al., 2005). This site survey reconnaissance method ranks each site according to its likely stormwater pollutant discharge potential. A detailed field sheet is used when surveying each site to assist with the visual inspections. Cross and Duke (2008) developed a methodology, described in greater detail in Chapter 6, to visually assess industrial facilities based on the level of activities exposed to stormwater. They devised four categories—Category A, no activities exposed to stormwater; Category B, low intensity; Category C, medium intensity; and Category D, high intensity—and tested this

BOX 4-4
Wisconsin's Monitoring of Industrial Stormwater

The State of Wisconsin also uses a site assessment method to rank industrial operations into three tiers, mostly based on their standard industrial codes. This system groups facilities by industry and how likely they are to contaminate stormwater. The general permits differ in monitoring requirements, inspection frequency, plan development requirements, and the annual permit fee. The Tier 1 general permit covers the facilities that are considered "heavy" industries, such as paper manufacturing, chemical manufacturing, petroleum refining, ship building/repair, and bulk storage of coal, minerals, and ores. The monitoring required of these facilities is presented in this box. The Tier 2 general permit covers facilities that are considered "light" industries and includes such sites as furniture manufacturing, printing, warehousing, and textiles. Facilities with no discharge of contaminated stormwater are in the Tier 3 category and include sites that have no outdoor storage of materials or waste products.

In accordance with the Wisconsin MSGP, Tier 1 industries are required to perform an annual chemical stormwater sampling at each outfall for those residual pollutants listed in the industry's stormwater pollution prevention plan. The one runoff event selected for sampling must occur between March and November and the rainfall depth must be at least 0.1 inch. At least 72 hours must separate the sampled event and the previous rainfall of 0.1 inch. The concentration of the pollutant must represent a composite of at least three grab samples collected in the first 30 minutes of the runoff event. There is concern about the value of collecting so few samples from just one storm each year.

To evaluate how well this sampling protocol characterizes pollutant concentrations in industrial runoff, the Wisconsin Department of Natural Resources partnered with the USGS to collect stormwater samples from three Tier 2 industrial sites (Roa-Espinosa and Bannerman, 1994). Seven runoff events were monitored at each site, and the samples were collected using five different sampling methods, including (1) flow-weighted composites, (2) time-based discrete samples, (3) time-based composites, (4) a composite of discrete samples from first 30 minutes, and (5) time-based composite sheet flow samples. The first three methods have been described previously. For the composite of discrete samples from the first 30 minutes, the sampler is programmed to take an aliquot after a set period of time (usually every 5 minutes) and the aliquots are combined into one container. The sampler stops collecting samples after 30 minutes. For many sites the samples are collected manually, so there is a high probability the sample does not represent the first 30 minutes of the event. For the time-based composite sheet flow samples, a sheet flow sampler is programmed to take an aliquot of sheet flow after a set period of time (usually about every 5 to 15 minutes). All the aliquots are deposited in one bottle beneath the surface of the ground. All of the parts of the hydrograph receive equal weight in the final concentration, but the larger number of aliquots makes for a reasonably accurate composite concentration. This method is unique in that it can be placed near the source of concern. Automatic samplers were used for the first four methods, while sheet flow samplers designed by the USGS were used for the fifth method (Bannerman et al., 1993). Samples were collected during the entire event. All the automatic samplers had to be installed at a location with concentrated flow, such as an outfall pipe, while the sheet flow samplers could be installed in the pavement near a potential source, such as a material storage area.

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BOX 4-4 Continued

The time-based discrete, time-based composite, first-30-minute composite, and sheet flow samples were analyzed for COD, total recoverable copper, total recoverable lead, total recoverable zinc, TSS, total solids, and hardness. In addition to these constituents, the flow-weighted composite samples were analyzed for antimony, arsenic, beryllium, chromium, ammonia-N, nitrate plus nitrite, TKN, and TP. All the analysis was done at the State Laboratory of Hygiene in Madison, Wisconsin, and the data are stored in the USGS's QWDATA database.

The number of samples collected during a runoff event varied greatly among the five types of sampling. By design, the median number of samples collected for the first 30 minutes was three. Limits on the funds available for laboratory cost limited the time-based discrete sampling to about six per storm. Since they are not restricted by laboratory cost, the composites can be based on more sub-samples during a storm. Thus, the median numbers of sub-samples collected for the flow-weighted composite and time-based composite were 13 and 24, respectively. The time-based composite sheet flow sample could not document the number of samples it collected, but it was set to collect a sample every few minutes.

To judge the accuracy of the sampling methods, one method had to be selected as the most representative of the concentration and load affecting the receiving water. Because a relatively large number of samples are collected and the timing of the sampling is weighted by volume, the flow-weighted composite concentrations were used as the best representation of the quality of the industrial runoff. Concentrations in water samples collected by the time-based composite method compared very well to those collected by the flow-weighted composite method, especially if the time-based composite resulted in 20 sub-samples or more. This was not true for the discrete sampling method, because many fewer sub-samples were used to represent changes across the hydrograph. The time-based composite sheet flow sampler produced concentrations slightly higher than the time-based composite samplers collecting water in the concentrated flow. Concentrations from the sheet flow sampler are probably not diluted by other source areas such as the roof.

Concentrations of total recoverable zinc and TSS collected in the first 30 minutes of the event were usually two to three times higher than the flow-weighted composite samples. For many of the events, the highest concentration of these constituents occurred in the first 10 minutes of the event. Although the concentrations might be higher in the first part of the event, the earlier parts of the event might only represent one third or less of the total runoff volume. Thus, using the concentrations from the first 30 minutes of the event could greatly overestimate the constituent load from the site.

Along with accuracy, the selection of an appropriate sampling method must consider cost and the criteria for installing the sampling equipment. To measure flow, the site must have a location where the flow is concentrated, such as a pipe or well-defined channel, and the runoff is just coming from the site. Out of 474 sites evaluated for this project, only 14 met the criteria for an accurate flow measurement. A few more sites might be suitable for using an automatic sampler without flow measurements, but the number of sites would still be limited. Sheet flow samplers can be used on most sites, since they are simply installed in the pavement near the source of concern.

For each sampling method, approximate costs were determined including equipment, installation of equipment, and the analysis of one sample (Table 4-5). Collecting the samples and processing the data should also be included, but they were not because this cost is highly variable. Flow-weighted composite and time-based discrete sampling had the highest cost. Flow measurements made the composite sampling more expensive, while the laboratory cost of analyzing six discrete samples increased the cost of the time-based

TABLE 4-5 Cost of Using Different Sampling Methods in 1993 Dollars

Method	Estimated Cost for Equipment, Installation, and Analysis of One Sample
Flow-weighted composite	$16,052
Time-based discrete	$22,682
Time-based composite	$5,920
First-30-minutes (automatic sampler)	$6,000
First-30-minutes (grab sample)	$1,800[1]
Time-based composite sheet flow sampler	$2,889

[1]Cost of laboratory analysis only. SOURCE: Reprinted, with permission, from Roa-Espinosa and Bannerman (1994). Copyright 1994 by the American Society of Civil Engineers.

discrete method. It should be noted that hand grab samples could be used to collect the discrete samples in the first 30 minutes at lower cost, although this depends strongly on the skill of the person collecting the sample. The sheet flow sampler could be the most cost effective approach to sampling an industrial site.

A determination must be made of how many runoff events should be sampled in order to accurately characterize a site's water quality. As shown in Table 4-6, representing a site with the results from one storm can be very misleading. Concentrations in Table 4-6 were collected by the flow-weighted composite method. The geometric means of EMCs from five or more events were very different than the lowest or highest concentration observed for the set of storms. The chances of observing an extreme value by sampling just one event is increased by selecting a sampling method designed to collect a limited number of sub-samples, such as the first-30-minutes method. Too few storms were monitored in this project to properly evaluate the variability in the EMCs, but sufficient changes occur between the zinc and TSS geometric means in Table 4-6 to suggest that a compliance monitoring schedule should include a minimum of five events be sampled each year.

To overcome the high COV observed for municipal stormwater data collected in Wisconsin, EMCs should be determined for about 40 events (Selbig and Bannerman, 2007; Horwatich et al., 2008). The 40 event mean concentrations would probably represent the long-range distribution of rainfall depths, and there would be sufficient data available to perform some trend analysis, such as evaluating the benefits of an SCM implemented at an industrial site. Monitoring 40 events each year, however, would be too costly for an annual compliance monitoring schedule for each industrial site.

Results from this project indicate that the stormwater monitoring required at industrial sites cannot adequately characterize the quality of runoff from an industrial site. Only collecting samples from the first 30 minutes of a storm is probably an overestimate of the concentration, and a load calculated from this concentration would exaggerate the impact of the site on the receiving waters. Time- and flow-based composite sampling would be much better methods for monitoring a site if there are locations to operate an automatic sampler. For sites without such a location, the time-based composite sheet flow sampler offers the best results at the least cost. Given all the variability in concentrations between runoff events, the annual monitoring schedule for any site should include sampling multiple storms.

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BOX 4-4 Continued

TABLE 4-6 Effects of Including a Different Number of Events in the Geometric Mean Calculation for Zinc and TSS[a]

Number of Events	Total Recoverable Zinc	Total Suspended Solids
	AC Rochester	
1 (Lowest Concentration)	57	8
1 (Highest Concentration)	150	84
3	76	24
5	91	36
	PPG Industries	
1 (Lowest Concentration)	140	32
1 (Highest Concentration)	330	49
3	153	57
6	186	53
	Warman International	
1 (Lowest Concentration)	68	17
1 (Highest Concentration)	140	56
3	67	15
5	81	26
7	74	19

[a]Samples were collected using the flow-weighted composite method. SOURCE: Reprinted, with permission, from Roa-Espinosa and Bannerman (1994). Copyright 1994 by the American Society of Civil Engineers.

scheme by examining many southern Florida industrial facilities. About 25 percent of the facilities surveyed that were officially included in the stormwater permit program had no stormwater exposure (Category A), but very few had submitted the necessary application to qualify for an exception under the "no exposure" rule. Slightly more than half of the of the surveyed facilities were included in the "no exposure" and "low exposure" categories, obviously deserving less attention compared to the higher impact categories.

Recommendations for Industrial Stormwater Monitoring

Suitable industrial monitoring programs can be implemented for different categories of industrial activities. The following is one such suggestion, based on the likely risks associated with stormwater discharges from each type of facility.

No Exposure to Industrial Activities and Other Low-Risk Industrial Operations

For sites having limited stormwater exposure to industrial operations, such as no outdoor storage of materials or waste products, basic monitoring would not normally be conducted. However, roof runoff (especially if galvanized metals are used) and large parking areas need to be addressed under basic stormwater regulations dealing with these common sources of contaminants and the large amounts of runoff that may be produced. Simple SCM guidance manuals can be used to select and size any needed controls for these sites, based on the areas of concern at the facility. For these facilities, simple visual inspections with no monitoring requirements may be appropriate to ensure compliance with the basic stormwater regulations. A regionally calibrated stormwater quality model can be used to evaluate these basic stormwater conditions and to calculate the expected benefits of control measures. Periodic random monitoring of sites in this category should be conducted to verify the small magnitude of discharges from these sites and the performance of SCMs.

Medium-Risk Industrial Operations

For "medium-intensity" industry facilities, site inspections and modeling should be supplemented with suitable outfall monitoring to ensure compliance. As noted in Box 4-2, there can be a tremendous amount of variability in industrial runoff characteristics. However, the dataset described in that example was a compilation of data from many different types of facilities, with no separation by industrial type. Even different facilities in a single industrial group may have highly variable runoff characteristics. However, a single facility has much less variability, and reasonable monitoring strategies can be developed for compliance purposes. As noted in Box 4-4, about 40 samples were expected to be needed for each site in that example. With typical permit periods of five years, this would require that less than ten samples per year (more than the three samples per year currently obtained at many locations) be collected in order to determine the EMC for the site for comparison to allowable discharge conditions. Obviously, the actual number of samples needed is dependent on the variability of the runoff characteristics and the allowable error, as described elsewhere. After about 10 to 15 storms have been monitored for a site, it would be possible to better estimate the total number of samples actually needed based on the data quality objectives. If the monitoring during the permit period indicated excessive stormwater discharges, then the SCMs are obviously not adequate and would need improvement. The permit for the next five-year period could then be modified to reflect the need for more stringent controls, and suitable fines accessed if the facility was not in compliance. It is recommended that absolute compliance not be expected in the industrial permits, but that appropriate benchmarks be established that allow a small fraction of the monitored events to exceed the goals. This is similar to discharge permit requirements for combined sewers, and for air quality regulations, where a certain number of excessive periods are allowed per year.

High-Risk Industrial Facilities

For "high-risk" industrial sites of the most critical nature, especially if noncompliance may cause significant human and environmental health problems, visual inspections and site modeling should be used in conjunction with monitoring of each event during the permit period. Because of the potential danger associated with noncompliance, the most stringent and robust controls would be required, and frequent monitoring would be needed to ensure compliance. If noncompliance was noted, immediate action would be needed to improve the discharge conditions. This is similar to industrial and municipal NPDES monitoring requirements for point sources.

MODELING TO LINKING SOURCES OF POLLUTION TO EFFECTS IN RECEIVING WATERS

Stormwater permitting is designed to regulate dischargers, develop information, and reduce the level of stormwater pollutants and impact on receiving waterbodies. An important assumption is that the level of understanding of the stormwater system, through a combination of monitoring and modeling, is sufficient to associate stormwater discharges with receiving waterbody impacts. Impairment of waterbodies can occur for a variety of physical, chemical, and biological reasons, often with a complex combination of causes. The ambient water quality of a receiving waterbody, which may result in a determination of impairment, is itself a function of the total mass loading of pollutant; dilution with stream discharge or standing waterbody volume; the capacity of the aquatic ecosystem to assimilate, transform, or disperse the pollutant; and transport out of the waterbody. In addition to the chemical and physical attributes of the water, impairment may also be characterized by degraded biologic structure or geomorphic form of the waterbody (e.g., channel incision in urban areas). Interactions between multiple pollutant loadings, long turnover and residence times, saturation effects, and cascading feedbacks with biological communities complicate the apparent response of waterbodies to pollutant discharge. This is particularly important when considering cumulative watershed effects, in which interactions between stressors and long-term alteration of watershed conditions may contribute to threshold responses of a waterbody to continued loading or alteration. Under these conditions, simple "loading-response" relations are often elusive and require consideration of historical and local watershed conditions.

As an example, pollutant loading at high stream flow or into strong tidally flushed systems may be advected downstream or into the coastal ocean without building up significant concentrations, while pollutant loading at low flow may not be effectively transported and dispersed and may build up to harmful concentrations. In the former case the pollutant may be rapidly transported out of the local waterbody, but may impact a more distant, downstream system. In addition, certain pollutants, such as inorganic nitrogen, may be discharged into surface waters and subsequently transformed and removed from the water column into vegetation or outgassed (e.g., volatilized or denitrified) into the atmosphere under certain ecosystem conditions. Sediment and other pollutants may be stored for long time periods in alluvial or lacustrine deposits, and then remobilized long after the initial loading into a stream reach or standing waterbody in response to extreme climate events, land-use change, reservoir management, or even reductions in the pollutant concentrations in the water column. Consequently, long lags may exist between the actual discharge of the sediment (and any pollutants adsorbed or otherwise stored within the deposits) and their contribution to waterbody impairment. Therefore, understanding the fate of pollutants, particularly nonconservative forms, may require consideration of the full ecosystem cycling and transport of the material over long time periods.

Impairment of waterbodies can be assessed on the basis of biological indicators, as discussed in Chapter 2. As organisms and communities respond to multiple stressors, it is not always clear what the direct or indirect effects of any specific pollutant discharge is, or how that may be exacerbated by correlated or interacting activity in the watershed. The association of specific types of impairment with surrounding land use implicitly accounts for these interactions but does not provide a mechanistic understanding of the linkage sufficient to specify effective remedial activity. However, much progress has been made in determining toxic effects of certain contaminants on different aquatic species assemblages (see, e.g., Shaver et al., 2007) and on quantifying impacts of land use on flow duration curves, EMCs, and loading rates for a number of pollutants (Maestre and Pitt, 2005). For the latter effort, it has been shown that there is large variability within land-use categories, both as a function of specific SCMs and of innate differences due to historical legacies, climate, and hydrogeology.

A protocol linking pollutants in stormwater discharges to ambient water quality criteria should be based on conservation of mass, in which the major inputs, outputs, transformations, and stores of the pollutant can be quantified. Indeed, these are the components of hydrologic and watershed models used to simulate the fate and transport of stormwater and its pollutants. SCMs that improve ambient water quality criteria are designed to act on one or more of these mass balance terms. A number of these measures act to reduce the magnitude of a stormwater source (e.g., porous pavement), while others are designed to absorb or dissipate a pollutant within a hydrologic flowpath downstream from a source (e.g., rain garden, detention pond, stream restoration). The latter requires some consideration of the flowpath from the source to the receiving waterbody. Therefore, determining the major sources, sinks, and transformations of the pollutant should be the first step in this procedure. For a number of pollutants there may be very few potential sources, while for others there may be multiple significant sources. The spatial diversity of these sources and sinks may also range from uniform distribution to “hot spot” patterns that are difficult to detect and quantify. Many stormwater models work effectively with sources, but are not structured to follow the transport or transformation of pollutants from source to waterbody along hydrologic flowpaths.

Figure 4-14 shows the drainage area of Jordan Lake, an important regional

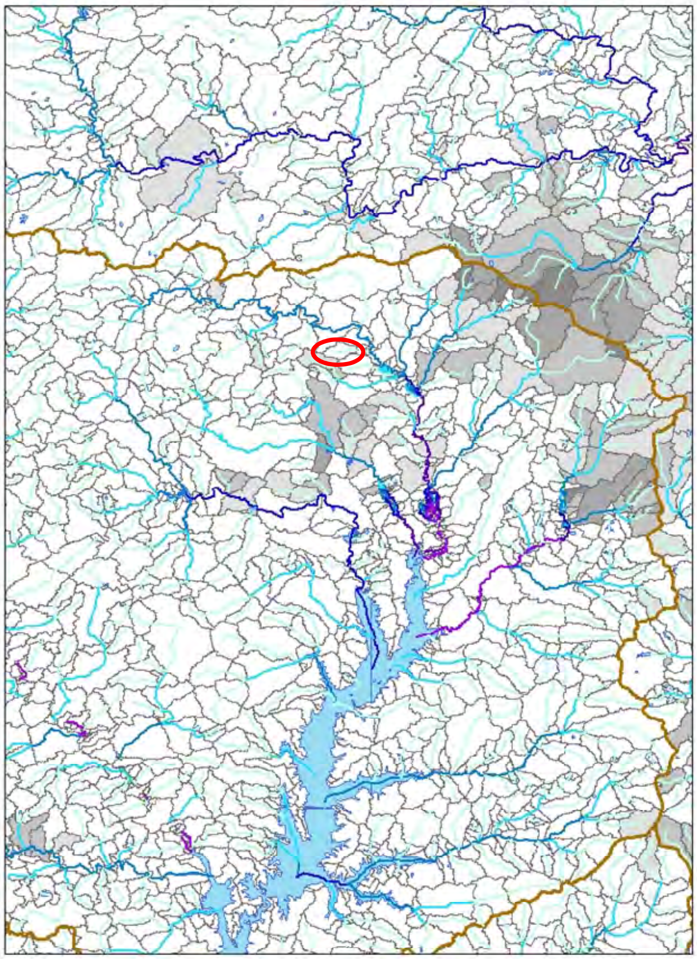

FIGURE 4-14 The drainage area to Jordan Lake, a major drinking water reservoir in the Triangle area of North Carolina, is under nutrient-sensitive rules, requiring reductions in total nitrogen and phosphorus. Drainage flowlines and catchment areas are from NHDplus, and are shaded according to their percentage of industrial and commercial land cover from the NLCD. The area outlined in black is a small urban catchment, detailed in Figure 4-15, and comprised of a wooded central region, surrounded by residential and institutional land use. SOURCE: Data from the NHD+.

drinking water source in the Triangle area of North Carolina. Catchment areas are shaded to relate the percentage of industrial and commercial land cover, according to the National Land Cover Database (NLCD). Figure 4-15 shows a small tributary within the Jordan Lake watershed in Chapel Hill (outlined in Figure 4-14) with a high-resolution image of all impervious surfaces overlain on the topographically defined surface flowpath network. Each of the distributed sources of stormwater is routed through a flowpath consisting of other pervious and impervious segments, within which additions, abstractions, and transformations of water and pollutants occur depending on weather, hydrologic, and ecosystem conditions. The cumulative delivery and impact of all stormwater sources include the transformations occurring along the flowpaths, which could include specific SCMs such as detention or infiltration facilities or simply infiltration or transformations in riparian areas or low-order streams. The riparian area may be bypassed depending on stormwater concentration or piping, and it may have various levels of effectiveness on reducing pollutants depending on geomorphic, ecosystem, and hydrologic conditions. The ability of a stormwater model to capture these types of effects is a key property influencing its ability to associate a stormwater source with a waterbody outcome.

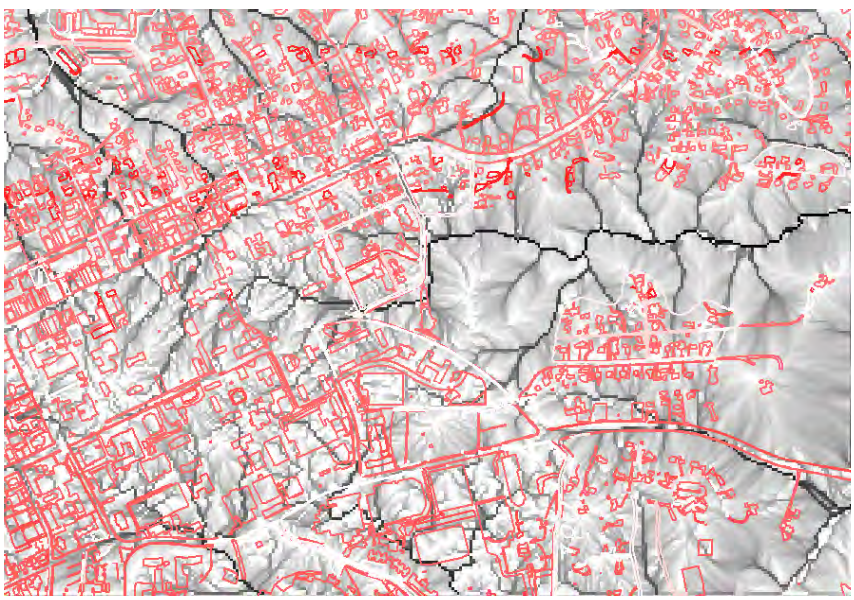

FIGURE 4-15 A small urban catchment in the Lake Jordan watershed of North Carolina with distributed sources of impervious surface (buildings and roads) stormwater arranged within the full surface drainage flowpath system. Stormwater from each source is routed down surface and subsurface flowpaths to the nearest tributary and out the drainage network, with additions and abstractions of water and pollutants along each flowpath segment. SOURCE: Data from the NHD+.

This section discusses the fundamentals of stormwater modeling and the capabilities of commonly used models. Much of this information is captured in a summary table at the end of the section (Table 4-7). The models included are the following:

- The Rational Method, or $Q = C*I*A$, where Q is the peak discharge for small urban catchments, A is the catchment area, I is the rainfall intensity, and C is a rainfall-runoff coefficient.
- The Simple Method, which classifies stormwater generation and impact regimes by the percent impervious cover
- TR-20 and TR-55
- The Generalized Watershed Loading Function (GWLF)
- Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds (P8)
- Model for Urban Stormwater Improvement Conceptualization (MUSIC)
- Stormwater Management Model (SWMM)
- Source Loading and Management Model (WinSLAMM)
- Soil and Water Assessment Tool (SWAT)
- Hydrologic Simulation Program–Fortran (HSPF)
- Western Washington Hydrologic Model
- Chesapeake Bay Watershed Model (CBWM)

Fundamentals of Stormwater Models

Stormwater models are designed to evaluate the impacts of a stormwater discharge on a receiving waterbody. In order to do this, the model must have the capability of describing the nature of the source term (volumes, constituents), transport and transformation to the receiving waterbody, and physical, chemical, and biological interaction with the receiving water body and ecosystem. No model can mechanistically reproduce all of these interactions because of current limitations in available data, incomplete understanding of all processes, and large uncertainties in model and data components. Computer resources, while rapidly advancing, still limit the complexity of certain applications, especially as spatial data become increasingly available and it is tempting to model at ever-increasing resolution and comprehensiveness. Therefore, models must make a set of simplifying assumptions, emphasizing more reliable and available data, while attempting to retain critical processes, feedbacks, and interactions. Models are typically developed for a variety of applications, ranging from hydraulic design for small urban catchments to urban and rural pollutant loading at a range of watershed scales.

An evaluation of the current state of stormwater modeling should say much about our ability to link pollutant sources with effects in receiving waters. Both stormwater models and models supporting the evaluation of SCM design and effectiveness are based on simulating a mass budget of water and specific pollutants. The detail of mass flux, transformation, and storage terms vary depending on the scale and purpose of the application, level of knowledge regarding the primary processes, and available data. In many cases, mechanisms of transformation may be either poorly understood or may be dependent on detailed interactions. As an example, nitrogen-cycle transformations are sensitive to very short temporal and spatial conditions, termed "hot spots" and "hot moments" relative to hydrologic flowpaths and moisture conditions (McClain et al., 2003).

Stormwater runoff production and routing are common components of these models. All models include an approach to estimate the production of stormwater runoff from one or more zones in the watershed, although runoff routing from the location(s) of runoff production to a point or waterbody is not always included explicitly. Major divisions between approaches are found in the representation of the watershed "geography" in terms of patterns and heterogeneity, and in runoff production and routing. Some stormwater models do not consider the effects of routing from a runoff source to a local waterbody directly, but may attempt to reproduce net impacts at larger scales through the use of unit hydrograph theory to estimate peak flows, and delivery ratios or stormwater control efficiency factors to estimate export to a waterbody.

There are a number of different approaches and paradigms used in stormwater models that include varying degrees of watershed physical, biological, and chemical process detail, as well as spatial and temporal resolution and the representation of uncertainty in model estimates. A number of researchers have written about the nature of watershed models (e.g., Beven, 2001; Pitt and Vorhees, 2002). At present, many hydrologic and stormwater models have become so complex, with multiple choices for different components, that standard descriptions apply only to specific components of the models. The following discussion is generalized; most models fit the descriptions only to certain degrees or only under specific conditions in which they are operated.

Lumped Versus Distributed Approaches

Central to the design of watershed models is the concept of a "control volume," which is a unit within which material and energy contents and balances are defined, with boundaries across which material and energy transport occurs. Control volumes can range from multiple subsurface layers and vegetation canopy layers bounded in three dimensions to a full watershed. Lumped models ignore or average spatial heterogeneity and patterns of watershed conditions, representing all control volumes, and the stores, sources, and sinks of water and pollutants in a vertically linked set of conceptual components, such as surface interception, unsaturated and saturated subsurface zones, and a single stream or river reach. For example, SWAT or HSPF are conceptually lumped at the scale of subwatersheds (e.g., the level of geography in Figure 4-14) and do not show any spatial patterns at higher resolutions (e.g., Figure 4-15) than these units. While multiple land-use/soil combinations may be represented, these models do not represent the connectivity of the land segments (e.g., which land segments drain into which land segments) and assume all unique land segment types drain directly to a stream.

Distributed models include some scheme to represent spatial heterogeneity of the watershed environment pertinent to stormwater generation, including land cover, soils, topography, meteorological inputs, and stream reach properties distributed through a set of linked control volumes. Control volumes representing land elements, including vertically linked surface and subsurface stores, are connected by a representation of water and pollutant lateral routing through a network of flowpaths that may be predefined or set by the dynamics of surface, soil, and saturated zone water storage. The land elements may be grid cells in a regular lattice, or irregular elements (e.g., triangles) with the pattern adapted to variations in land surface characteristics or hydraulic gradients.

A number of models are intermediate between lumped and distributed, with approaches such as lumping at the subwatershed scale, incorporating statistical distributions of land element types within subwatersheds but without explicit pattern representation, or lumping some variables and processes (such as groundwater storage and flux), while including distributed representation of topography and land cover. Thus, within the model SLAMM (Pitt and Vorhees, 2002), the catchment is described in sufficient detail to summarize the breakdown of different drainage sequences. As an example, roof area will be broken down to the proportion that drains to pervious areas and to directly connected impervious areas. An important distinction is that there is no routing of the output of one land element into another, such that there is no drainage sequence that may significantly modify the stormwater runoff from its source to the stream. Implicitly, all land elements drain directly into a stream, although a loss rate or delivery ratio can be specified.

The choice of a more lumped or distributed model is often dependent on available data and overall complexity of the model. Simpler, lumped models may be preferred in the absence of sufficient data to effectively parameterize a distributed approach, or for simplicity and computational speed. However, fully lumped models may be limited in their ability to represent spatial dependency, such as the development and dynamics of riparian zones, or the effects of SCM patterns and placement. As there is typically an irreducible level of spatial heterogeneity in land surface characteristics down to very small levels below the resolution of individual flow elements, we note that all models lump at some scale (Beven, 2000).

Mechanistic Versus Conceptual Process Representation

Mechanistic, or process-based, approaches attempt to reproduce key stormwater transport and transformation processes with more physically, chemically, or biologically based detail, while conceptual models represent fluxes between stores and transformations with aggregate, simplified mathematical forms. No operational models are built purely from first principles, so the distinction between mechanistic and conceptual process basis is one of degree.

The level of sampling necessary to support detailed mechanistic models, as well as remaining uncertainty in physicochemical processes active in heterogeneous environments typically limits the application of first-principle methods. The development or application of more mechanistic approaches is currently limited by available measurements, which require both time and resources to adequately carry out. Unfortunately, modeling and monitoring have often been mutually exclusive in terms of budgets, although it is necessary for both to be carefully planned and integrated. A new generation of sensors and a more rigorous and formal sampling protocol for existing methods will be necessary to advance beyond the current practice.

At present, most operational hydrologic and transport models are based on a strong set of simplifying assumptions regarding active processes and/or the spatial variation of sources, sinks, and stores in the watershed. Runoff production can be computed by a range of more mechanistic to more conceptual or empirical methods. More mechanistic methods include estimation of infiltration capacities based on soil hydraulic properties and moisture conditions, excess runoff production, and hydraulic routing over land surfaces into and through a stream-channel network. More conceptual approaches use a National Resources Conservation Service (NRCS) curve number approach (see Box 4-5) and unit hydrograph methods to estimate runoff volume and time of concentration. Pollutant concentrations or loads are often estimated on the basis of look-up tables using land use or land cover. Land use- or land cover-specific EMC or unit area loading for pollutants can be developed directly from monitoring data or from local, regional, or national databases. The NSQD statistically summarizes the results of a large number of stormwater monitoring projects (as discussed previously in this chapter). The effects of SCM performance (typically percent removal) can be estimated from similar databases (e.g., www.bmpdatabase.org). A set of models, such as SWAT, incorporate fairly detailed descriptions of nutrient cycling as an alternative to using EMC, requiring more detailed inputs of soil, crop, and management information. Unfortunately, the detailed biogeochemistry of this and similar models is typically not matched by the hydrology, which remains lumped at individual Hydrologic Response Unit (HRU) levels using NRCS curve number methods, although options exist to incorporate more mechanistic infiltration excess runoff.

BOX 4-5
NRCS Technical Release 55

NRCS methods to estimate runoff volumes and flows have been popular since the early 1950s (Rallison, 1980). Fundamentally they can be broken into the separation of runoff from the rainfall volume (Curve Number Method), the pattern of runoff over time (dimensionless unit hydrograph), and their application within computer simulation models. In the late 1970s these components were packaged together in a desktop hydrology method known as Technical Release 55 (TR-55). TR-55 became the primary model used by the majority of stormwater designers, and there is considerable confusion over the terms used to describe what aspects of the NRCS methods are in use.

The NRCS Curve Number Method was first derived in the 1950s for prediction of runoff from ungauged agricultural areas. It relates two summation ratios, that of runoff to rainfall and that of moisture retained to maximum potential retention. Two statistically based relations were developed to drive the ratio, the first of which is based on a "curve number" which depicts the soil type, land cover, and initial moisture content. The second or initial abstraction is defined as the volume of losses that occur prior to the initiation of runoff, and is also related to the curve number. Data were used to derive curve numbers for each soil type and cover as shown in Figure 4-16 (Rallison, 1980).

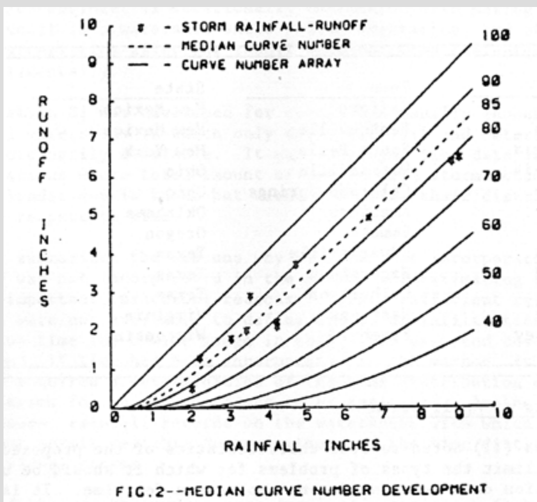

FIGURE 4-16 Development of curve number from collected data. SOURCE: Reprinted, with permission, from Rallison (1980). Copyright 1980 by the American Society of Civil Engineers.

The Curve Number method is a very practical method that gives "average" runoff results from a watershed and is used in many models (WIN TR-55, TR-20, SWMM, GWLF, HEC-HMS, etc.). Caution has to be exercised when using it for smaller urbanizing storm events. For example, past practice was to average curve numbers for developments for pavement and grass based on percent imperviousness. While this works well for large storms, for smaller storms it gives erroneous answers through violation of the initial abstraction relationship. Current state manuals (MDE, 2000; PaDEP, 2006) do not allow paved- and unpaved-area curve numbers to be averaged. When applied to continuous simulation models (such as in SWMM or GWLF), it requires an additional method to recover the capacity to remove runoff because the soil capacity to infiltrate water is restored over time.

The NRCS Dimensionless Unit Hydrograph has also evolved over many years and simply creates a temporal pattern from the runoff generated from the curve number method. This transformation is based upon the time of concentration, defined as the length of time the water takes to travel from the top to the bottom of the watershed. The dimensionless curve ensures that conservation of mass is maintained. The main purpose of this method is to estimate how long it takes the runoff generated by the curve number to run off the land and produce discharge at the watershed outlet.

The NRCS curve number and dimensionless unit hydrograph were first incorporated in the Soil Conservation Service (SCS) TR-20 hydrologic computer model developed in the 1960s. As most stormwater professionals did not have access to mainframes, SCS put together TR-55, which created a hand or calculator method to apply the curve number and dimensionless unit hydrograph. In order to create this hand method, many runs were generated using TR-20 to develop patterns for different times of concentration. The difficulty with using the original TR-55 in the modern era is that the simplifications to the hydrograph development do not allow the benefits of SCMs to be easily accounted for.

The use of the term TR-55 has been equated with the curve number method; this has created confusion, especially when it is included in municipal code. Further clouding the issue, there are two types of TR-55 computer models available. One is based on the original, outdated, simplified hand method, and the other (Win TR-55) returns to the more appropriate application of the curve number and dimensionless hydrograph methods. In either case, the focus of these models is on single event hydrology and cannot easily incorporate or demonstrate the benefits of the wide range of structural and nonstructural SCMs. Note that the curve number and dimensionless unit hydrograph methods are incorporated in many continuous flow models, including SWMM and GWLF, as the basis of runoff generation and runoff timing.

Deterministic Versus Stochastic Methods

Deterministic models are fully determined by their equation sets, initial and boundary conditions, and forcing meteorology. There are no components that include random variation. In a stochastic model, at least one parameter or variable is drawn from a probability distribution function such that the same model set-up (initial and boundary conditions, meteorology, parameter sets) will have randomly varying results. The advantage of the latter approach is the ability to generate statistical variability of outcomes, reflecting uncertainty in parameters, processes, or any other component. In fact, any deterministic model can be operated in a stochastic manner by sampling parameter values from specified probability distributions.

It is recognized that information on the probability distribution of input parameters may be scarce. For situations with limited information on parameter values, one option is to assume a uniform distribution that brackets a range of values of the parameter reported in the literature. This would at least be a start in considering the impacts of the variability of model inputs on outputs. A thorough discussion on methods for incorporating uncertainty analysis into model evaluation is provided in Chapter 14 of Ramaswami et al. (2005). It should be noted that the ability to generate probability distribution information on stormwater outcomes requires a potentially large number of model runs, which may be difficult for detailed mechanistic and distributed models that have large computational loads.

Continuous Versus Event-Based Approaches

Another division between modeling approaches is the time domain of the simulation. Event-based models limit simulation time domains to a storm event, covering the time of rainfall and runoff generation and routing. Initial conditions need to be estimated on the basis of antecedent moisture or precipitation conditions. For catchments in which runoff is dominated by impervious surfaces, this is a reasonable approach. In landscapes dominated by variable source area runoff dynamics in which runoff is generated from areas that actively expand and contract on the basis of soil moisture conditions, a fuller accounting of the soil moisture budget is required. Furthermore, event-based modeling is inappropriate for water quality purposes because it will not reproduce the full distribution of receiving water problems. Continuous models include simulation of a full time domain composed of storm and inter-storm periods, thus tracking soil moisture budgets up to and including storm events.

Outfall Models

After beneficial use impairments are recognized, cause-and-effect relationships need to be established and restorative discharge goals need to be developed. Models are commonly used to calculate the expected discharges for different outfalls affecting the receiving water in a community. All of the models shown in Table 4-7 can calculate outfall discharge quantities, although some may only give expected average annual discharge. Models calculate these discharges using a variety of processes, but all use an urban hydrology component to determine the runoff quantity and various methods to calculate the quality of the runoff. The runoff quantity is multiplied by the pollutant concentration in the outfall to obtain the mass discharges of the different pollutants. The outfall mass discharge from the various outfalls in the area can then be compared to identify the most significant outfalls that should be targeted for control.

The most common hydrology "engines" in simple stormwater models are the NRCS curve number method or a simple volumetric runoff coefficient—R_v, the ratio of runoff to rainfall—for either single rainfall events or the total annual rainfall depth. Runoff quality in the simple models is usually calculated based on published EMCs for similar land uses in the same geographical area. More complex models may use build-up and wash-off of pollutants from impervious surfaces in a time series or they may derive pollutant concentrations from more detailed biogeochemical cycling mechanisms, including atmospheric deposition and other inputs (e.g., fertilizer). Some models use a combination of these processes depending on the area considered, and others offer choices to the model user. Again, these processes all need local calibration and verification to reduce the likely uncertainty associated with the resultant calculated discharge conditions.

Source Area

When the outfalls are ranked according to their discharges of the pollutants of importance, further detailed modeling can be conducted to identify sources of the significant pollutants within the outfall drainage area. Lumped parameter models cannot be used, as the model parameters vary within the drainage area according to the different source areas. Distributed area models can be used to calculate contributions from different source areas within the watershed area. This information can then be used to rank the land uses and source area contributions. In-stream responses can be calculated if the land-area models are linked to appropriate receiving-water models.

Need for Coupling Models

As urban areas become increasingly extensive and heterogeneous, including a gradient of dense urban to forest and agricultural areas, linkage and coupling of models to develop feedback and interactions (e.g., impacts of urban runoff hydraulics with stream scour and sedimentation, mixed with agricultural nutrient and sediment production on receiving waterbodies) is a critical area that requires more development. In general, stormwater models were designed to track and predict discharges from sources by surface water flowpaths into receiving waterbodies, such that infiltration was considered to be a loss (or retention) of water and its constituents. To fully evaluate catchment-scale impacts of urbanization on receiving waterbodies, the infiltration term needs to be considered a source term for the groundwater, and a groundwater component or model needs to be coupled to complete the surface–subsurface hydrologic interactions and loadings to the waterbody.

Finally, each of the models may or may not incorporate explicit consideration of SCM performance based on design, implementation and location within the catchment. As discussed in the next chapter, SCM models can range from simple efficiency factors (0–1 multipliers on source discharge) to more detailed treatment of physical, chemical, and biological transport and transformations.

Linking to Receiving-Water Models

Specific problems for urban receiving waters need to be identified through comprehensive field monitoring and modeling. Monitoring can identify current problems and may identify the stressors of importance (see Burton and Pitt [2002] for tools to evaluate receiving water impairments). However, monitoring cannot predict conditions that do not yet exist and for other periods of time that are not represented at the time of monitoring. Modeling is therefore needed to gain a more comprehensive understanding of the problem. In small-scale totally urbanized systems, less complex receiving-water models are needed. However, as the watershed becomes more complex and larger with multiple land uses, the receiving-water models also need to become more complex. Complex receiving-water models need to include transport and transformations of the pollutants of concern, for example. Examples of models shown on the comparison table that include receiving-water processes are MUSIC and HSPF. Other models (such as WinSLAMM) provide direct data links to external receiving-water models. Calibration and verification of important receiving-water processes that are to be implemented in a model can be very expensive and time consuming, and still result in substantial uncertainty.

Model Calibration and Verification

Calibration is the process where model parameters are adjusted to minimize the difference between model output and field measurements, with an aim of keeping model parameters within a range of values reported in the literature. Model *verification*, similar to model validation, is used to mean comparison between calibrated model results using part of a data set as input and results from application of the calibrated model using a second (independent) part of the data set as input. Oreskes et al. (1994) present the viewpoint that no model can really be verified; at best, verification should be taken to mean that a model is consistent with a physical system under a given set of comparison data. This is not synonymous with saying that the model can reliably represent the real system under any set of conditions. In general, the water quantity aspects of stormwater modeling are easier to calibrate and verify than the water quality aspects, in part because there are more water quantity data available and because chemical transformations are more complex to simulate. A thorough discussion of the broad topic of model evaluation is provided by several excellent texts on this subject, including Schnoor (1996) and Ramaswami et al. (2005).

Models in Practice Today

Table 4-7 presents a set of models used for stormwater evaluation that range in complexity from first-generation stormwater models making use of simple empirical land cover/runoff and loading relations to more detailed and information-demanding models. The columns in Table 4-7 provide an abbreviated description of some of the attributes of these models—common usage, typical application scales, the degree of model complexity, some data requirements (for the hydrologic component), whether the model addresses groundwater, and whether the model has the ability to simulate SCMs. Models capable of simulating a water quality component require EMC data, with some models also having a simple build-up/wash-off approach to water quality simulation (e.g., SWMM, WinSLAMM, and MUSIC) and others simulating more complex geochemistry (e.g., SWAT and HSPF). The set of columns in Table 4-7 is not meant to be exhaustive in describing the models, which is why websites are provided for comprehensive model descriptions and data requirements.

In addition to the models listed in Table 4-7, a representative set of emerging research models that are not specifically designed for stormwater, but may offer some advantages for specific uses, are also described below. In general, it is important that models that integrate hydrologic, hydraulic, meteorologic, water quality, and biologic processes maintain balance in their treatment of process details. Both model design and data collection should proceed in concert and should be geared toward evaluating and diagnosing the consistency of model or coupled model predictions and the uncertainty attached to each component and the integrated modeling system. The models should be used in a manner that produces both best estimates of stormwater discharge impacts on receiving waterbodies, as well as the level of uncertainty in the predictions.

The Rational Method is a highly simplified model widely used to estimate peak flows for in sizing storm sewer pipes and other low level drainage pathways. The method assumes a constant rainfall rate (intensity), such that the runoff rate will increase until the time at which all of the drainage area contributes to flow at its outlet (termed the *time of concentration*). The product of the drainage area and rainfall intensity is considered to be the input flow rate to the drainage area under consideration; the ratio of the input flow rate to an outflow discharge rate is termed the runoff coefficient. Runoff coefficients for a variety of land surface types and slopes have been compiled in standard tables (see e.g., Chow et al., 1988). The outflow is determined by multiplying inflow (rainfall intensity times drainage area) by the runoff coefficient for the land-surface type. As pointed out by Chow et al. (1988), this method is often criticized owing to its simplified approach, so its use is limited to stormwater inlet and piping designs.

The Simple Method estimates stormwater pollutant loads for urban areas, and it is most valuable for assessing and comparing the relative stormwater pollutant load changes of different land use and stormwater management scenarios. It requires a modest amount of information, including the subwatershed drainage area and impervious cover, stormwater pollutant concentrations (as defined by the EMC), and annual precipitation. The subwatershed can be broken up into specific land uses, such that annual pollutant loads are calculated for each type of land use. Stormwater pollutant concentrations are usually estimated from local or regional data, or from national data sources. The Simple Method estimates pollutant loads for chemical constituents as a product of annual runoff volume and pollutant concentration, as $L = 0.226\ R \times C \times A$, where L = annual load (lbs), R = annual runoff (inches), C = pollutant concentration (mg/l), and A = area (acres).

Of slightly increased complexity are those models initially developed decades ago by the Soil Conservation Service, now the NRCS of the U.S. Department of Agriculture (USDA). NRCS Technical Releases (TR) 20 and 55 are widely used in many municipalities, despite the availability of more rigorous, updated stormwater models. Box 4-5 provides an overview of the NRCS TR-55 assumptions and approaches.

A number of watershed models that are used for stormwater assessment are lumped, conceptual forms, with varying levels of process simplification and spatial patterns aggregated at the subwatershed level, with aspatial statistical distribution of land types as described above. The GWLF model (Haith and Shoemaker, 1987) is an example of this type of approach, using simple land use-based EMC with NRCS curve number estimates of runoff within a watershed context. GWLF is a continuous model with simplified upper- and lower-zone subsurface water stores, and a simple linear aquifer to deliver groundwater flow. EMCs are assigned or calibrated for subsurface and surface flow delivery, while sediment erosion and delivery are computed with the use of the Universal Soil Loss Equation and delivery coefficients. The methods are easily linked to a Geographical Information System (GIS), which provides land-use composition at the subwatershed level and develops estimates of runoff and loading that are typically used to estimate annual loading. AVGWLF links GWLF with ArcView and is used as a planning- or screening-level tool. A recent example of AVGWLF for nutrient loading linked to a simple stream network nutrient decay model for the development of a TMDL for a North Carolina water supply area is given in Box 4-6.

BOX 4-6
The B. Everett Jordan Lake GWLF Watershed Model Development

Jordan Lake is a regionally important water supply reservoir at the base of the 1,686-square-mile Haw watershed in North Carolina (see Figure 4-17). It is considered a nutrient-sensitive waterbody. Officials are now in the process of implementing watershed goals to reduce nitrogen and phosphorus, with the reduction goals differentiated by geographic location within the basin. In support of the development of these rules as part of a TMDL effort, the North Carolina Division of Water Quality commissioned a water quality modeling study (Tetra Tech, 2003). The modeling effort was needed to support the evaluation of nutrient reduction strategies in different parts of the watershed relative to Jordan Lake, which requires both a model of nutrient loading, as well as river transport and transformation. Given data and resource restrictions, a more detailed model was not considered feasible. As GWLF does not support nutrient transformations in the stream network, the model was used in conjunction with a method to decay nutrient source loading by river transport distance to the lake. A spreadsheet model was designed to take as input GWLF estimates of seasonal loads for 14-digit hydrologic unit code (HUC) subbasins of the Haw, and to reduce the loads by river miles between the subwatershed and Jordan Lake. The GWLF loading model was calibrated to observations in small subwatersheds within the Haw using HRUs developed from soil and NLCD land classes, updated with additional information from county GIS parcel databases and the 2000 Census. This information was used to estimate subwatershed impervious surface cover, fertilizer inputs, runoff curve numbers, soil water capacity, and vegetation cover to adjust evapotranspiration rates. Wastewater disposal (sewer or septic) was estimated on the basis of urban service boundaries. GWLF was used to provide loading estimates, using limited information on soil and groundwater nutrient concentrations, and calibrated delivery ratios. In-stream loss was based on a first-order exponential decay function of river travel time to Jordan Lake, with the decay coefficient generated by estimates of residence time in the river network, and upstream/downstream nutrient loads following non-linear regression methods used in SPARROW (Alexander et al., 2000). Further adjustments based on impoundment trapping of sediment and associated nutrient loads were carried out for larger reservoirs in the Haw. The results provided estimates of both loading and transport efficiency to Jordan Lake, with estimates of relative effectiveness of sectoral loading reductions in different parts of the watershed.

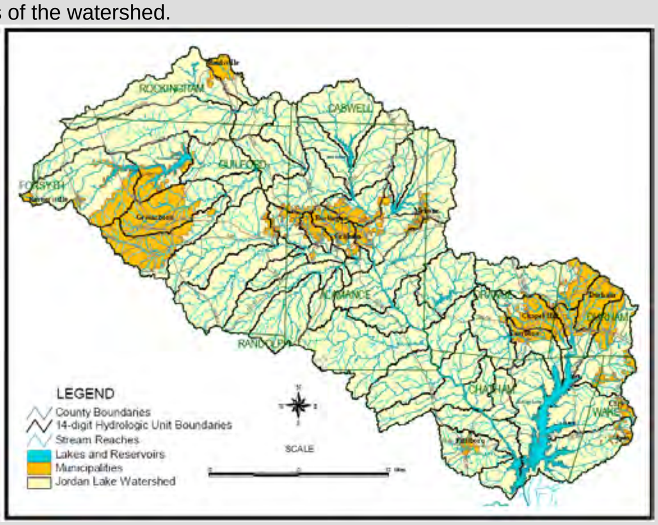

FIGURE 4-17 14 digit HUCs draining to Jordan Lake in the Haw River watershed of North Carolina. SOURCE: Tetra Tech (2003).

P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds) is a curve number-based model for predicting the generation and transport of stormwater runoff pollutants in urban watersheds, originally developed to help design and evaluate nutrient control in wet detention ponds (Palmstrom and Walker, 1990; http://wwwalker.net/p8/). Continuous water-balance and mass-balance calculations are performed and consist of the following elements: watersheds, devices, particle classes, and water quality components. Continuous simulations use hourly rainfall and daily air temperature time series. The model was initially calibrated to predict runoff quality typical of that measured under NURP (EPA, 1983). SCMs in P8 include detention ponds (wet, dry, extended), infiltration basins, swales, and buffer strips. Groundwater and baseflows are also included in the model using linear reservoir processes.

MUSIC is a part of the Catchment Modelling Toolkit (www.toolkit.net.au) developed by the Cooperative Research Center for Catchment Hydrology in Australia (Wong et al., 2001). The model concentrates on the quality and quantity of urban stormwater, including detailed accounting of multiple SCMs acting within a treatment train and life-cycle costing. It employs a simplified rainfall–runoff model (Chiew and McMahon, 1997) based on impervious area and two moisture stores (shallow and deep). TSS, total nitrogen, and total phosphorus are based on EMCs, sampled from lognormal distributions. The model does not contain detailed hydraulics required for routing or sizing of SCMs, and it is designed as a planning tool.

EPA's SWMM has the capability of simulating water quantity and quality for a single storm event or for continuous runoff. The model is commonly used to design and evaluate storm, sanitary, and combined sewer systems. SWMM accounts for hydrologic processes that produce runoff from urban areas, including time-varying rainfall, evaporation, snow accumulation and melting, depression storage, infiltration into soil, percolation to groundwater, interflow between groundwater and the drainage system, and nonlinear reservoir routing of overland flow. Spatial variability is modeled by dividing a study area into a collection of smaller, homogeneous subcatchment areas, each containing its own fraction of pervious and impervious sub-areas. Overland flow can be routed between sub-areas, between subcatchments, or between entry points of a drainage system. SWMM can also be used to estimate the production of pollutant loads associated with runoff for a number of user-defined water quality constituents. Transport processes include dry-weather pollutant buildup over different land uses, pollutant wash-off from specific land uses, direct contribution of rainfall deposition, and the action of such SCMs as street cleaning, source control, and treatment in storage units, among others.

Watershed models such as SWAT (Arnold et al., 1998) or HSPF (Bicknell et al., 1997, 2005) have components based on similar land-use runoff and loading factors, but also incorporate options to utilize detailed descriptions of interception, infiltration, runoff, routing, and biogeochemical transformations. Both models are based on hydrologic models that were developed prior to the availability of detailed digital spatial information on watershed form and use conceptual control volumes that are not spatially linked. HRUs are based on land use, soils, and vegetation (and crop) type, among other characteristics, and are considered uniformly distributed through a subbasin. Within each HRU, simplified representations of soil upper and lower zones, or unsaturated and saturated components, are vertically integrated with a conceptual groundwater storage-release component. There is no land surface routing and all runoff from a land element is considered to reach the river reach, with some delivery ratio if appropriate for sediment and other constituents. Like GWLF, the models are typically not designed to estimate loadings from individual dischargers, but are used to help guide and develop TMDL for watersheds. SWAT and HSPF are integrated within the EPA BASINS system (http://www.epa.gov/waterscience/basins) with GIS tools designed to use available spatial data to set up and parameterize simulations for watersheds within the United States. Examples of combining one of these models, typically designed for larger-scale applications (such as the area shown in Figure 4-14) with more site-specific models such as SLAMM or SWMM, are given in Box 4-7.

BOX 4-7
Using SWAT and WinSLAMM to Predict Phosphorus Loads in the Rock River Basin, Wisconsin

Wisconsin Administrative Code NR 217 states that wastewater treatment facilities in Wisconsin must achieve an effluent concentration of 1 mg/L for phosphorus. Alternative limits are allowed if it can be demonstrated that achieving the 1 mg/L limit will not "result in an environmentally significant improvement in water quality" (NR 217.04(2)(b)1). In response to NR 217, a group of municipal wastewater treatment facilities formed the Rock River Partnership (RRP) to assess water quality management issues (Kirsch, 2000). The RRP and the Wisconsin Department of Natural Resources funded a study to seek water quality solutions across all media, and not just pursue additional reductions from point sources. A significant portion of the study required a modeling effort to determine the magnitude of various nutrient sources and determine potential reductions through the implementation of global SCMs.

The Rock River Basin covers approximately 9,530 square kilometers and lies within the glaciated portion of south central and eastern Wisconsin (Figure 4-18). The Rock River and its numerous tributaries thread their way through this landscape that spreads over 10 counties inhabited by more than 750,000 residents. There are 40 permitted municipalities in the watershed, representing 4 percent of the land area, and they are served by 57 sewage treatment plants. Urban centers include Madison, Janesville, and Beloit as well as smaller cities such as Waupun, Watertown, Oconomowoc, Jefferson, and Beaver Dam. Although the basin is experiencing rapid growth, it is still largely rural in character with agriculture using nearly 75 percent of the land area. Crops range from continuous corn and corn–soybean rotations in the south to a mix of dairy, feeder operations, and cash cropping in the north. The basin enjoys a healthy economy with a good balance of agricultural, industrial, and service businesses.

continues next page

BOX 4-7 Continued

The focus of the modeling was to construct an intermediate-level macroscale model to better quantify phosphorus loads from point and nonpoint sources throughout the basin. The three goals of the modeling effort were to (1) estimate the average annual phosphorus load, (2) estimate the relative contribution of phosphorus loads from both nonpoint (urban and agricultural) and point sources, and (3) estimate changes in average annual phosphorus loads from the application of global SCMs and point source controls.

SWAT was selected for the agricultural analysis and WinSLAMM was selected to develop phosphorus loads for the urban areas. WinSLAMM was selected to make estimates of stormwater loads, because it is already calibrated in Wisconsin for stormwater volumes and pollutant concentrations. Outputs of phosphorus loads from WinSLAMM were used as input to SWAT. One output of SWAT was a total nonpoint phosphorus load based on agricultural loads calculated in SWAT and stormwater loads estimated by WinSLAMM.

SWAT was calibrated with data from 23 USGS gauging stations in the Rock River Basin. Hydrology was balanced first on a yearly basis looking at average annual totals, then monthly to verify snowfall and snowmelt routines, and then daily. Daily calibration was conducted to check crop growth, evapotranspiration, and daily peak flows. Crop yields predicted by SWAT were calibrated to those published in the USDA Agricultural Statistics.

Under current land-use and management conditions, the model predicted an average annual load of approximately 1,680,000 pounds of total phosphorus for the basin with 41 percent from point sources and 59 percent from nonpoint sources. Less than 10 percent of the annual phosphorus load is generated by the urban areas in the watershed. Evaluation of various SCM scenarios shows that with implementation of NR 217 (applicable point source effluent at 1 mg/L) and improvement in tillage practices and nutrient management practices, total phosphorus can be reduced across the basin by approximately 40 percent. It is important to note that the nonpoint management practices that were analyzed were limited to two options: modifications in tillage practices, and adoption of recommended nutrient application rates. No other management practices (i.e., urban controls, riparian buffer strips, etc.) were simulated. Urban controls were not included because the urban areas contributed a relatively small percentage of the total phosphorus load. Thus, loadings depicted by SWAT under these management scenarios do not necessarily represent the lowest attainable loads. Results suggest that a combination of point and nonpoint controls will be required to attain significant phosphorus reductions.

The CBWM is a detailed watershed model that is extended from HSPF as a base, but includes additional components to incorporate stormwater controls at the land segment level. HSPF is operated for a number of subbasins, and each subbasin model includes different land segments based on land cover and soil units as aspatial, lumped distribution functions, but also includes representation of SCMs and (large) stream routing. Model implementation at the scale of the full Chesapeake Bay watershed requires fairly coarse-grained land partitioning. A threshold of 100 cfs mean annual flow is used to represent streams and rivers, and the one-to-one mapping of land segment to river reach produces large, heterogeneous land segments as the basic runoff-producing zones. SCMs are implemented either at the field or runoff production unit as distinct land segment types in terms of management or land cover, or as “edge-of-field” reductions of runoff or pollutant loads. The latter are assigned as static efficiency factors irrespective of flow conditions or season, with all SCMs within a land segment integrated into a single weighted efficiency value.

FIGURE 4-18 Rock River Basin, Wisconsin. SOURCE: Reprinted, with permission, from Kirsch (2000). Copyright 2000 by American Society for Biological and Agricultural Engineers.

SLAMM is designed for complex, urban catchments and is used as a planning tool to assess both stormwater and pollutant runoff production and the capability of specific stormwater control strategies to reduce stormwater discharges from urban sources. It is specifically designed to capture the most significant distributed and sequential drainage effects of variable source areas in urban catchments (Pitt and Vorhees, 2002) and is based on detailed descriptions of the catchment composition, including both type and relative position (drainage sequence) of land elements. The model is dependent on high-resolution classification or description of the catchment that has become increasingly available in urban areas over the past two decades, and comprehensive field assessment of runoff and pollutant loading from different urban land elements. SLAMM uses continuous simulation for some aspects, such as the build up of street pollutant loads between storms, while using event-based simulation for runoff. The description of build-up and wash-off is a critical component in urban stormwater models applied to areas with substantial impervious surfaces and is a good example of the need to match detailed and rigorous field sampling in order to adequately describe and represent dominant processes. Details of measurement and model representation for build-up and wash-off of contaminants are given in Box 4-8.

Potential New Applications of Coupled Distributed Models

The advent of high-resolution digital topographic and land-cover data over the past two decades has fueled a significant shift in runoff modeling towards "spatially explicit" simulations that distinguish and connect runoff producing elements in a detailed flow routing network. While models developed prior to the availability of high-resolution data or based on older paradigms developed in the absence of this information required spatial and conceptual lumping of control volumes, more recently developed distributed models may contain control volumes linked in multiple vertical layers (soil and aquifer elements) and laterally from a drainage divide to the stream, including stream-channel and riparian segments. A set of models has been developed and applied to stormwater generation using this paradigm that can be applied at the scale of residential neighborhoods, resolving land cover and topography at the parcel level. These models also vary in terms of their emphasis, with some models better representing coupled surface water–groundwater interactions, water, carbon and nutrient cycling, or land–atmosphere interactions. Boyer et al. (2006) have recently reviewed a set of hydrologic and ecosystem models in terms of their ability to simulate sources, transport, and transformation of nitrogen within terrestrial and aquatic ecosystems. Data and information requirements are typically high, and the level of process specificity may outstrip the available information necessary to parameterize the integrated models. However, an emphasis is placed on providing mechanistic linkage and feedbacks between important surface, subsurface, atmospheric, and ecosystem components. Examples of these models include the Distributed Hydrology Soil Vegetation model (DHSVM, Wigmosta et al., 1994); the Regional Hydro-Ecologic Simulation System (RHESSys, Band et al., 1993; Tague and Band, 2004); ParFlow-Common Land Model (CLM, Maxwell and Miller, 2007); the Penn State Integrated Hydrologic Model (PIHM, Qu and Duffy, 2007); the Soil Moisture Distribution and Routing (SMDR) model (Easton et al., 2007); and that of Xiao et al. (2007).

One advantage of integrating surface and subsurface flow systems within any of these model structures is the ability to incorporate different SCMs by specifying characteristics of specific locations within the flow element networks linked to the subsurface drainage. Examples can include alteration of surface detention storage and release curves to simulate detention ponds, or soil depth, texture, vegetation, and drainage release for rainfall gardens. The advantage of this approach is the tight coupling of these SCM features with the connected surface and subsurface drainage systems, allowing the direct incorporation of the SCM as sink or source terms within the flowpath network. Burgess et al. (1998) effectively demonstrated that suburban lawns can become the major

BOX 4-8
Build-up and Wash-off of Contaminants from Impervious Surfaces

The accumulation and wash-off of street particulates have been studied for many years (Sartor and Boyd, 1972; Pitt, 1979, 1985, 1987) and are important considerations in many stormwater models, such as SWMM, HSPF, and SLAMM, that require information pertaining to the movement of pollutants over land surfaces. Accumulation rates are usually obtained through trial and error during calibration, with little, if any, actual direct measurements. Furthermore, those direct measurements that have been made are often misapplied in modeling applications, resulting in unreasonable model predictions.

Historically, streets have been considered the most important directly connected impervious surface. Therefore, much early research was directed toward measuring the processes on these surfaces. Although it was eventually realized that other surfaces can also be significant pollutant sources (see Pitt et al., 2005a,b for reviews), additional research to study accumulation and wash-off for these other areas has not been conducted, such that the following discussion is focused on street dirt accumulation and wash-off.

Accumulation of Particulates on Street Surfaces

The permanent storage component of street surface particulates is a function of street texture and condition and is the quantity of street dust and dirt that cannot be removed naturally by rain or wind, or by street cleaning equipment. It is literally trapped in the texture of the street. The street dirt loading at any time is this initial permanent loading plus the accumulation amount corresponding to the exposure period, minus the resuspended material removal by wind and traffic-induced turbulence.

One of the first research studies to attempt to measure street dirt accumulation was conducted by Sartor and Boyd (1972). Field investigations were conducted between 1969 and 1971 in several cities throughout the United States and in residential, commercial, and industrial land-use areas. Figure 4-19 is a plot of the 26 test area measurements collected from different cities, but separated by the three land uses. The data are the accumulated solids loading plotted against the number of days since the street had been cleaned by the municipal street cleaning operation or a "significant" rain. There is a large amount of variability. The street cleaning and this rain were both assumed to remove all of the street dirt; hence, the curves were all forced through zero loading at zero days.

A more thorough study was conducted in San Jose, California by Pitt (1979), during which the measured street dirt loading for a smooth street was also found to be a function of time. As shown in Figure 4-20, both accumulation rates and increases in particle size of the street dirt increase as time between street cleaning lengthens. However, it is also evident that there is a substantial residual loading on the streets immediately after the street cleaning, which differs substantially from the assumption of Sartor and Boyd that rains reduce street dirt to zero.

The San Jose study also investigated the role of different street textures, which resulted in very different street dirt loadings. Although the accumulation and deposition rates are quite similar, the initial loading values (the permanent storage values) are very different, with greater amounts of street dirt trapped by the coarser (oil and screens) pavement. Street cleaning and rains are not able to remove this residual material. The early, uncorrected Sartor and Boyd accumulation rates that ignored the initial loading values were almost ten times the corrected values that had reasonable "initial loads."

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BOX 4-8 Continued

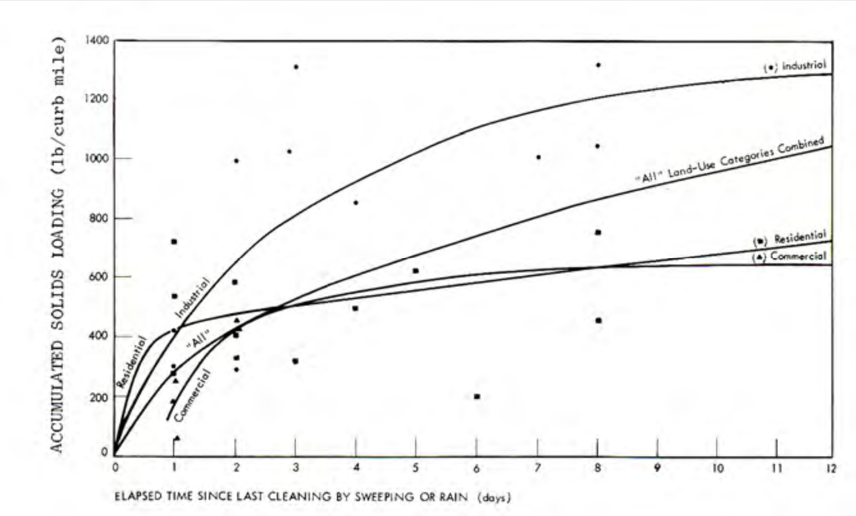

FIGURE 4-19 Accumulation curves developed during early street cleaning research. SOURCE: Sartor and Boyd (1972).

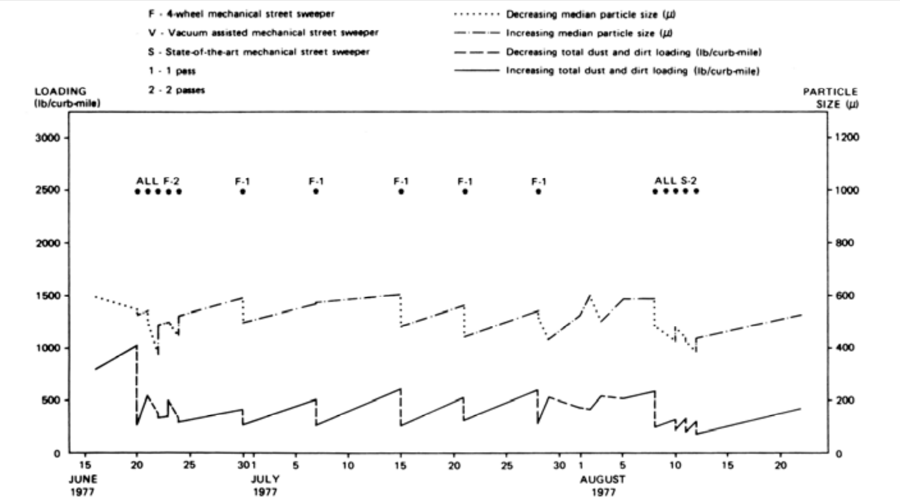

FIGURE 4-20 Street dirt accumulation and particle size changes on good asphalt streets in San Jose, California. SOURCE: Pitt (1979).

Finally, it was found that, at very long accumulation periods relative to the rain frequency, the wind losses (fugitive dust) may approximate the deposition rate, resulting in very little increases in loading. In Bellevue, Washington, with inter-event rain periods averaging about three days, steady loadings were observed after about one week (Pitt, 1985). However, in Castro Valley, California, the rain inter-event periods were much longer (ranging from about 20 to 100 days), and steady loadings were never observed (Pitt and Shawley, 1982).

Taking many studies into account (Sartor and Boyd 1972—corrected; Pitt, 1979, 1983, 1985; Pitt and Shawley, 1982; Pitt and Sutherland, 1982; Pitt and McLean, 1986), the most important factors affecting the initial loading and maximum loading values have been found to be street texture and street condition, and not land use. When data from many locations are studied, it is apparent that smooth streets have substantially less loadings at any accumulation period compared to rough streets for the same land use. Very long accumulation periods relative to the rain frequency result in high street dirt loadings. However, during these conditions the wind losses of street dirt (as fugitive dust) may approximate the deposition rate, resulting in relatively constant street dirt loadings.

Wash-off of Street Surface Pollutants

Wash-off of particulates from impervious surfaces is dependent on the available supply of particulates on the surface that can be removed by rains, the rain energy available to loosen the material, and the capacity of the runoff to transport the loosened material. Observations of particulate wash-off during controlled tests have resulted in empirical wash-off models. The earliest controlled street dirt wash-off experiments were conducted by Sartor and Boyd (1972) to estimate the percentage of the available particulates on the streets that would wash off during rains of different magnitudes. Sartor and Boyd fitted their data to an exponential curve, as shown in Figure 4-21 (accumulative wash-off curves for several particle sizes). The empirical equation that they developed, $N = N_o e^{-kR}$, is only sensitive to the total rain depth up to the time of interest and the initial street dirt loading.

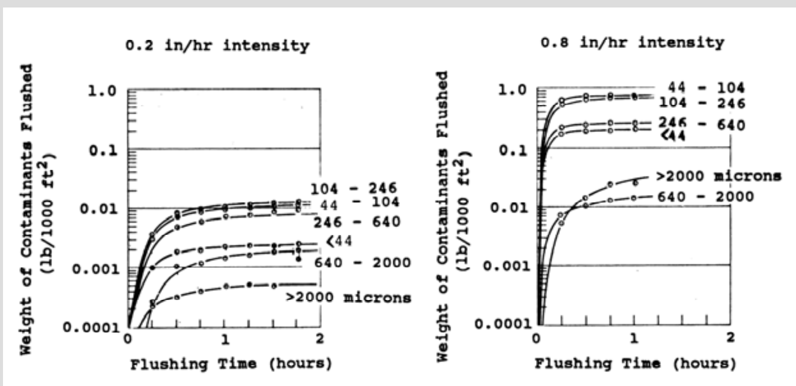

FIGURE 4-21 Street dirt wash-off during high-intensity rain tests. SOURCE: Sartor and Boyd (1972).

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BOX 4-8 Continued

There are several problems with this approach. First, these figures did not show the total street dirt loading that was present before the wash-off tests. Most modelers have assumed that the asymptotic maximum shown was the total "before-rain" street dirt loading; that is, the N_o factor has been assumed to be the total initial street loading, when in fact it is only the portion of the total street load available for wash-off (the maximum asymptotic wash-off load observed during the wash-off tests). The actual total street dirt loadings were several times greater than the maximum wash-off amounts observed. STORM and SWMM now use an availability factor (*A*) for particulate residue as a calibration procedure in order to reduce the wash-off quantity for different rain intensities (Novotny and Chesters, 1981). Second, the proportionality constant, *k*, was found by Sartor and Boyd to be slightly dependent on street texture and condition, but was independent of rain intensity and particle size. The value of this constant is usually taken as 0.18/mm, assuming that 90 percent of the particulates will be washed from a paved surface in one hour during a 13 mm/h rain. However, Alley (1981) fitted this model to watershed outfall runoff data and found that the constant varied for different storms and pollutants for a single study area. Novotny examined "before" and "after" rain-event street particulate loading data using the Milwaukee NURP stormwater data (Bannerman et al., 1983) and found almost a three-fold difference between the proportionality constant value for fine (<45 μm) and medium-sized particles (100 to 250 μm). Jewell et al. (1980) also found large variations in outfall "fitted" values for different rains compared to the typical default value. They stressed the need to have local calibration data before using the exponential wash-off equation, as the default values can be very misleading. The exponential wash-off equation for impervious areas is justified, but wash-off coefficients for each pollutant would improve its accuracy. The current SWMM5 version discourages the use of accumulation and wash-off functions due to lack of data, and the misinterpretation of available data.

It turns out that particle dislodgement and transport characteristics at impervious areas can be directly measured using relatively simple wash-off tests. The Bellevue, Washington, urban runoff project (Pitt, 1985) included about 50 pairs of street dirt loading observations close to the beginnings and ends of rains to determine the differences in loadings that may have been caused by the rains. The observations were affected by rains falling directly on the streets, along with flows and particulates originating from non-street areas. When all the data were considered together, the net loading difference was about 10 to 13 g/curb-m removed, which amounted to a street dirt load reduction of about 15 percent. Large reductions in street dirt loadings for the small particles were observed during these Bellevue rains. Most of the weight of solid material in the runoff was concentrated in fine particle sizes (<63 μm). Very few wash-off particles greater than 1,000 μm were found; in fact, street dirt loadings increased for the largest sizes, presumably due to settled erosion materials. Urban runoff outfall particle size analyses in Bellevue (Pitt, 1985) resulted in a median particle size of about 50 μm; similar results were obtained in the Milwaukee NURP study (Bannerman et al., 1983). The results make sense because the rain energy needed to remove larger particles is much greater than for small particles.

In order to clarify street dirt wash-off, Pitt (1987) conducted numerous controlled wash-off tests on city streets in Toronto. The experimental factors examined included rain intensity, street texture, and street dirt loading. The differences between available and total street dirt loads were also related to the experimental factors. The runoff flow quantities were also carefully monitored to determine the magnitude of initial and total rain water losses on impervious surfaces. The test setup was designed and tested to best represent actual rainfall conditions, such as rain intensities (3 mm/h) and peak rain intensities (12 mm/h). The kinetic energies of the "rains" during these tests were therefore comparable to actual rains under investigation. Figure 4-22 shows the asymptotic wash-off values observed in the tests, along with the measured total street dirt loadings. The maximum asymptotic values are the "available" street dirt loadings (N_o). As can be seen, the measured

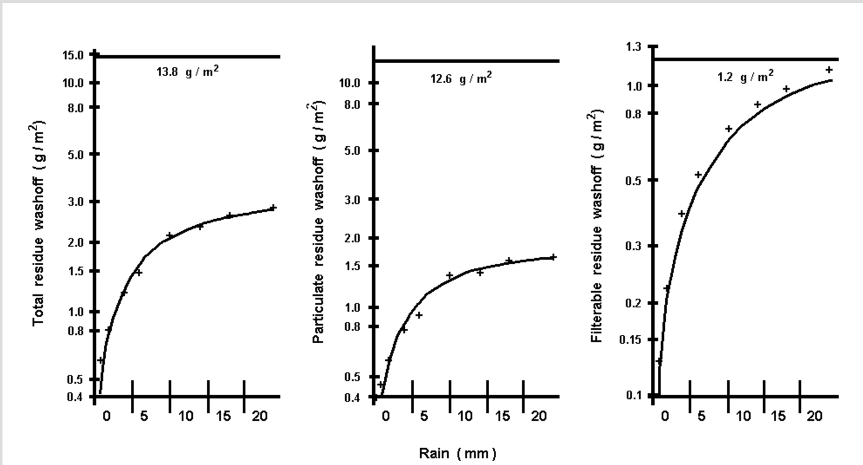

FIGURE 4-22 Wash-off plots for high rain intensity, dirty street, and smooth street test, showing the total street dirt loading. SOURCE: Pitt (1987).

total loadings are several times larger than these "available" loading values. For example, the asymptotic available total solids value for the high-intensity rain–dirty street–smooth street test was about 3 g/m^2 while the total load on the street for this test was about 14 g/m^2, or about five times the available load. The differences between available and total loadings for the other tests were even greater, with the total loads typically about ten times greater than the available loads. The total loading and available loading values for dissolved solids were quite close, indicating almost complete wash-off of the very small particles.

The availability factor (the ratio of the available loading, N_0, to the total loading) depended on the rain intensity and the street roughness, such that wash-off was more efficient for the higher rain energy and smoother pavement tests. The worst case was for a low rain intensity and rough street, where only about 4.5 percent of the street dirt would be washed from the pavement. In contrast, the high rain intensities on the smooth streets were more than four times more efficient in removing street dirt (20 percent removal).

A final important consideration in calculating wash-off of street dirt during rains is the carrying capacity of the flowing water to transport sediment. If the calculated wash-off is greater than the carrying capacity (such as would occur for relatively heavy street dirt loads and low to moderate rain intensities), then the carrying capacity is limiting. For high rain intensities, the carrying capacity is likely sufficient to transport most or all of the wash-off material. Figure 4-23 shows the maximum wash-off amounts (g/m^2) for the different tests conducted on smooth streets plotted against the rain intensity (mm/h) used for the tests (data from Sartor and Boyd, 1972, and Pitt, 1987). Wash-off limitations for rough streets would be more restrictive.

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BOX 4-8 Continued

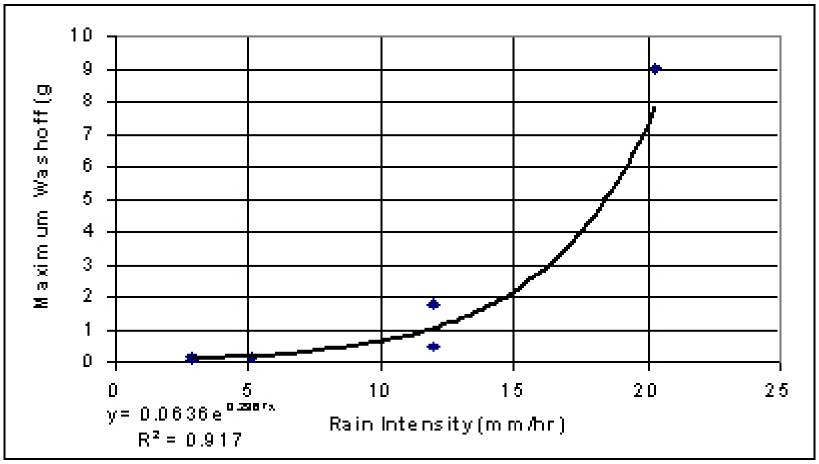

FIGURE 4-23 Maximum wash-off capacity for smooth streets (based on measurements of Sartor and Boyd, 1972; Pitt, 1987). If the predicted wash-off, using the previous "standard" wash-off equations, is smaller than the values shown in this figure, then those values can be used directly. However, if the predicted wash-off is greater than the values shown in this figure, then the values in the figure should be used.

Accumulation and Wash-off Summary

This discussion summarized street particulate wash-off observations obtained during special wash-off tests, along with associated street dirt accumulation measurements. The objectives of these tests were to identify the significant rain and street factors affecting particulate wash-off and to develop appropriate wash-off models. The controlled wash-off experiments identified important relationships between "available" and "total" particulate loadings and the significant effects of the test variables on the wash-off model parameters. Past modeling efforts have typically ignored or misused this relationship to inaccurately predict the importance of street particulate wash-off. The available loadings were almost completely washed off streets during rains of about 25 mm (as previously assumed). However, the fraction of the total loading that was available was at most only 20 percent of the total loading, and averaged only 10 percent, with resultant actual wash-offs of only about 9 percent of the total loadings.

In many model applications, total initial loading values (as usually measured during field studies) are used in conjunction with model parameters as the available loadings, resulting in predicted wash-off values that are many times larger than observed. This has the effect of incorrectly assuming greater pollutant contributions originating from streets and less from other areas during rains. This in turn results in inaccurate estimates of the effectiveness of different source area urban runoff controls. Although streets can be important sources of runoff and stormwater pollutants, their significance varies greatly depending on the land use and rainfall pattern. They are much more important sources in areas having relatively mild rains (e.g., the Pacific Northwest), where contaminants from other potential sources are not effectively transported to the storm drainage system.

source of stormwater in seasonally wet conditions (Seattle), while Cuo et al. (2008) have explored the modification of DHSVM to include detention SCMs. Xiao et al. (2007) explicitly integrated and evaluated parcel scale SCM design and efficiency into their model. Wang et al. (2008) integrated a canopy interception model with a semi-distributed subsurface moisture scheme (TOPMODEL) to evaluate the effectiveness of urban tree canopy interception on stormwater production, utilizing a detailed spatial dataset of urban tree cover. Band et al. (2001) and Law (2003) coupled a water-, carbon-, and nitrogen-cycling model to a distributed water routing system modified from DHSVM to simulate nitrogen cycling and export in a high-spatial-resolution representation of forested and suburban catchments. While these models have the potential to directly link stormwater generation with specific dischargers, the challenge of scaling to larger watersheds remains. SMDR (Easton et al., 2007) has recently been used to integrate rural and urban stormwater production, including dissolved phosphorus source and transport in New York State.

Alternatives to mass budget-based models include fully statistical approaches such as simple regressions based on watershed land use and population (e.g., Boyer et al., 2002); nonlinear regression using detailed watershed spatial data and observed loads to estimate retention parameters and loading of nutrients, sediment, and other pollutants (e.g., Smith et al., 1997; Brakebill and Preston, 1999; Schwarz et al., 2006); and Bayesian chain models (e.g., Reckhow and Chapra, 1999; Borsuk et al., 2001). These models have the advantage of being data-based, and therefore capable of assimilating observations as they become available to update water quality probabilities, but also lack a process basis that might support management intervention. A major debate exists within the literature as to the relative advantages of detailed process-based models that may not have inadequate information for parameterization, and the more empirical, data-based approaches.

Limitations in Extending Stormwater Models to Biological Impacts

The mass budget approach may be successful in developing the physical and chemical characteristics of the receiving waterbody in terms of the flow (or stage) duration curve, the distribution of concentrations over time, and the integrated pollutant storage and flux (load) terms. However, the biological status of the waterbody requires a link between the physical and chemical conditions, primary productivity, and trophic system interactions. Progressing from aquatic ecosystem productivity to trophic systems includes increasingly complex ecological processes such as competition, herbivory, predation, and migration. To date, mechanistic linkage between flow path hydraulics, biogeochemistry, and the ecological structure of the aquatic environment has not been developed. Instead, habitat suitability for different communities is identified through empirical sampling and analysis, with the implicit assumption that, as relative

TABLE 4-7 Example Mathematical Models That Have Been or Can Be Used in Stormwater Modeling

Model	Common Use	Typical Scale	Complexity	Data Requirements	Ground-water	SCM	Reference
Rational Method	Urban hydraulic design—peak flow	Small	Simple	Land cover, rainfall intensity, T_c	None	None	Standard hydrology text
Simple Method	Urban annual runoff, loads	Small to medium	Simple	Impervious surface cover, land use, annual rainfall	None	None	http://www.stormwatercenter.net/monitoring%20and%20assessment/simple%20meth/simple.htm
TR-20 TR-55	Rural/urban runoff production for simple stormwater models, hydraulic design	Small to medium	Simple to medium	Land use, soil texture, T_c	None	Pond sizing for hydraulic benefits and others through CN modification	http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models
GWLF	Rural/urban runoff, pollutant loading	Medium to watershed	Simple to medium	Land use, soil texture, precipitation time series	Simple linear reservoir	Runoff reduction with CN modification	Haith and Shoemaker (1987) http://www.avgwlf.psu.edu/overview.htm
P8	Urban runoff, pollutant loading	Small to large	Simple to medium	Land use, soil texture, precipitation time series, SCM type and sizing	Simple linear reservoir	Runoff reduction with CN modification, ponds (evaluation and sizing), infiltration, street cleaning	Palmstrom and Walker (1990) http://www.wwwalker.net/p8/
MUSIC	Urban runoff, pollutant loading, hydraulic design, simple receiving water	Small to large	Medium to complex	Land use, soil texture, precipitation/PET? time series, drainage system details, SCM type and sizing	Simple linear reservoir	Comprehensive evaluation of SCM systems	Wong (2000) (proprietary) http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit.woa/wa/productDetails?productID=1000000

SWMM	Urban runoff, pollutant loading, hydraulic design	Small to large	Medium to complex	Land use, soil texture, meteorological time series, drainage system details, SCM type and sizing	Simple linear reservoir?	Infiltration practices, ponds, street cleaning	http://www.epa.gov/ednnrmrl/models/swmm
PCSWMM	Same as above	Same as above	Same as above	Same as above	Same as above	Enhanced SCM compared to SWMM	(proprietary) http://www.computationalhydraulics.com/Software/PCSWMM.NET
WinSLAMM	Urban runoff, pollutant loads	Small to large	Intermediate	Land cover, land use, development characteristics, soil texture, compaction, rainfall event time series, monthly PET, monthly water evaporation, SCM type and sizing	Mounding under infiltration controls	Comprehensive evaluation of SCM systems	(proprietary) http://www.winslamm.com/prod01.htm
SWAT	Rural runoff, loading	Medium to watershed	Intermediate	Land cover/land use, soil texture, precipitation, temperature, humidity, solar radiation time or PET series	Simple subbasin reservoir	Impoundments, agricultural conservation practices, nutrient management, buffers	http://www.epa.gov/waterscience/BASINS/bsnsdocs.html#swat
HSPF	Comprehensive watershed evaluation, receiving water dynamics	Medium to watershed	Complex	Land cover/land use, soil texture, precipitation, temperature, humidity, solar radiation or PET time series	Subbasin reservoir	Infiltration, ponds	Bicknell et al. (2005) http://www.epa.gov/ceampubl/swater/hspf/index.htm http://www.epa.gov/waterscience/BASINS/bsnsdocs.html#hspf
WWHM	HSPF engine with regional modifications,	Puget Sound	Complex	Same as above	Same as above	Enhanced infiltration, ponds (from HSPF)	http://www.ecy.wa.gov/programs/wg/stormwater/wwhm_training/index.html.
CBWM	HSPF engine with regional modifications,	Chesapeake Bay Watershed	Complex	Same as above	Same as above	Enhanced infiltration, ponds (from HSPF)	http://www.chesapeakebay.net/phase5.htm

Note: CN, curve number

habitat suitability changes, transitions will occur between species or assemblages. These methods may work well at the base of the trophic system (algae, phytoplankton) and for specific conditions such as DO limitations on fish communities, but the impacts of low to moderate concentrations of pollutants on aquatic ecosystems may still be poorly understood. A critical assumption in these and similar models (e.g., ecological community change resulting from physical changes to the watershed or climate) is the substitution of space for time. More detailed understanding of the mechanisms leading to a shift in ecological communities and interactions with the physical environment is necessary to develop models of transient change, stability of the shifts, and feedback to the biophysical environment.

Given these limitations, it should be noted that statistical databases on species tolerance to a range of aquatic conditions have been compiled that will allow the development of habitat suitability mapping as a mechanism for (1) targeting ecosystem restoration, (2) determining vulnerable sites (for use in application of the Endangered Species Act), and (3) assessing aquatic ecosystem impairment and "best use" relative to reference sites.

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Stormwater models have been developed to meet a range of objectives, including small-scale hydraulic design (e.g., siting and sizing a detention pond), estimation of potential contributions of stormwater pollutants from different land covers and locations using empirically generated EMC, and large watershed hydrology and gross pollutant loading. The ability to associate a given discharger with a particular waterbody impairment is limited by the scale and complexity of watersheds (i.e., there maybe multiple discharge interactions); by the ability of a model to accurately reproduce the distribution function of discharge events and their cumulative impacts (as opposed to focusing only on design storms of specific return periods); and by the availability of monitoring data of sufficient number and design to characterize basic processes (e.g., build-up/wash-off), to parameterize the models, and to validate model predictions.

In smaller urban catchments with few dominant dischargers and significant impervious area, current modeling capabilities may be sufficient to associate the cumulative impact of discharge to waterbody impairment. However, many impaired waterbodies have larger, more heterogeneous stormwater sources, with impacts that are complex functions of current and past conditions. The level of sampling that would be necessary to support linked model calibration and verification using current measurement technologies is both time-consuming and expensive. In order to develop a more consistent capability to support stormwater permitting needs, there should be increased investment in improving model paradigms, especially the practice and methods of model linkage as described above, and in stormwater monitoring. The latter may require investment in a new generation of sensors that can sample at temporal resolutions that can adjust to characterize low flow and the dynamics of storm flow, but are sufficiently inexpensive and autonomous to be deployed in multiple locations from distributed sources to receiving waterbodies of interest. Finally, as urban areas extend to encompass progressively lower-density development, the interactions of surface water and groundwater become more critical to the cumulative impact of stormwater on impaired waterbodies.

EPA needs to ensure continuous support and development of their water quality models and spatial data infrastructure. Beyond this, a set of distributed watershed models has been developed that can resolve the location and position of parcels within hydrologic flow fields; these are being modified for use as urban stormwater models. These models avoid the pitfalls of lumping, but they require much greater volumes of spatial data, provided by current remote sensing technology (e.g., lidar, airborne digital optical and infrared sensors) as well as the emerging set of in-stream sensor systems. While these methods are not yet operational or widespread, they should be further investigated and tested for their capabilities to support stormwater management.

CONCLUSIONS AND RECOMMENDATIONS

This chapter addresses what might be the two weakest areas of the stormwater program—monitoring and modeling of stormwater. The MS4 and particularly the industrial stormwater monitoring programs suffer from (1) a paucity of data, (2) inconsistent sampling techniques, (3) a lack of analyses of available data and guidance on how permittees should be using the data to improve stormwater management decisions, and (4) requirements that are difficult to relate to the compliance of individual dischargers. The current state of stormwater modeling is similarly limited. Stormwater modeling has not evolved enough to consistently say whether a particular discharger can be linked to a specific waterbody impairment, although there are many correlative studies showing how parameters co-vary in important but complex and poorly understood ways (see Chapter 3). Some quantitative predictions can be made, particularly those that are based on well-supported causal relationships of a variable that responds to changes in a relatively simple driver (e.g., modeling how a runoff hydrograph or pollutant loading change in response to increased impervious land cover). However, in almost all cases, the uncertainty in the modeling and the data, the scale of the problems, and the presence of multiple stressors in a watershed make it difficult to assign to any given source a specific contribution to water quality impairment. More detailed conclusions and recommendations about monitoring and modeling are given below.

Because of a ten-year effort to collect and analyze monitoring data from MS4s nationwide, the quality of stormwater from urbanized areas is well characterized. These results come from many thousands of storm events, systematically compiled and widely accessible; they form a robust dataset of utility to theoreticians and practitioners alike. These data make it possible to accurately estimate the EMC of many pollutants. Additional data are available from other stormwater permit holders that were not originally included in the database and from ongoing projects, and these should be acquired to augment the database and improve its value in stormwater management decision-making.

Industry should monitor the quality of stormwater discharges from certain critical industrial sectors in a more sophisticated manner, so that permitting authorities can better establish benchmarks and technology-based effluent guidelines. Many of the benchmark monitoring requirements and effluent guidelines for certain industrial subsectors are based on inaccurate and old information. Furthermore, there has been no nationwide compilation and analysis of industrial benchmark data, as has occurred for MS4 monitoring data, to better understand typical stormwater concentrations of pollutants from various industries. The absence of accurate benchmarks and effluent guidelines for critical industrial sectors discharging stormwater may explain the lack of enforcement by permitting authorities, as compared to the vigorous enforcement within the wastewater discharge program.

Industrial monitoring should be targeted to those sites having the greatest risk associated with their stormwater discharges. Many industrial sites have no or limited exposure to runoff and should not be required to undertake extensive monitoring. Visual inspections should be made, and basic controls should be implemented at these areas. Medium-risk industrial sites should conduct monitoring so that a sufficient number of storms are measured over the life of the permit for comparison to regional benchmarks. Again, visual inspections and basic controls are needed for these sites, along with specialized controls to minimize discharges of the critical pollutants. Stormwater from high-risk industrial sites needs to be continuously monitored, similar to current point source monitoring practices. The use of a regionally calibrated stormwater model and random monitoring of the lower-risk areas will likely require additional monitoring.

Continuous, flow-weighted sampling methods should replace the traditional collection of stormwater data using grab samples. Data obtained from too few grab samples are highly variable, particularly for industrial monitoring programs, and subject to greater uncertainly because of experimenter error and poor data-collection practices. In order to use stormwater data for decision making in a scientifically defensible fashion, grab sampling should be abandoned as a credible stormwater sampling approach for virtually all applications. It should be replaced by more accurate and frequent continuous sampling methods that are flow weighted. Flow-weighted composite monitoring should continue for the duration of the rain event. Emerging sensor systems that provide high temporal resolution and real-time estimates for specific pollutants should be further investigated, with the aim of providing lower costs and more extensive monitoring systems to sample both streamflow and constituent loads.

Flow monitoring and on-site rainfall monitoring need to be included as part of stormwater characterization monitoring. The additional information associated with flow and rainfall data greatly enhance the usefulness of the much more expensive water quality monitoring. Flow monitoring should also be correctly conducted, with adequate verification and correct base-flow subtraction methods applied. Using regional rainfall data from locations distant from the monitoring location is likely to be a major source of error when rainfall factors are being investigated. The measurement, quality assurance, and maintenance of long-term precipitation records are both vital and nontrivial to stormwater management.

Whether a first flush of contaminants occurs at the start of a rainfall event depends on the intensity of rainfall, the land use, and the specific pollutant. First flushes are more common for smaller sites with greater imperviousness and thus tend to be associated with more intense land uses such as commercial areas. Even though a site may have a first flush of a constituent of concern, it is still important that any SCM be designed to treat as much of the runoff from the site as possible. In many situations, elevated discharges may occur later in an event associated with delayed periods of peak rainfall intensity.

Stormwater runoff in arid and semi-arid climates demonstrates a seasonal first-flush effect (i.e., the dirtiest storms are the first storms of the season). In these cases, it is important that SCMs are able to adequately handle these flows. As an example, early spring rains mixed with snowmelt may occur during periods when wet detention ponds are still frozen, hindering their performance. The first fall rains in the southwestern regions of the United States may occur after extended periods of dry weather. Some SCMs, such as street cleaning targeting leaf removal, may be more effective before these rains than at other times of the year.

Watershed models are useful tools for predicting downstream impacts from urbanization and designing mitigation to reduce those impacts, but they are incomplete in scope and typically do not offer definitive causal links between polluted discharges and downstream degradation. Every model simulates only a subset of the multiple interconnections between physical, chemical, and biological processes found in any watershed, and they all use a grossly simplified representation of the true spatial and temporal variability of a watershed. To speak of a "comprehensive watershed model" is thus an oxymoron, because the science of stormwater is not sufficiently far advanced to determine causality between all sources, resulting stressors, and their physical, chemical, and biological responses. Thus, it is not yet possible to create a protocol that mechanistically links stormwater dischargers to the quality of receiving waters. The utility of models with more modest goals, however, can still be high—as long as the questions being addressed by the model are in fact relevant and important to the functioning of the watershed to which that model is being applied, and sufficient data are available to calibrate the model for the processes included therein.

EPA needs to ensure that the modeling and monitoring capabilities of the nation are continued and enhanced to avoid losing momentum in understanding and eliminating stormwater pollutant discharges. There is a need to extend, develop, and support current modeling capabilities, emphasizing (1) the impacts of flow energy, sediment transport, contaminated sediment, and acute and chronic toxicity on biological systems in receiving waterbodies; (2) more mechanistic representation (physical, chemical, biological) of SCMs; and (3) coupling between a set of functionally specific models to promote the linkage of source, transport and transformation, and receiving water impacts of stormwater discharges. Stormwater models have typically not incorporated interactions with groundwater and have treated infiltration and recharge of groundwater as a loss term with minimal consideration of groundwater contamination or transport to receiving waterbodies. Emerging distributed modeling paradigms that simulate interactions of surface and subsurface flowpaths provide promising tools that should be further developed and tested for applications in stormwater analysis.

REFERENCES

Adams, B., and F. Papa. 2000. Urban Stormwater Management Planning with Analytical Probabilistic Methods. New York: John Wiley and Sons.

Alexander, R. B., R. A. Smith, and G. E. Schwarz. 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. Nature 403:758–761.

Alley, W. M. 1981. Estimation of impervious-area washoff parameters. Water Resources Research 17(4):1161–1166.

Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams. 1998. Large area hydrologic modeling and assessment Part I: Model development. Journal of the American Water Resources Association 34(1):73e89.

Band, L. E., P. Patterson, R. R. Nemani, and S. W. Running. 1993. Forest ecosystem processes at the watershed scale: 2. Adding hillslope hydrology. Agricultural and Forest Meteorology 63:93–126.

Band, L. E., C. L. Tague, P. Groffman, and K. Belt. 2001. Forest ecosystem processes at the watershed scale: hydrological and ecological controls of nitrogen export. Hydrological Processes 15:2013–2028.

Bannerman, R., K. M. Baun, P. E. Bohn, and D. A. Graczyk. 1983. Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin. PB 84-114164. Chicago: EPA.

Bannerman, R. T., D. W. Owens, R. B. Dodds, and N. J. Hornewer. 1993. Sources of pollutants in Wisconsin stormwater. Water Science and Technology 28(3–5):241–259.

Batroney, T. 2008. The Implications of the First Flush Phenomenon on Infiltration BMP Design. Master's Thesis. Water Resources and Environmental Engineering, Villanova University, Villanova, PA, May.

Beven, K. J. 2000. On the future of distributed modelling in hydrology. Hydrological Processes 14:3183–3184.

Beven, K. J. 2001. Dalton Medal Lecture: How far can we go in distributed hydrological modelling? Hydrology and Earth System Sciences 5(1):1–12.

Bicknell, B. R., J. C. Imhoff, J. L. Kittle, Jr., A. S. Donigian, Jr., and R. C. Johanson. 1997. Hydrological Simulation Program—Fortran, User's manual for version 11. EPA/600/R-97/080. Athens, GA: EPA National Exposure Research Laboratory.

Bicknell, B. R., J. C. Imhoff, J. L. Kittle, Jr., T. H. Jobes, and A. S. Donigian, Jr. 2005. HSPF Version 12.2 User's Manual. AQUA TERRA Consultants, Mountain View, CA. In cooperation with Office of Surface Water, Water Resources Discipline, U.S. Geological Survey, Reston, VA, and National Exposure Research Laboratory Office of Research and Development, EPA, Athens, GA.

Borsuk, M. E., D. Higdon, C. A. Stow, and K. H. Reckhow. 2001. A Bayesian hierarchical model to predict benthic oxygen demand from organic matter loading in estuaries and coastal zones. Ecological Modeling 143:165–181.

Boyer, E. W., C. L. Goodale, N. A. Jaworski, and R.W. Howarth. 2002. Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA. Biogeochemistry 57:137–169.

Boyer, E. W., R. B. Alexander, W. J. Parton, C. Li, K. Butterbach-Bahl, S. D. Donner, R. W. Skaggs, and S. J. Del Grosso. 2006. Modeling denitrification in terrestrial and aquatic ecosystems at regional scales. Ecological Applications 16:2123–2142.

Brakebill, J. W., and S. E. Preston. 1999. Digital Data Used to Relate Nutrient Inputs to Water Quality in the Chesapeake Bay Watershed, Version 1.0. U.S. Geological Survey Water Open-File Report 99-60.

Brown, T., W. Burd, J. Lewis, and G. Chang. 1995. Methods and procedures in stormwater data collection. *In:* Stormwater NPDES Related Monitoring Needs. H. C. Torno (ed.). Reston, VA: Engineering Foundation and ASCE.

Burgess, S. J., M. S. Wigmosta, and J. M. Meena. 1998. Hydrological effects of land-use change in a zero-order catchment. Journal of Hydrological Engineering ASCE 3:86–97.

Burton, G. A., Jr., and R. Pitt. 2002. Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers. Boca Raton, FL: CRC Press, 911 pp.

Chiew, F. H. S., and T. A. McMahon. 1997. Modelling daily runoff and pollutant load from urban catchments. Water (AWWA Journal) 24:16–17.

Chow, V. T., D. R. Maidment, and L. W. Mays. 1988. Applied Hydrology. McGraw Hill.

Clark, S. E., C. Y. S. Siu, R. E. Pitt, C. D. Roenning, and D. P. Treese. 2008. Peristaltic pump autosamplers for solids measurement in stormwater runoff.

Water Environment Research 80. doi:10.2175/106143008X325737.

Cross, L. M., and L. D. Duke. 2008. Regulating industrial stormwater: state permits, municipal implementation, and a protocol for prioritization. Journal of the American Water Resources Association 44(1):86–106.

Cuo, L., D. P. Lettenmaier, B. V. Mattheussen, P. Storck, and M. Wiley. 2008. Hydrologic prediction for urban watersheds with the Distributed Hydrology-Soil-Vegetation-Model. Hydrological Processes, DOI: 10.1002/hyp.7023

Deletic, A. 1998. The first flush load of urban surface runoff. Water Research 32(8):2462–2470.

Easton, Z. M., P. Gérard-Marchant, M. T. Walter, A. M. Petrovic, and T. S. Steenhuis. 2007. Hydrologic assessment of an urban variable source watershed in the northeast United States. Water Resources Research 43:W03413, doi:10.1029/2006WR005076.

EPA (U.S. Environmental Protection Agency). 1983. Results of the Nationwide Urban Runoff Program. PB 84-185552. Washington, DC: Water Planning Division.

Gibbons, J., and S. Chakraborti. 2003. Nonparametric Statistical Inference, 4th edition. New York: Marcel Dekker, 645 pp.

Haith, D. A., and L. L. Shoemaker. 1987. Generalized watershed loading functions for stream flow nutrients. Water Resources Bulletin 23(3):471–478.

Horwatich, J., R. Bannerman, and R. Pearson. 2008. Effectiveness of Hydrodynamic Settling Device and a Stormwater Filtration Device in Milwaukee, Wisconsin. U.S. Geological Survey Investigative Report. Middleton, WI: USGS.

Jewell, T. K., D. D. Adrian, and D. W. Hosmer. 1980. Analysis of stormwater pollutant washoff estimation techniques. International Symposium on Urban Storm Runoff. University of Kentucky, Lexington, KY.

Kirsch, K. J. 2000. Predicting Sediment and Phosphorus Loads in the Rock River Basin Using SWAT. Presented at the ASAE International Meeting, Paper 002175. July 9–12. St. Joseph, MI: ASAE.

Law, N. L. 2003. Sources and Pathways of Nitrate in Urbanizing Watersheds. Ph.D. Dissertation Proposal, Department of Geography, University of North Carolina at Chapel Hill.

Lee, H., X. Swamikannu, D. Radulescu, S. Kim, and M. K. Stenstrom. 2007. Design of stormwater monitoring programs. Journal of Water Research, doi:10.1016/j.watres.2007.05.016.

Maestre, A., and R. Pitt. 2005. The National Stormwater Quality Database, Version 1.1. A Compilation and Analysis of NPDES Stormwater Monitoring Information. Washington, DC: EPA Office of Water.

Maestre, A., and R. Pitt. 2006. Identification of significant factors affecting stormwater quality using the National Stormwater Quality Database. Pp. 287–326 *In:* Stormwater and Urban Water Systems Modeling, Monograph 14. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Maestre, A., R. E. Pitt, and D. Williamson. 2004. Nonparametric statistical tests comparing first flush with composite samples from the NPDES Phase 1 municipal stormwater monitoring data. Stormwater and urban water systems modeling. Pp. 317–338 *In:* Models and Applications to Urban Water Systems, Vol. 12. W. James (ed.). Guelph, Ontario: CHI.

Maestre, A., R. Pitt, S. R. Durrans, and S. Chakraborti. 2005. Stormwater quality descriptions using the three parameter lognormal distribution. Stormwater and urban water systems modeling. *In:* Models and More for Urban Water Systems, Monograph 13. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Mahler, B. J., P. C. VanMetre, T. J. Bashara, J. T. Wilson, and D. A. Johns. 2005. Parking lot sealcoat: An unrecognized source of urban polycyclic aromatic hydrocarbons. Environmental Science and Technology 39:5560–5566.

Maxwell, R. H., and M. Miller. 2005. Development of a coupled land surface and groundwater model. Journal Hydrometeorology 6:233–247.

McClain, M. E., E. W. Boyer, C. L. Dent, S. E. Gergel, N. B. Grimm, P. M. Groffman, S. C. Hart, J. W. Harvey, C. A. Johnston, E. Mayorga, W. H. McDowell, and G. Pinay. 2003. Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems . Ecosystems 6:301–312.

MDE (Maryland Department of the Environment). 2000. 2000 Maryland Stormwater Design Manual, Volumes I & II. Prepared by the Center for Watershed Protection and the Maryland Department of the Environment, Water Management Administration, Baltimore, MD.

Novotny, V., and G. Chesters. 1981. Handbook of Nonpoint Pollution Sources and Management. New York: Van Nostrand Reinhold.

Oreskes, N., Shrader-Frechette K., Belitz, K. 1994. Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences. Science, New Series, 263(5147):641-646.

PaDEP (Pennsylvania Department of Environmental Protection). 2006. Pennsylvania Stormwater Best Management Practices Manual. Harrisburg, PA: Pennsylvania Department of Environmental Protection.

Palmstrom, N., and W. Walker. 1990. The P8 Urban Catchment Model for Evaluating Nonpoint Source Controls at the Local Level. Enhancing States' Lake Management Programs, USEPA.

Pitt, R. 1979. Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices. EPA-600/2-79-161 Cincinnati, OH: EPA Office of Research and Development.

Pitt, R. 1983. Urban Bacteria Sources and Control in the Lower Rideau River Watershed. Ottawa, Ontario: Ontario Ministry of the Environment.

Pitt, R. 1985. Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning. EPA/600/S2-85/038. PB 85-186500. Cincinnati, OH: EPA. Storm and Combined Sewer Program. Risk Reduction Engineering Laboratory.

Pitt, R. 1986. The incorporation of urban runoff controls in the Wisconsin Priority Watershed Program. Pp. 290–313 *In:* Advanced Topics in Urban Runoff Research. B. Urbonas and L. A. Roesner (eds.). New York: Engineering Foundation and ASCE.

Pitt, R. 1987. Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges. Ph.D. Dissertation. Department of Civil and Environmental Engineering, University of Wisconsin–Madison.

Pitt, R., and J. McLean. 1986. Toronto Area Watershed Management Strategy Study. Humber River Pilot Watershed Project. Toronto, Ontario: Ontario Ministry of the Environment.

Pitt, R., and G. Shawley. 1982. A Demonstration of Nonpoint Source Pollution Management on Castro Valley Creek. Alameda County Flood Control and Water Conservation District (Hayward, CA) for the Nationwide Urban Runoff Program. Washington, DC: EPA, Water Planning Division.

Pitt, R., and R. Sutherland. 1982. Washoe County Urban Stormwater Management Program. Reno, NV: Washoe Council of Governments.

Pitt, R., and J. Voorhees. 1995. Source loading and management model (SLAMM). Pp. 225–243 *In:* Seminar Publication: National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels. March 30–April 2, 1993. EPA/625/R-95/003. Cincinnati, OH: EPA Center for Environmental Research Information.

Pitt, R., and J. Voorhees. 2002. SLAMM, the Source Loading and Management Model. Pp. 103–139 *In:* Wet-Weather Flow in the Urban Watershed. R. Field and D. Sullivan (eds.). Boca Raton, FL: CRC Press.

Pitt, R., A. Maestre, H. Hyche, and N. Togawa. 2008. The updated National Stormwater Quality Database (NSQD), Version 3. Conference CD. 2008 Water Environment Federation Technical Exposition and Conference, Chicago, IL.

Pitt, R. S., Clark, J. Lantrip, and J. Day. 1998. Telecommunication Manhole Water and Sediment Study; Vol. 1: Evaluation of Field Test Kits, 483 pp.; Vol. 2: Water and Sediment Characteristics, 1290 pp.; Vol. 3: Discharge Evaluation Report, 218 pp.; Vol. 4: Treatment of Pumped Water, 104 pp. Special Report SR-3841. Morriston, NJ: Bellcore, Inc.

Pitt, R., A. Maestre, and R. Morquecho. 2003. Evaluation of NPDES Phase I municipal stormwater monitoring data. *In:* National Conference on Urban Stormwater: Enhancing the Programs at the Local Level. EPA/625/R-03/003.

Pitt, R. E., A. Maestre, R. Morquecho, and D. Williamson. 2004. Collection and examination of a municipal separate storm sewer system database. Stormwater and Urban Water Systems Modeling. Pp. 257–294 *In:* Models and Applications to Urban Water Systems, Vol. 12. W. James (eds.). Guelph, Ontario: CHI.

Pitt, R., R. Bannerman, S. Clark, and D. Williamson. 2005a. Sources of pollutants in urban areas (Part 1)—Older monitoring projects. Pp. 465–484 and

507–530 *In:* Effective Modeling of Urban Water Systems, Monograph 13. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Pitt, R., R. Bannerman, S. Clark, and D. Williamson. 2005b. Sources of pollutants in urban areas (Part 2)—Recent sheetflow monitoring results. Pp. 485–530 *In:* Effective Modeling of Urban Water Systems, Monograph 13. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt (eds.). Guelph, Ontario: CHI.

Qu, Y., and C. J. Duffy. 2007. A semidiscrete finite volume formulation for multiprocess watershed simulation. Water Resources Research 43:W08419, doi:10.1029/2006WR005752.

Rallison, R. K. 1980. Origin and evolution of the SCS runoff equation. Pp. 912–924 *In:* Proceedings of Symposium on Watershed Management, Boise, Idaho. New York: American Society of Civil Engineers.

Ramaswami, A., J. B. Milford, and M. J. Small. 2005. Integrated Environmental Modeling: Pollutant Transport, Fate, and Risk in the Environment. New York: John Wiley and Sons.

Reckhow, K. H., and S. C. Chapra. 1999. Modeling excessive nutrient loading in the environment. Environmental Pollution 100:197–207.

Roa-Espinosa, A., and R. Bannerman. 1994. Monitoring BMP effectiveness at industrial sites. Pp. 467–486 *In:* Proceedings of Engineering Foundation Conference, Stormwater NPDES Related Monitoring Needs. H. C. Torno (ed.).

Sartor, J., and G. Boyd. 1972. Water Pollution Aspects of Street Surface Contaminants. EPA-R2-72-081.

Schnoor, J. L. 1996. Environmental Modeling: Fate and Transport of Pollutants in Water, Air, and Soil. New York: John Wiley and Sons.

Schwarz, G. E., A. B. Hoos, R. B. Alexander, and R. A. Smith. 2006. The SPARROW surface water-quality model: theory, application, and user documentation. U.S. Geological Survey Techniques and Methods Report, Book 6, Chapter B3.

Selbig, W. R., and R. T. Bannerman. 2007. Evaluation of Street Sweeping as a Stormwater-Quality-Management Tool in Three Residential Basins in Madison, Wisconsin. USGS Scientific Investigations Report 2007-5156, 103 pp.

Shaver, E., R. Horner, J. Skupien, C. May, and G. Ridley. 2007. Fundamentals of Urban Runoff Management: Technical and Institutional Issues, 2nd edition. Madison, WI: EPA and North American Lake Management Society, 237 pp.

Smith, R. A., G. E. Schwarz, and R. B. Alexander. 1997. Regional interpretation of water-quality monitoring data. Water Resources Research 33(12):2781–2798.

Soeur, C., J. Hubka, and G. Chang. 1995. Methods for assessing urban storm water pollution. Pp. 558 *In:* Stormwater NPDES Related Monitoring Needs. H. C. Torno (ed.). Reston, VA: Engineering Foundation and

ASCE.

Stenstrom, M. 2007. The Future of Industrial Stormwater Monitoring or, What Are Some Pitfalls and Ways We Can Improve Monitoring, for Industries and Others as Well. Presentation to the NRC Committee on Reducing Stormwater Discharge Contributions to Water Pollution. December 17, Irvine, CA.

Stenstrom, M. K., and H. Lee. 2005. Final Report. Industrial Stormwater Monitoring Program. Existing Statewide Permit Utility and Proposed Modifications.

Tague, C. L., and L. E. Band. 2004. RHESSys: Regional Hydro-Ecologic Simulation System—An object-oriented approach to spatially distributed modeling of carbon, water, and nutrient cycling. Earth Interactions 8:1–42.

TetraTech. 2003. B. Everett Jordan Lake TMDL Watershed Model Development. NC DWQ Contract No. EW030318, Project Number 1-2.

Wang, J., T. A. Endrenyi, and D. J. Nowak. 2008. Mechanistic simulation of tree canopy effects in an urban water balance model. Hydrological Processes 44:75–85.

WEF and ASCE. 1998. Urban Runoff Quality Management. WEF Manual Practice No. 23. ASCE Manual and Report on Engineering Practice No. 87. Reston, VA.

Wigmosta, M. S., L. W. Vail, and D. A. Lettenmaier. 1994. A distributed hydrology-vegetation model for complex terrain. Water Resources Research 30:1665–1679.

Wong, T. H. F. 2000. Improving Urban Stormwater Quality–From Theory to Implementation. Journal of the Australian Water Association 27(6):28–31.

Wong, T. H. F., H. P. Duncan, T. D. Fletcher, G. A. Jenkins, and J. R. Coleman. 2001. A Unified Approach to Modeling Urban Stormwater Treatment. Paper presented at the Second South Pacific Stormwater Conference, Auckland, June 27–29, pp. 319–327.

Wright, T., C. Swann, K. Cappiella, and T. Schueler. 2005. Urban Subwatershed Restoration Manual No. 11: Unified Subwatershed and Site Reconnaissance: A User's Manual (Version 2.0). Ellicott City, MD: Center for Watershed Protection.

Xiao, Q., E. G. McPherson, J. R. Simpson, S. L. Ustin and Mo. 2007. Hydrologic processes at the urban residential scale. Hydrological Processes 21:2174-2188.

5
Stormwater Management Approaches

A fundamental component of the U.S. Environmental Protection Agency's (EPA) Stormwater Program, for municipalities as well as industries and construction, is the creation of stormwater pollution prevention plans. These plans invariably document the stormwater control measures that will be used to prevent the permittee's stormwater discharges from degrading local waterbodies. Thus, a consideration of these measures—their effectiveness in meeting different goals, their cost, and how they are coordinated with one another—is central to any evaluation of the Stormwater Program. This report uses the term stormwater control measure (SCM) instead of the term best management practice (BMP) because the latter is poorly defined and not specific to the field of stormwater.

The committee's statement of task asks for an evaluation of the relationship between different levels of stormwater pollution prevention plan implementation and in-stream water quality. As discussed in the last two chapters, the state of the science has yet to reveal the mechanistic links that would allow for a full assessment of that relationship. However, enough is known to design systems of SCMs, on a site scale or local watershed scale, to lessen many of the effects of urbanization. Also, for many regulated entities the current approach to stormwater management consists of choosing one or more SCMs from a preapproved list. Both of these facts argue for the more comprehensive discussion of SCMs found in this chapter, including information on their characteristics, applicability, goals, effectiveness, and cost. In addition, a multitude of case studies illustrate the use of SCMs in specific settings and demonstrate that a particular SCM can have a measurable positive effect on water quality or a biological metric. The discussion of SCMs is organized along the gradient from the rooftop to the stream. Thus, pollutant and runoff prevention are discussed first, followed by runoff reduction and finally pollutant reduction.

HISTORICAL PERSPECTIVE ON STORMWATER CONTROL MEASURES

Over the centuries, SCMs have met different needs for cities around the world. Cities in the Mesopotamian Empire during the second millennium BC had practices for flood control, to convey waste, and to store rain water for household and irrigation uses (Manor, 1966) (see Figure 5-1). Today, SCMs are considered a vital part of managing flooding and drainage problems in a city. What is relatively new is an emphasis on using the practices to remove pollutants from stormwater and selecting practices capable of providing groundwater recharge. These recent expectations for SCMs are not readily accepted and require an increased commitment to the proper design and maintenance of the practices.

With the help of a method for estimating peak flows (the Rational Method, see Chapter 4), the modern urban drainage system came into being soon after World War II. This generally consisted of a system of catch basins and pipes to prevent flooding and drainage problems by efficiently delivering runoff water to the nearest waterbody. However, it was soon realized that delivering the water too quickly caused severe downstream flooding and bank erosion in the receiving water. To prevent bank erosion and provide more space for flood waters, some stream channels were enlarged and lined with concrete (see Figure 5-2). But while hardening and enlarging natural channels is a cost-effective solution to erosion and flooding, the modified channel increases downstream peak flows and it does not provide habitat to support a healthy aquatic ecosystem.

FIGURE 5-1 Cistern tank, Kamiros, Rhodes (ancient Greece, 7th century BC). SOURCE: Robert Pitt, University of Alabama.

FIGURE 5-2 Concrete channel in Lincoln Creek, Milwaukee, Wisconsin. SOURCE: Roger Bannerman, Wisconsin Department of Natural Resources.

Some way was needed to control the quantity of water reaching the end of pipes during a runoff event, and on-site detention (Figure 5-3) became the standard for accomplishing this. Ordinances started appearing in the early 1970s, requiring developers to reduce the peaks of different size storms, such as the 10-year, 24-hour storm. The ordinances were usually intended to prevent future problems with peak flows by requiring the installation of flow control structures, such as detention basins, in new developments. Detention basins can control peak flows directly below the point of discharge and at the property boundary. However, when designed on a site-by-site basis without taking other basins into account, they can lead to downstream flooding problems because volume is not reduced (McCuen, 1979; Ferguson, 1991; Traver and Chadderton, 1992; EPA, 2005d). In addition, out of concerns for clogging, openings in the outlet structure of most basins are generally too large to hold back flows from smaller, more frequent storms. Furthermore, low-flow channels have been constructed or the basins have been graded to move the runoff through the structure without delay to prevent wet areas and to make it easier to mow and maintain the detention basin.

Because of the limitations of on-site detention, infiltration of urban runoff to control its volume has become a recent goal of stormwater management. Without stormwater infiltration, municipalities in wetter regions of the country can expect drops in local groundwater levels, declining stream base flows (Wang et al., 2003a), and flows diminished or stopped altogether from springs feeding wetlands and lakes (Leopold, 1968; Ferguson, 1994).

FIGURE 5-3 On-site detention. SOURCE: Tom Schueler, Chesapeake Stormwater Network, Inc.

The need to provide volume control marked the beginning of low-impact development (LID) and conservation design (Arendt, 1996; Prince George's County, 2000), which were founded on the seminal work of landscape architect Ian McHarg and associates decades earlier (McHarg and Sutton, 1975; McHarg and Steiner, 1998). The goal of LID is to allow for development of a site while maintaining as much of its natural hydrology as possible, such as infiltration, frequency and volume of discharges, and groundwater recharge. This is accomplished with infiltration practices, functional grading, open channels, disconnection of impervious areas, and the use of fewer impervious surfaces. Much of the LID focus is to manage the stormwater as close as possible to its source—that is, on each individual lot rather than conveying the runoff to a larger regional SCM. Individual practices include rain gardens (see Figure 5-4), disconnected roof drains, porous pavement, narrower streets, and grass swales. In some cases, LID site plans still have to include a method for passing the larger storms safely, such as a regional infiltration or detention basin or by increasing the capacity of grass swales.

Infiltration has been practiced in a few scattered locations for a long time. For example, on Long Island, New York, infiltration basins were built starting in 1930 to reduce the need for a storm sewer system and to recharge the aquifer, which was the only source of drinking water (Ferguson, 1998). The Cities of Fresno, California, and El Paso, Texas, which faced rapidly dropping groundwater tables, began comprehensive infiltration efforts in the 1960s and 1970s. In the 1980s Maryland took the lead on the east coast by creating an ambitious

FIGURE 5-4 Rain Garden in Madison, Wisconsin. SOURCE: Roger Bannerman, Wisconsin Department of Natural Resources.

statewide infiltration program. The number of states embracing elements of LID, especially infiltration, has increased during the 1990s and into the new century and includes California, Florida, Minnesota, New Jersey, Vermont, Washington, and Wisconsin.

Evidence gathered in the 1970s and 1980s suggested that pollutants be added to the list of things needing control in stormwater (EPA, 1983). Damages caused by elevated flows, such as stream habitat destruction and floods, were relatively easy to document with something as simple as photographs. Documentation of elevated concentrations of conventional pollutants and potentially toxic pollutants, however, required intensive collection of water quality samples during runoff events. Samples collected from storm sewer pipes and urban streams in the Menomonee River watershed in the late 1970s clearly showed the concentrations of many pollutants, such as heavy metals and sediment, were elevated in urban runoff (Bannerman et al., 1979). Levels of heavy metals were especially high in industrial-site runoff, and construction-site erosion was calculated to be a large source of sediment in the watershed. This study was followed by the National Urban Runoff Program, which added more evidence about the high levels of some pollutants found in urban runoff (Athayde et al., 1983; Bannerman et al., 1983).

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With new development rapidly adding to the environmental impacts of existing urban areas, the need to develop good stormwater management programs is more urgent than ever. For a variety of reasons, the greatest potential for stormwater management to reduce the footprint of urbanization is in the suburbs. These areas are experiencing the fastest rates of growth, they are more amenable to stormwater management because buildings and infrastructure are not yet in place, and costs for stormwater management can be borne by the developer rather than by taxpayers. Indeed, most structural SCMs are applied to new development rather than existing urban areas. Many of the most innovative stormwater programs around the country are found in the suburbs of large cities such as Seattle, Austin, and Washington, D.C. When stormwater management in ultra-urban areas is required, it entails the retrofitting of detention basins and other flow control structures or the introduction of innovative below-ground structures characterized by greater technical constraints and higher costs, most of which are charged to local taxpayers.

Current-day SCMs represent a radical departure from past practices, which focused on dealing with extreme flood events via large detention basins designed to reduce peak flows at the downstream property line. As defined in this chapter, SCMs now include practices intended to meet broad watershed goals of protecting the biology and geomorphology of receiving waters in addition to flood peak protection. The term encompasses such diverse actions as using more conventional practices like basins and wetland to installing stream buffers, reducing impervious surfaces, and educating the public.

REVIEW OF STORMWATER CONTROL MEASURES

Stormwater control measures refer to what is defined by EPA (1999) as "a technique, measure, or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner." SCMs are designed to mitigate the changes to both the quantity and quality of stormwater runoff that are caused by urbanization. Some SCMs are engineered or constructed facilities, such as a stormwater wetland or infiltration basin, that reduce pollutant loading and modify volumes and flow. Other SCMs are preventative, including such activities as education and better site design to limit the generation of stormwater runoff or pollutants.

Stormwater Management Goals

It is impossible to discuss SCMs without first considering the goals that they are expected to meet. A broadly stated goal for stormwater management is to reduce pollutant loads to waterbodies and maintain, as much as possible, the natural hydrology of a watershed. On a practical level, these goals must be made specific to the region of concern and embedded in the strategy for that region. Depending on the designated uses of the receiving waters, climate, geomorphology, and historical development, a given area may be more or less sensitive to both pollutants and hydrologic modifications. For example, goals for groundwater recharge might be higher in an area with sandy soils as compared to one with mostly clayey soils; watersheds in the coastal zone may not require hydrologic controls. Ideally, the goals of stormwater management should be linked to the water quality standards for a given state's receiving waters. However, because of the substantial knowledge gap about the effect of a particular stormwater discharge on a particular receiving water (see Chapter 3 conclusions), surrogate goals are often used by state stormwater programs in lieu of water quality standards. Examples include credit systems, mandating the use of specific SCMs, or achieving stormwater volume reduction. Credit systems might be used for practices that are known to be productive but are difficult to quantify, such as planting trees. Specific SCMs might be assumed to remove a percent of pollutants, for example 85 percent removal of total suspended solids (TSS) within a stormwater wetland. Reducing the volume of runoff from impervious surfaces (e.g., using an infiltration device) might be assumed to capture the first flush of pollutants during a storm event. Before discussing specific state goals, it is worth understanding the broader context in which goals are set.

Trade-offs Between Stormwater Control Goals and Costs

The potentially substantial costs of implementing SCMs raise a number of fundamental social choices concerning land-use decisions, designated uses, and priority setting for urban waters. To illustrate some of these choices, consider a hypothetical urban watershed with three possible land-cover scenarios: 25, 50, and 75 percent impervious surface. A number of different beneficial uses could be selected for the streams in this watershed. At a minimum, the goal may be to establish low-level standards to protect public health and safety. To achieve this, sufficient and appropriate SCMs might be applied to protect residents from flooding and achieve water quality conditions consistent with secondary human contact. Alternatively, the designated use could be to achieve the physical, chemical, and/or biological conditions sufficient to provide exceptional aquatic habitat (e.g., a high-quality recreational fishery). The physical, biological, and chemical conditions supportive of this use might be similar to a reference stream located in a much less disturbed watershed. Achieving this particular designated use would require substantially greater resources and effort than achieving a secondary human contact use. Intermediate designated uses could also be imagined, including improving ambient water quality conditions that would make the water safe for full-body emersion (primary human contact) or habitat conditions for more tolerant aquatic species.

Figure 5-5 sketches what the marginal (incremental) SCM costs (opportunity costs) might be to achieve different designated uses given different amounts of impervious surface in the watershed. The horizontal axis orders potential

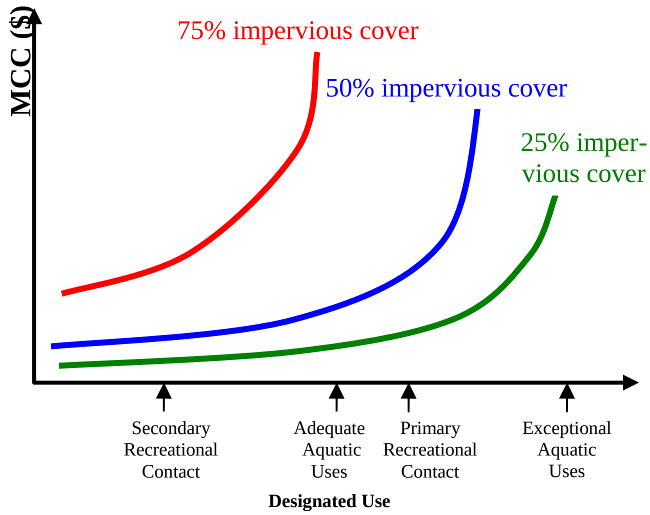

FIGURE 5-5 Cost of achieving designated uses in a hypothetical urban watershed. MCC is the marginal control cost, which represents the incremental costs to achieve successive expansion of designated uses through SCMs. The curves are constructed on the assumption that the lowest cost combination of SCMs would be implemented at each point on the curve.

designated uses in terms of least difficult to most difficult to achieve. The three conceptual curves represent the SCM costs under three different impervious surface scenarios. The relative positions of the cost curves indicate that achieving any specific designated use will be more costly in situations with a higher percentage of the watershed in impervious cover. All cost curves are upward sloping, reflecting the fact that incremental improvements in designated uses will be increasingly costly to achieve. The cost curves are purely conceptual, but nonetheless might reasonably reflect the relative costs and direction of change associated with achieving specific designated uses in different watershed conditions.

The locations of the cost curves suggest that in certain circumstances not all designated uses can be achieved or can be achieved only at an extremely high cost. For example, the attainment of exceptional aquatic uses may be unachievable in areas with 50 percent impervious surface even with maximum application of SCMs. In this illustration, the cost of achieving even secondary human contact use is high for areas with 75 percent impervious surfaces. In such highly urbanized settings, achievement of only adequate levels of aquatic uses could be exceedingly high and strain the limits of what is technically achievable. Finally, the existing and likely expected future land-use conditions have significant implications for what is achievable and at what cost. Clearly land-use decisions have an impact on the cost and whether a use can be achieved, and thus they need to be included in the decision process. The trade-off between costs and achieving specific designated uses can change substantially given different development patterns.

The purpose of Figure 5-5 is not to identify the precise location of the cost curves or to identify thresholds for achieving specific designated uses. Rather, these concepts are used to illustrate some fundamental trade-offs that confront public and private investment and regulatory decisions concerning stormwater management. The general relationships shown in Figure 5-5 suggest the need for establishing priorities for investments in stormwater management and controls, and connecting land usage and watershed goals. Setting overly ambitious or costly goals for urban streams may result in the perverse consequence of causing more waters to fail to meet designated uses. For example, consider efforts to secure ambitious designated uses in highly developed areas or in an area slated for future high-density development. Regulatory requirements and investments to limit stormwater quantity and quality through open-space requirements, areas set aside for infiltration and water detention, and strict application of maximum extent practicable controls have the effect of both increasing development costs and diminishing land available for residential and commercial properties. Policies designed to achieve exceedingly costly or infeasible designated uses in urban or urbanizing areas could have the net consequence of shifting development (and associated impervious surface) out into neighboring areas and watersheds. The end result might be minimal improvements in "within-watershed" ambient conditions but a decrease in designated uses (more impairments) elsewhere. In such a case, it might be sound water quality policy to accept higher levels of impervious surface in targeted locations, more stormwater-related impacts, and less ambitious designated uses in urban watersheds in order to preserve and protect designated uses in other watersheds.

Setting unrealistic or unachievable water quality objectives in urban areas can also pose political risks for stormwater management. The cost and difficulty of achieving ambitious water quality standards for urban stream goals may be understood by program managers but pursued nonetheless in efforts to demonstrate public commitment to achieving high-quality urban waters. Yet, promising what cannot be realistically achieved may act to undermine public support for urban stormwater programs. Increasing costs without significant observable improvements in ambient water conditions or achievement of water quality standards could ultimately reduce public commitment to the program. Thus, there are risks of "setting the bar" too high, or not coordinating land use and designated stream uses.

The cost of setting the bar too low can also be significant. Stormwater requirements that result in ineffective stormwater management will not achieve or maintain the desired water uses and can result in impairments. Loss of property, degraded waters, and failed infrastructure are tangible costs to the public (Johnston et al., 2006). Streambank rehabilitation costs can be severe, and loss of confidence in the ability to meet stormwater goals can result.

The above should not be construed as an argument for or against devoting resources to SCMs; rather, such decisions should be made with an open and transparent acknowledgment and understanding of the costs and consequences involved in those decisions.

Common State Stormwater Goals

Most states do not and have never had an overriding water quality objective in their stormwater program, but rather have used engineering criteria for SCM performance to guide stormwater management. These criteria can be loosely categorized as:

- Erosion and sedimentation control,
- Recharge/base flow,
- Water quality,
- Channel protection, and
- Flooding events.

The SCMs used to address these goals work by minimizing or eliminating increases in stormwater runoff volume, peak flows, and/or the pollutant load carried by stormwater.

The criteria chosen by any given state usually integrate state, federal, and regional laws and regulations. Areas of differing climates may emphasize one goal over another, and the levels of control may vary drastically. Contrast a desert region where rainwater harvesting is extremely important versus a coastal region subject to hurricanes. Some areas like Seattle have frequent smaller volume rainfalls—the direct opposite of Austin, Texas—such that small volume controls would be much more effective in Seattle than Austin. Regional geology (karst) or the presence of Brownfields may affect the chosen criteria as well.

The committee's survey of State Stormwater Programs (Appendix C) reflects a wide variation in program goals as reflected in the criteria found in their SCM manuals. Some states have no specific criteria because they do not produce SCM manuals, while others have manuals that address every category of criteria from flooding events to groundwater recharge. Some states rely upon EPA or other states' or transportation agencies' manuals. In general, soil and erosion control criteria are the most common and often exist in the absence of any other state criteria. This wide variation reflects the difficulties that states face in keeping up with rapidly changing information about SCM design and performance.

The criteria are ordered below (after the section on erosion and sediment control) according to the size of the storm they address, from smallest to most extreme. The criteria can be expressed in a variety of ways, from a simple requirement to control a certain volume of rainfall or runoff (expressed as a depth) to the size of a design storm to more esoteric requirements, such as limiting the time that flow can be above a certain threshold. The volumes of rainfall or runoff are based on statistics of a region's daily rainfall, and they approximate one another as the percentage of impervious cover increases. Design storms for larger events that address channel protection and flooding are usually based on extreme event statistics and tend to represent a temporal pattern of rainfall over a set period, usually a day. Finally, it should be noted that the categories are not mutually exclusive; for example, recharge of groundwater may enhance water quality via pollutant removal during the infiltration process.

Erosion and Sedimentation Control. This criterion refers to the prevention of erosion and sedimentation of sites during construction and is focused at the site level. Criteria usually include a barrier plan to prevent sedimentation from leaving the site (e.g., silt fences), practices to minimize the potential erosion (phased construction), and facilities to capture and remove sediment from the runoff (detention). Because these measures are considered temporary, smaller extreme events are designated as the design storm than what typically would be used if flood control were the goal.

Recharge/Base Flow. This criterion is focused on sustaining the preconstruction hydrology of a site as it relates to base flow and recharge of groundwater supplies. It may also include consideration of water usage of the property owners and return through septic tanks and tile fields. The criterion, expressed as a volume requirement, is usually to capture around 0.5 to 1.0 inch of runoff from impervious surfaces depending on the climate and soil type of the region. (For this range of rainfall, very little runoff occurs from grass or forested areas, which is why runoff from impervious surfaces is used as the criterion.)

Water Quality. Criteria for water quality are the most widespread, and are usually crafted as specific percent removal for pollutants in stormwater discharge. Generally, a water quality criterion is based on a set volume of stormwater being treated by the SCM. The size of the storm can run from the first inch of rainfall off impervious surfaces to the runoff from the one-year, 24-hour extreme storm event. It should be noted that the term "water quality" covers a wide range of groundwater and surface water pollutants, including water temperature and emerging contaminants.

Many of the water quality criteria are surrogates for more meaningful parameters that are difficult to quantify or cannot be quantified, or they reflect situations where the science is not developed enough to set more explicit goals. For example, the Wisconsin state requirement of an 80 percent reduction in TSS in stormwater discharge does not apply to receiving waters themselves. However, it presumes that there will be some water quality benefits in receiving waters; that is, phosphorus and fecal coliform might be captured by the TSS requirement. Similarly water quality criteria may be expressed as credits for good practices, such as using LID, street sweeping, or stream buffers.

Channel Protection. This criterion refers to protecting channels from accelerated erosion during storm events due to the increased runoff. It is tied to either the presumed "channel-forming event"—what geomorphologists once believed was the storm size that created the channel due to erosion and deposition—or to the minimum flow that accomplishes any degree of sediment transport. It is generally defined as somewhere between the one- and five-year, 24-hour storm event or a discharge level typically exceeded once to several times per year. Some states require a reduction in runoff volume for these events to match preconstruction levels. Others may require that the average annual duration of flows that are large enough to erode the streambank be held the same on an annual basis under pre- and postdevelopment conditions.

It is not uncommon to find states where a channel protection goal will be written poorly, such that it does not actually prevent channel widening. For example, MacRae (1997) presented a review of the common "zero runoff increase" discharge criterion, which is commonly met by using ponds designed to detain the two-year, 24-hour storm. MacRae showed that stream bed and bank erosion occur during much lower events, namely mid-depth flows that generally occur more than once a year, not just during bank-full conditions (approximated by the two-year event). This finding is entirely consistent with the well-established geomorphological literature (e.g., Pickup and Warner, 1976; Andrews, 1984; Carling, 1988; Sidle, 1988). During monitoring near Toronto, MacRae found that the duration of the geomorphically significant predevelopment mid-bankfull flows increased by more than four-fold after 34 percent of the basin had been urbanized. The channel had responded by increasing in cross-sectional area by as much as three times in some areas, and was still expanding.

Flooding Events. This criterion addresses public safety and the protection of property and is applicable to storm events that exceed the channel capacity. The 10- through the 100-year storm is generally used as the standard. Volume-reduction SCMs can aid or meet this criterion depending on the density of development, but usually assistance is needed in the form of detention SCMs. In some areas, it may be necessary to reduce the peak flow to below preconstruction levels in order to avoid the combined effects of increased volume, altered timing, and a changed hydrograph. It should be noted that some states do not consider the larger storms (100-year) to be a stormwater issue and have separate flood control requirements.

Each state develops a framework of goals, and the corresponding SCMs used to meet them, which will depend on the scale and focus of the stormwater management strategy. A few states have opted to express stormwater goals within the context of watershed plans for regions of the state. However, the setting of goals on a watershed basis is time-consuming and requires study of the watersheds in question. The more common approach has been to set generic or minimal controls for a region that are not based on a watershed plan. This has been done in Maryland, Wisconsin (see Box 5-1), and Pennsylvania (see Box 5-2). This strategy has the advantage of more rapid implementation of

BOX 5-1
Wisconsin Statewide Goal of TSS Reduction for Stormwater Management

To measure the success of stormwater management, Wisconsin has statewide goals for sediment and flow (Wisconsin DNR, 2002). A lot is known about the impacts of sediment on receiving waters, and any reduction is thought to be beneficial. Flow can be a good indicator of other factors; for example, reducing peak flows will prevent bank erosion.

Developing areas in Wisconsin are required to reduce the annual TSS load by 80 percent compared to no controls (Wisconsin DNR, 2002). Two flow-rated requirements for developing areas are in the administrative rules. One is that the site must maintain the peak flow for the two-year, 24-hour rainfall event. Second, the annual infiltration volume for postdevelopment must be within 90 percent of the predevelopment volumes for residential land uses; the number for non-residential is 60 percent. Both of these flow control goals are thought to also have water quality benefits.

The goal for existing urban areas is an annual reduction in TSS loads. Municipalities must reduce their annual TSS loads by 20 percent, compared to no controls, by 2008. This number is increased to 40 percent by 2013. All of these goals were partially selected to be reasonable based on cost and technical feasibility.

BOX 5-2
Volume-Based Stormwater Goals in Pennsylvania

Pennsylvania has developed a stormwater *Best Management Practices* manual to support the Commonwealth's Storm Water Management Act. This manual and an accompanying sample ordinance advocates two methods for stormwater control based on volume, termed Control Guidance (CG) 1 and 2. The first (CG-1) requires that the runoff volume be maintained at the two-year, 24-hour storm level (which corresponds to approximately 3.5 inches of rainfall in this region) through infiltration, evapotranspiration, or reuse. This criterion addresses recharge/base flow, water quality, and channel protection, as well as helping to meet flooding requirements.

The second method (CG-2) requires capture and removal of the first inch of runoff from paved areas, with infiltration strongly recommended to address recharge and water quality issues. Additionally, to meet channel protection criteria, the second inch is required to be held for 24 hours, which should reduce the channel-forming flows. (This is an unusual criterion in that it is expressed as what an SCM can accomplish, not as the flow that the channel can handle.) Peak flows for larger events are required to be at preconstruction levels or less if the need is established by a watershed plan. These criteria are the starting point for watershed or regional plans, to reduce the effort of plan development. Some credits are available for tree planting, and other nonstructural practices are advocated for dissolved solids mitigation. See http://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/stormwatermanagement/default.htm.

some SCMs because watershed management plans are not required. In order to be applicable to all watersheds in the state, the goals must target common pollutants or flow modification factors where the processes are well known. It must also be possible for these goals to be stated in National Pollutant Discharge Elimination System (NPDES) permits. Many states have selected TSS reduction, volume reduction, and peak flow control as generic goals. A generic goal is not usually based on potentially toxic pollutants, such as heavy metals, due to the complexity of their interaction in the environment, the dependence on the existing baseline conditions, and the need for more understanding on what are acceptable levels. The difficulty with the generic approach is that specific watershed issues are not addressed, and the beneficial uses of waters are not guaranteed.

One potential drawback of a strategy based on a generic goal coupled to the permit process is that the implementation of the goal is usually on a site-by-site basis, especially for developing areas. Generic goals may be appropriate for certain ubiquitous watershed processes and are clearly better than having no goals at all. However, they do not incorporate the effects of differences in past development and any unique watershed characteristics; they should be considered just a good starting point for setting watershed-based goals.

Role of SCMs in Achieving Stormwater Management Goals

One important fundamental change in SCM design philosophy has come about because of the recent understanding of the roles of smaller storms and of impervious surfaces. This is demonstrated by Box 3-4, which shows that for the Milwaukee area more than 50 percent of the rainfall by volume occurs in storms that have a depth of less then 0.75 inch. If extreme events are the only design criteria for SCMs, the vast majority of the annual rainfall will go untreated or uncontrolled, as it is smaller than the minimum extreme event. This relationship is not the same in all regions. For example, in Austin, Texas, the total yearly rainfall is smaller than in Milwaukee, but a large part of the volume occurs during larger storm events, with long dry periods in between.

The upshot is that the design strategy for stormwater management, including drainage systems and SCMs, should take a region's rainfall and associated runoff conditions into account. For example, an SCM chosen to capture the majority of the suspended solids, recharge the baseflow, reduce streambank erosion, and reduce downstream flooding in Pennsylvania or Seattle (which have moderate and regular rainfall) would likely not be as effective in Texas, where storms are infrequent and larger. In some areas, a reduction in runoff volume may not be sufficient to control streambank erosion and flooding, such that a second SCM like an extended detention stormwater wetland may be needed to meet management goals.

Finally, as discussed in greater detail in a subsequent section, SCMs are most effective from the perspective of both efficiency and cost when stormwater management is incorporated in the early planning stages of a community. Retrofitting existing development with SCMs is much more technically difficult and costly because the space may not be available, other infrastructure is already installed, or utilities may interfere. Furthermore, if the property is on private land or dedicated as an easement to a homeowners association, there may be regulatory limitations to what can be done. Because of these barriers, retrofitting existing urban areas often depends on engineered or manufactured SCMs, which are more expensive in both construction and operation.

Stormwater Control Measures

SCMs reduce or mitigate the generation of stormwater runoff and associated pollutants. These practices include both “structural” or engineered devices as well as more “nonstructural measures” such as land-use planning, site design, land conservation, education, and stewardship practices. Structural practices may be defined as any facility constructed to mitigate the adverse impacts of stormwater and urban runoff pollution. Nonstructural practices, which tend to be longer-term and lower-maintenance solutions, can greatly reduce the need for or increase the effectiveness of structural SCMs. For example, product substitution and land-use planning may be key to the successful implementation of an infiltration SCM. Preserving wooded areas and reducing street widths can allow the size of detention basins in the area to be reduced.

Table 5-1 presents the expansive list of SCMs that are described in this chapter. For most of the SCMs, each listed item represents a class of related practices, with individual methods discussed in greater detail later in the chapter. There are nearly 20 different broad categories of SCMs that can be applied, often in combination, to treat the quality and quantity of stormwater runoff. A primary difference among the SCMs relates to which stage of the development cycle they are applied, where in the watershed they are installed, and who is responsible for implementing them.

The development cycle extends from broad planning and zoning to site design, construction, occupancy, retrofitting, and redevelopment. As can be seen, SCMs are applied throughout the entire cycle. The scale at which the SCM is applied also varies considerably. While many SCMs are installed at individual sites as part of development or redevelopment applications, many are also applied at the scale of the stream corridor or the watershed or to existing municipal stormwater infrastructure. The final column in Table 5-1 suggests who would implement the SCM. In general, the responsibility for implementing SCMs primarily resides with developers and local stormwater agencies, but planning agencies, landowners, existing industry, regulatory agencies, and municipal separate storm sewer system (MS4) permittees can also be responsible for implementing many key SCMs.

In Table 5-1, the SCMs are ordered in such a way as to mimic natural systems as rain travels from the roof to the stream through combined application of

TABLE 5-1 Summary of Stormwater Control Measures—When, Where, and Who

Stormwater Control Measure	When	Where	Who
Product Substitution	Continuous	National, state, regional	Regulatory agencies
Watershed and Land-Use Planning	Planning stage	Watershed	Local planning agencies
Conservation of Natural Areas	Site and watershed planning stage	Site, watershed	Developer, local planning agency
Impervious Cover Minimization	Site planning stage	Site	Developer, local review authority
Earthwork Minimization	Grading plan	Site	Developer, local review authority
Erosion and Sediment Control	Construction	Site	Developer, local review authority
Reforestation and Soil Conservation	Site planning and construction	Site	Developer, local review authority
Pollution Prevention SCMs for Stormwater Hotspots	Post-construction or retrofit	Site	Operators and local and state permitting agencies
Runoff Volume Reduction—Rainwater harvesting	Post-construction or retrofit	Rooftop	Developer, local planning agency and review authority
Runoff Volume Reduction—Vegetated	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Runoff Volume Reduction—Subsurface	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Peak Reduction and Runoff Treatment	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Runoff Treatment	Post-construction or retrofit	Site	Developer, local planning agency and review authority
Aquatic Buffers and Managed Floodplains	Planning, construction and post-construction	Stream corridor	Developer, local planning agency and review authority, landowners
Stream Rehabilitation	Postdevelopment	Stream corridor	Local planning agency and review authority

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TABLE 5-1 Continued

Stormwater Control Measure	When	Where	Who
Municipal Housekeeping	Postdevelopment	Streets and stormwater infrastructure	MS4 Permittee
Illicit Discharge Detection and Elimination	Postdevelopment	Stormwater infrastructure	MS4 Permittee
Stormwater Education	Postdevelopment	Stormwater infrastructure	MS4 Permittee
Residential Stewardship	Postdevelopment	Stormwater infrastructure	MS4 Permittee

Note: Nonstructural SCMs are in italics.

a series of practices throughout the entire development site. This order is upheld throughout the chapter, with the implication that no SCM should be chosen without first considering those that precede it on the list.

Given that there are 20 different SCM groups and a much larger number of individual design variations or practices within each group, it is difficult to authoritatively define the specific performance or effectiveness of SCMs. In addition, our understanding of their performance is rapidly changing to reflect new research, testing, field experience, and maintenance history. The translation of these new data into design and implementation guidance is accelerating as well. What is possible is to describe their basic hydrologic and water quality objectives and make a general comparative assessment of what is known about their design, performance, and maintenance as of mid-2008. This broad technology assessment is provided in Table 5-2, which reflects the committee's collective understanding about the SCMs from three broad perspectives:

- Is widely accepted design or implementation guidance available for the SCM and has it been widely disseminated to the user community?
- Have enough research studies been published to accurately characterize the expected hydrologic or pollutant removal performance of the SCM in most regions of the country?
- Is there enough experience with the SCM to adequately define the type and scope of maintenance needed to ensure its longevity over several decades?

Affirmative answers to these three questions are needed to be able to reliably quantify or model the ability of the SCM, which is an important element in defining whether the SCM can be linked to improvements in receiving water quality. As will be discussed in subsequent sections of this chapter, there are many SCMs for which there is only a limited understanding, particularly those that are nonstructural in nature.

The columns in Table 5-2 summarize several important factors about each SCM, including the ability of the SCM to meet hydrologic control objectives and water quality objectives, the availability of design guidance, the availability of performance studies, and whether there are maintenance protocols. The hydrologic control objectives range from complete prevention of stormwater flow to reduction in runoff volume and reduction in peak flows. The column on water quality objectives describes whether the SCM can prevent the generation of, or remove, contaminants of concern in stormwater.

The availability of design guidance tends to be greatest for the structural practices. Some but not all nonstructural practices are of recent origin, and communities lack available design guidance to include them as an integral element of local stormwater solutions. Where design guidance is available, it may not yet have been disseminated to the full population of Phase II MS4 communities.

TABLE 5-2 Current Understanding of Stormwater Control Measure Capabilities

SCM	Hydrologic Control Objectives	Water Quality Objectives	Available Design Guidance	Performance Studies Available	Defined Maintenance Protocols
Product Substitution	NA	Prevention	NA	Limited	NA
Watershed and Land-Use Planning	All objectives	Prevention	Available	Limited	Yes
Conservation of Natural Areas	Prevention	Prevention	Available	None	Yes
Impervious Cover Minimization	Prevention and reduction	Prevention	Available	Limited	No
Earthwork Minimization	Prevention	Prevention	Emerging	Limited	Yes
Erosion and Sediment Control	Prevention and reduction	Prevention and removal	Available	Limited	Yes
Reforestation and Soil Conservation	Prevention and reduction	Prevention and removal	Emerging	None	No
Pollution Prevention SCMs for Hotspots	NA	Prevention	Emerging	Very few	No
Runoff Volume Reduction—Rainwater harvesting	Reduction	NA	Emerging	Limited	Yes
Runoff Volume Reduction—Vegetated (Green Roofs, Bioretention, Bioinfiltration, Bioswales)	Reduction and some peak attenuation	Removal	Available	Limited	Emerging
Runoff Volume Reduction—Subsurface (Infiltration Trenches, Pervious Pavements)	Reduction and some peak attenuation	Removal	Available	Limited	Yes

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TABLE 5-2 Continued

SCM	Hydrologic Control Objectives	Water Quality Objectives	Available Design Guidance	Performance Studies Available	Defined Maintenance Protocols
Peak Reduction and Runoff Treatment (Stormwater Wetlands, Dry/Wet Ponds)	Peak attenuation	Removal	Available	Adequate	Yes
Runoff Treatment (Sand Filters, Manufactured Devices)	None	Removal	Emerging	Adequate—sand filters Limited—manufactured devices	Yes
Aquatic Buffers and Managed Floodplains	NA	Prevention and removal	Available	Very few	Emerging
Stream Rehabilitation	NA	Prevention and removal	Emerging	Limited	Unknown
Municipal Housekeeping (Street Sweeping/ Storm-Drain Cleanouts)	NA	Removal	Emerging	Limited	Emerging
Illicit Discharge Detection/ Elimination	NA	Prevention and removal	Available	Very few	No
Stormwater Education	Prevention	Prevention	Available	Very few	Emerging
Residential Stewardship	Prevention	Prevention	Emerging	Very few	No

Note: Nonstructural SCMs are in italics.

Key:		
Hydrologic Objective	Water Quality Objective	Available Design Guidance?
Prevention: Prevents generation of runoff **Reduction:** Reduces volume of runoff **Treatment:** Delays runoff delivery only **Peak Attenuation**: Reduction of peak flows through detention	**Prevention**: Prevents generation, accumulation, or wash-off of pollutants and/or reduces runoff volume **Removal:** Reduces pollutant concentrations in runoff by physical, chemical, or biological means	**Available:** Basic design or implementation guidance is available in most areas of the country are readily available **Emerging:** Design guidance is still under development, is missing in many parts of the country, or requires more performance data
Performance Data Available?	Defined Maintenance Protocol?	Notes:
Very Few: Handful of studies, not enough data to generalize about SCM performance **Limited:** Numerous studies have been done, but results are variable or inconsistent **Adequate**: Enough studies have been done to adequately define performance	**No:** Extremely limited understanding of procedures to maintain SCM in the future **Emerging:** Still learning about how to maintain the SCM **Yes**: Solid understanding of maintenance for future SCM needs	**NA:** Not applicable for the SCM

The column on the availability of performance data is divided into those SCMs where enough studies have been done to adequately define performance, those SCMs where limited work has been done and the results are variable, and those SCMs where only a handful of studies are available. A large and growing number of performance studies are available that report the efficiencies of structural SCMs in reducing flows and pollutant loading (Strecker et al., 2004; ASCE, 2007; Schueler et al., 2007; Selbig and Bannerman, 2008). Many of these are compiled in the Center for Watershed Protection's National Pollutant Removal Performance Database for Stormwater Treatment Practices (http://www.cwp.org/Resource_Library/Center_Docs/SW/bmpwriteup_092007_v3.pdf), in the International Stormwater BMP Database (http://www.bmpdatabase.org/Docs/Performance%20Summary%20June%202008.pdf), and by the Water Environment Research Foundation (WERF, 2008). In cases where there is incomplete understanding of their performance, often information can be gleaned from other fields including agronomy, forestry, petroleum exploration, and sanitary engineering. Current research suggests that it is not a question if whether structural SCMs "work" but more of a question of to what degree and with what longevity (Heasom et al., 2006; Davis et al., 2008; Emerson and Traver, 2008). There is considerably less known about the performance of nonstructural practices for stormwater treatment, partly because their application has been uneven around the country and it remains fairly low in comparison to structural stormwater practices.

Finally, defined maintenance protocols for SCMs can be nonexistent, emerging, or fully available. SCMs differ widely in the extent to which they can be considered permanent solutions. For those SCMs that work on the individual site scale on private property, such as rain gardens, local stormwater managers may be reluctant to adopt such practices due to concerns about their ability to enforce private landowners to conduct maintenance over time. Similarly, those SCMs that involve local government decisions (such as education, residential stewardship practices, zoning, or street sweeping) may be less attractive because governments are likely to change over time.

The following sections contain more detailed information about the individual SCMs listed in Tables 5-1 and 5-2, including the operating unit processes, the pollutants treated, the typical performance for both runoff and pollutant reduction, the strengths and weaknesses, maintenance and inspection requirements, and the largest sources of variability and uncertainty.

Product Substitution

Product substitution refers to the classic pollution prevention approach of reducing the emissions of pollutants available for future wash-off into stormwater runoff. The most notable example is the introduction of unleaded gasoline, which resulted in an order-of-magnitude reduction of lead levels in stormwater runoff in a decade (Pitt et al., 2004a,b). Similar reductions are expected with the phase-out of methyl tert-butyl ether (MTBE) additives in gasoline. Other examples of product substitution are the ban on coal-tar sealants during parking lot renovation that has reduced PAH runoff (Van Metre et al., 2006), phosphorus-free fertilizers that have measurably reduced phosphorus runoff to Minnesota lakes (Barten and Johnson, 2007), the painting of galvanized metal surfaces, and alternative rooftop surfaces (Clark et al., 2005). Given the importance of coal power plant emissions in the atmospheric deposition of nitrogen and mercury, it is possible that future emissions reductions for such plants may result in lower stormwater runoff concentrations for these two pollutants.

The level of control afforded by product substitution is quite high if major reductions in emissions or deposition can be achieved. The difficulty is that these reductions require action in another environmental regulatory arena, such as air quality, hazardous waste, or pesticide regulations, which may not see stormwater quality as a core part of their mission.

Watershed and Land-Use Planning

Communities can address stormwater problems by making land-use decisions that change the location or quantity of impervious cover created by new development. This can be accomplished through zoning, watershed plans, comprehensive land-use plans, or Smart Growth incentives.

The unit process that is managed is the amount of impervious cover, which is strongly related to various residential and commercial zoning categories (Cappiella and Brown, 2000). Numerous techniques exist to forecast future watershed impervious cover and its probable impact on the quality of aquatic resources (see the discussion of the Impervious Cover Model in Chapter 3; CWP, 1998a; MD DNR, 2005). Using these techniques and simple or complex simulation models, planners can estimate stormwater flows and pollutant loads through the watershed planning process and alter the location or intensity of development to reduce them.

The level of control that can be achieved by watershed and land-use planning is theoretically high, but relatively few communities have aggressively exercised it. The most common application of downzoning has been applied to watersheds that drain to drinking water reservoirs (Kitchell, 2002). The strength of this practice is that it has the potential to directly address the underlying causes of the stormwater problem rather than just treating its numerous symptoms. The weakness is that local decisions on zoning and Smart Growth are reversible and often driven by other community concerns such as economic development, adequate infrastructure, and transportation. In addition, powerful consumer and market forces often have promoted low-density sprawl development. Communities that use watershed-based zoning often require a compelling local environmental goal, since state and federal regulatory authorities have traditionally been extremely reluctant to interfere with the local land-use and zoning powers.

Conservation of Natural Areas

Natural-area conservation protects natural features and environmental resources that help maintain the predevelopment hydrology of a site by reducing runoff, promoting infiltration, and preventing soil erosion. Natural areas are protected by a permanent conservation easement prescribing allowable uses and activities on the parcel and preventing future development. Examples include any areas of undisturbed vegetation preserved at the development site, including forests, wetlands, native grasslands, floodplains and riparian areas, zero-order stream channels, spring and seeps, ridge tops or steep slopes, and stream, wetland, or shoreline buffers. In general, conservation should maximize contiguous area and avoid habitat fragmentation.

While natural areas are conserved at many development sites, most of these requirements are prompted by other local, state, and federal habitat protections, and are not explicitly designed or intended to provide runoff reduction and stormwater treatment. To date, there are virtually no data to quantify the runoff reduction and/or pollutant removal capability of specific types of natural area conservation, or the ability to explicitly link them to site design.

Impervious Cover Reduction

A variety of practices, some of which fall under the broader term "better site design," can be used to minimize the creation of new impervious cover and disconnect or make more permeable the hard surfaces that are needed (Nichols et al., 1997; Richman, 1997; CWP, 1998a). A list of some common impervious cover reduction practices for both residential and commercial areas is provided below.

<u>Elements of Better Site Design: Single-Family Residential</u>

- Maximum residential street width
- Maximum street right-of-way width
- Swales and other stormwater practices can be located within the right-of-way
- Maximum cul-de-sac radius with a bioretention island in the center
- Alternative turnaround options such as hammerheads are acceptable if they reduce impervious cover
- Narrow sidewalks on one side of the street (or move pedestrian pathways away from the street entirely)
- Disconnect rooftops from the storm-drain systems
- Minimize driveway length and width and utilize permeable surfaces
- Allow for cluster or open-space designs that reduce lot size or setbacks in exchange for conservation of natural areas
- Permeable pavement in parking areas, driveways, sidewalks, walkways, and patios

Elements of Better Site Design: Multi-Family Residential and Commercial

- Design buildings and parking to have multiple levels
- Store rooftop runoff in green roofs, foundation planters, bioretention areas, or cisterns
- Reduce parking lot size by reducing parking demand ratios and stall dimensions
- Use landscaping areas, tree pits, and planters for stormwater treatment
- Use permeable pavement over parking areas, plazas, and courtyards

CWP (1998a) recommends minimum or maximum geometric dimensions for subdivisions, individual lots, streets, sidewalks, cul-de-sacs, and parking lots that minimize the generation of needless impervious cover, based on a national roundtable of fire safety, planning, transportation and zoning experts. Specific changes in local development codes can be made using these criteria, but it is often important to engage as many municipal agencies that are involved in development as possible in order to gain consensus on code changes.

At the present time, there is little research available to define the runoff reduction benefits of these practices. However, modeling studies consistently show a 10 to 45 percent reduction in runoff compared to conventional development (CWP, 1998b,c, 2002). Several monitoring studies have documented a major reduction in stormwater runoff from development sites that employ various forms of impervious cover reduction and LID in the United States and Australia (Coombes et al., 2000; Philips et al., 2003; Cheng et al., 2005) compared to those that do not.

Unfortunately, better site design has been slowly adopted by local planners, developers, designers, and public works officials. For example, although the project pictured in Figure 5-6 has been very successful in terms of controlling stormwater, the better-site-design principles used have not been widely adopted in the Seattle area. Existing local development codes may discourage or even prohibit the application of environmental site design practices, and many engineers and plan reviewers are hesitant to embrace them. Impervious cover reduction must be incorporated at the earliest stage of site layout and design to be effective, but outdated development codes in many communities can greatly restrict the scope of impervious cover reduction (see Chapter 2). Finally, the performance and longevity of impervious cover reduction are dependent on the infiltration capability of local soils, the intensity of development, and the future management actions of landowners.

Earthwork Minimization

This source control measure seeks to limit the degree of clearing and grading on a development site in order to prevent soil compaction, conserve soils, prevent erosion from steep slopes, and protect zero-order streams. This is accomplished by (1) identifying key soils, drainage features, and slopes to protect

FIGURE 5-6 110th Street, Seattle, part of the Natural Drainage Systems Project. This location exhibits several elements of impervious cover reduction. In particular, vegetated swales were installed and curbs and gutters removed. There are sidewalks on only one side of the street, and they are separated from the road by the swales. The residences' rooftops have been disconnected from the storm-drain systems and are redirected into the swales. SOURCE: Seattle Public Utilities.

and then (2) establishing a limit of disturbance where construction equipment is excluded. This element is an important, but often under-utilized component of local erosion and sediment control plans.

Numerous researchers have documented the impact of mass grading, clearing, and the passage of construction equipment on the compaction of soils, as measured by increase in bulk density, declines in soil permeability, and increases in the runoff coefficient (Lichter and Lindsey, 1994; Legg et al., 1996; Schueler, 2001a,b; Gregory et al., 2006). Another goal of earthwork minimization is to protect zero-order streams, which are channels with defined banks that emanate from a hollow or ravine with convergent contour lines (Gomi et al., 2002). They represent the uppermost definable channels that possess temporary or intermittent flow. Functioning zero-order channels provide major watershed functions, including groundwater recharge and discharge (Schollen et al., 2006; Winter, 2007), important nutrient storage and transformation functions (Bernot and Dodds, 2005; Groffman et al., 2005), storage and retention of eroded hillslope sediments (Meyers, 2003), and delivery of leaf inputs and large woody debris. Compared to high-order network streams, zero-order streams are disproportionately disturbed by mass grading, enclosure, or channelization (Gomi et al., 2002; Meyer, 2003).

The practice of earthwork minimization is not widely applied across the country. This is partly due to the limited performance data available to quantify its benefits, and the absence of local or national design guidance or performance benchmarks for the practice.

Erosion and Sediment Control

Erosion and sediment control predates much of the NPDES stormwater permitting program. It consists of the temporary installation and operation of a series of structural and nonstructural practices throughout the entire construction process to minimize soil erosion and prevent off-site delivery of sediment. Because construction is expected to last for a finite and short period of time, the design standards are usually smaller and thus riskier (25-year versus the 100-year storm). By phasing construction, thereby limiting the exposure of bare earth at any one time, the risk to the environment is reduced significantly.

The basic practices include clearing limits, dikes, berms, temporary buffers, protection of drainage-ways, soil stabilization through hydroseeding or mulching, perimeter controls, and various types of sediment traps and basins. All plans have some component that requires filtration of runoff crossing construction areas to prevent sediment from leaving the site. This usually requires a sediment collection system including, but not limited to, conventional settling ponds and advanced sediment collection devices such as polymer-assisted sedimentation and advanced sand filtration. Silt fences are commonly specified to filter distributed flows, and they require maintenance and replacement after storms as shown in Figure 5-7. Filter systems are added to inlets until the streets are paved and the surrounding area has a cover of vegetation (Figure 5-8). Sedimentation basins (Figure 5-9) are constructed to filter out sediments through rock filters, or are equipped with floating skimmers or chemical treatment to settle out pollutants. Other common erosion and sediment control measures include temporary seeding and rock or rigged entrances to construction sites to remove dirt from vehicle tires (see Figure 5-10).

Control of the runoff's erosive potential is a critical element. Most erosion and sediment control manuals provide design guidance on the capacity and ability of swales to handle runoff without eroding, on the design of flow paths to transport runoff at non-erosive velocities, and on the dissipation of energy at pipe outlets. Examples include rock energy dissipaters, level spreaders (see Figure 5-11), and other devices.

Box 5-3 provides a comprehensive list of recommended construction SCMs. The reader is directed to reviews by Brown and Caraco (1997) and Shaver et al. (2007) for more information. Although erosion and sediment control practices are temporary, they require constant operation and maintenance during the complicated sequence of construction and after major storm events. It is exceptionally important to ensure that practices are frequently inspected and repaired and that sediments are cleaned out. Erosion and sediment control are

FIGURE 5-7 A functioning silt fence (top) and an improperly maintained silt fence (bottom). SOURCES: Top, EPA NPDES Menu of BMPs (available at http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=56) and, bottom, Robert Traver, Villanova University.

FIGURE 5-8 Sediment filter left in place after construction. SOURCE: Robert Traver, Villanova University.

FIGURE 5-9 Sediment basin. SOURCE: EPA NPDES Menu of BMPs (available at http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&vew=specific&bmp=56).

FIGURE 5-10 Rumble strips to remove dirt from vehicle tires. SOURCE: Laura Ehlers, National Research Council.

FIGURE 5-11 Level spreader. SOURCE: Robert Traver, Villanova University.

BOX 5-3
Recommended Construction Stormwater Control Measures

1. As the top priority, emphasize construction management SCMs as follows:

- Maintain existing vegetation cover, if it exists, as long as possible.
- Perform ground-disturbing work in the season with smaller risk of erosion, and work off disturbed ground in the higher risk season.
- Limit ground disturbance to the amount that can be effectively controlled in the event of rain.
- Use natural depressions and planning excavation to drain runoff internally and isolate areas of potential sediment and other pollutant generation from draining off the site, so long as safe in large storms.
- Schedule and coordinate rough grading, finish grading, and erosion control application to be completed in the shortest possible time overall and with the shortest possible lag between these work activities.

2. Stabilize with cover appropriate to site conditions, season, and future work plans. For example:

- Rapidly stabilize disturbed areas that could drain off the site, and that will not be worked again, with permanent vegetation supplemented with highly effective temporary erosion controls until achievement of at least 90 percent vegetative soil cover.
- Rapidly stabilize disturbed areas that could drain off the site, and that will not be worked again for more than three days, with highly effective temporary erosion controls.
- If at least 0.1 inch of rain is predicted with a probability of 40 percent or more, before rain falls stabilize or isolate disturbed areas that could drain off the site, and that are being actively worked or will be within three days, with measures that will prevent or minimize transport of sediment off the property.

continues next page

BOX 5-3 Continued

3. As backup for cases where all of the above measures are used to the maximum extent possible but sediments still could be released from the site, consider the need for sediment collection systems including, but not limited to, conventional settling ponds and advanced sediment collection devices such as polymer-assisted sedimentation and advanced sand filtration.

4. Specify emergency stabilization and/or runoff collection (e.g., using temporary depressions) procedures for areas of active work when rain is forecast.

5. If runoff can enter storm drains, use a perimeter control strategy as backup where some soil exposure will still occur, even with the best possible erosion control (above measures) or when there is discharge to a sensitive waterbody.

6. Specify flow control SCMs to prevent or minimize to the extent possible:
- Flow of relatively clean off-site water over bare soil or potentially contaminated areas;
- Flow of relatively clean intercepted groundwater over bare soil or potentially contaminated areas;
- High velocities of flow over relatively steep and/or long slopes, in excess of what erosion control coverings can withstand; and
- Erosion of channels by concentrated flows, by using channel lining, velocity control, or both.

7. Specify stabilization of construction entrance and exit areas, provision of a nearby tire and chassis wash for dirty vehicles leaving the site with a wash water sediment trap, and a sweeping plan.

8. Specify construction road stabilization.

9. Specify wind erosion control.

10. Prevent contact between rainfall or runoff and potentially polluting construction materials, processes, wastes, and vehicle and equipment fluids by such measures as enclosures, covers, and containments, as well as berming to direct runoff.

widely applied in many communities, and most states have some level of design guidance or standards and specifications. Nonetheless, few communities have quantified the effectiveness of a series of construction SCMs applied to an individual site, nor have they clearly defined performance benchmarks for individual practices or their collective effect at the site. In general, there has been little monitoring in the past few decades to characterize the performance of construction SCMs, although a few notable studies have been recently published (e.g., Line and White, 2007). Box 5-4 describes the effectiveness of filter fences and filter fences plus grass buffers to reduce sediment loadings from construction activities and the resulting biological impacts.

BOX 5-4
Receiving Water Impacts Associated with Construction Site Discharges

The following is a summary of a recent research project that investigated in-stream biological conditions downstream of construction sites having varying levels of erosion controls (none, the use of filter fences, and filter fences plus grass buffers) for comparison. The project title is *Studies to Evaluate the Effectiveness of Current BMPs in Controlling Stormwater Discharges from Small Construction Sites* and was conducted for the Alabama Water Resources Research Institute, Project 2001AL4121B, by Drs. Robert Angus, Ken Marion, and Melinda Lalor of the University of Alabama at Birmingham. The initial phase of the project, described below, was completed in 2002 (Angus et al., 2002). While this case study is felt to be representative of many sites across the United States, there are other examples of where silt fences have been observed to be more effective (e.g., Barrett et al., 1998).

Methods

This study was conducted in the upper Cahaba River watershed in north central Alabama, near Birmingham. The study areas had the following characteristics. (1) Topography and soil types representative of the upland physiographic regions in the Southeast (i.e., southern Appalachian and foothill areas); thus, findings from this study should be relevant to a large portion of the Southeast. (2) The rainfall amounts and intensities in this region are representative of many areas of the Southeast and (3) the expanding suburbs of the Birmingham metropolitan area are rapidly encroaching upon the upper Cahaba River and its tributaries. Stormwater runoff samples were manually collected from sheet flows above silt fences, and from points below the fence within the vegetated buffer. Water was sampled during "intense" (≥1 inch/hour) rain events. The runoff samples were analyzed for turbidity, particle size distribution (using a Coulter Counter Multi-Sizer IIe), and total solids (dissolved solids plus suspended/non-filterable solids). Sampling was only carried out on sites with properly installed and well-maintained silt fences, located immediately upgrade from areas with good vegetative cover.

Six tributary or upper mainstream sites were studied to investigate the effects of sedimentation from construction sites on both habitat quality and the biological "health" of the aquatic ecosystem (using benthic macroinvertebrates and fish). EPA's Revision to Rapid Bioassessment Protocols for Use in Streams and Rivers was used to assess the habitat quality at the study sites. Each site was assessed in the spring to evaluate immediate effects of the sediment, and again during the following late summer or early fall to evaluate delayed effects.

Results

Effectiveness of Silt Fences. Silt fences were found to be better than no control measures at all, but not substantially. The mean counts of small particles (<5 μm) below the silt fences were about 50 percent less than that from areas with no erosion control measures, even though the fences appeared to be properly installed and in good order. However, the variabilities were large and the difference between the means was not statistically significant. For every variable measured, the mean values of samples taken below silt fences were significantly higher ($p < 0.001$) than samples collected from undisturbed vegetated control sites collected nearby and at the same time. These data therefore indicate that silt fences are only marginally effective at reducing soil particulates in runoff water.

Effectiveness of Filter Fences with Vegetated Buffers. Runoff samples were also collected immediately below filter fences, and below filter fences after flow over buffers having 5, 10, and 15 feet of dense (intact) vegetation. Mean total solids in samples collected below silt fences and a 15-foot-wide vegetated buffer zone were about 20 percent lower, on average, than those samples collected only below the silt fence. The installation of filter fences above an intact, good vegetated buffer removes sediment from construction site runoff more effectively than with the use of filter fences alone.

Biological Metrics Sensitive to Sedimentation Effects (Fish). Analysis of the fish biota indicates that various metrics used to evaluate the biological integrity of the fish community also are affected by highly sedimented streams. As shown in Figure 5-12, the overall composition of the population, as quantified by the Index of Biotic Integrity (IBI) is lower; the proportion and biomass of darters, a disturbance-sensitive group, is lower; the proportion and biomass of sunfish is higher; the Shannon-Weiner diversity index is lower; and the number of disturbance-tolerant species is higher as mean sediment depth increases.

Benthic Macroinvertebrates. A number of stream benthic macroinvertebrate community characteristics were also found to be sensitive to sedimentation. Metrics based on these characteristics differ greatly between sediment-impacted and control sites (Figure 5-13). Some of the metrics that appear to reflect sediment-associated stresses include the Hilsenhoff Biotic Index (HBI), a variation of the EPT index (percent EPT minus Baetis), and the Sorensen Index of Similarity to a reference site. The HBI is a weighted mean tolerance value; high HBI values indicate sites dominated by disturbance-tolerant macroinvertebrate taxa. The EPT% index is the percent of the collection represented by organisms in the generally disturbance-sensitive orders *Ephemeroptera, Plecoptera,* and *Trichoptera*. Specimens of the genus *Baetis* were not included in the index as they are relatively disturbance-tolerant. The HBI and the EPT indices also show positive correlations to several other measures of disturbance, such as percent of the watershed altered by development.

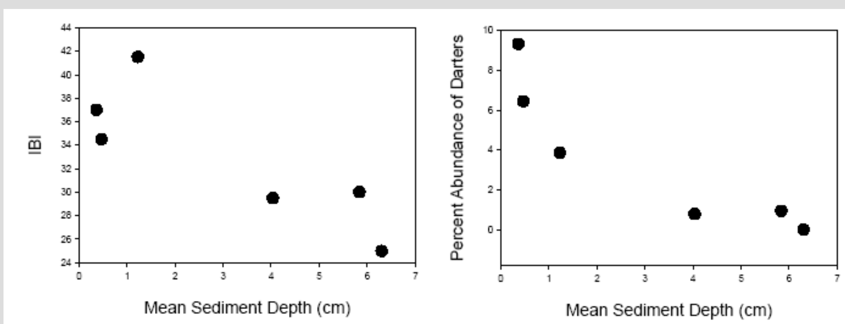

FIGURE 5-12 Association between two fish metrics and amount of stream sediment. NOTE: The IBI is based on numerous characteristics of the fish population. The percent relative abundance of darters is the percentage of darters to all the fish collected at a site. SOURCE: Angus et al. (2002).

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BOX 5-4 Continued

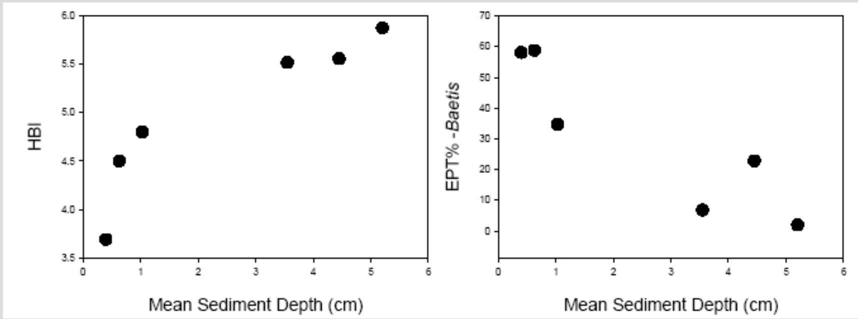

FIGURE 5-13 Associations between two macroinvertebrate metrics and the amount of stream sediment. SOURCE: Angus et al. (2002).

Reforestation and Soil Compost Amendments

This set of practices seeks to improve the quality of native vegetation and soils present at the site. Depending on the ecoregion, this may involve forest, prairie, or chapparal plantings, tilling, and amending compacted soils to improve their hydrologic properties.

The goal is to maintain as much predevelopment hydrologic function at a development site as possible by retaining canopy interception, duff/soil layer interception, evapotranspiration, and surface infiltration. The basic methods to implement this practice are described in Cappiella et al. (2006), Pitt et al. (2005), Chollak and Rosenfeld (1998), and Balusek (2003).

At this time, there are few monitoring data to assess the degree to which land reforestation or soil amendments can improve the quality of stormwater runoff at a particular development site, apart from the presumptive watershed research that has shown that forests with undisturbed soils have very low rates of surface runoff and extremely low levels of pollutants in runoff (Singer and Rust, 1975; Johnson et al., 2000; Chang, 2006). More data are needed on the hydrologic properties of urban forests and soils whose ecological functions are stressed or degraded by the urbanization process (Pouyat et al., 1995, 2007).

Pollution Prevention SCMs for Stormwater Hotspots

Certain classes of municipal and industrial operations are required to maintain a series of pollution prevention practices to prevent or minimize contact of pollutants with rainfall and runoff. Pollution prevention practices involve a wide range of operational practices at a site related to vehicle repairs, fueling, washing and storage, loading and unloading areas, outdoor storage of materials, spill prevention and response, building repair and maintenance, landscape and turf management, and other activities that can introduce pollutants into the stormwater system (CWP, 2005). Training of personnel at the affected area is needed to ensure that industrial and municipal managers and employees understand and implement the correct stormwater pollution prevention practices needed for their site or operation.

Examples of municipal operations that may need pollution prevention plans include public works yards, landfills, wastewater treatment plants, recycling and solid waste transfer stations, maintenance depots, school bus and fleet storage and maintenance areas, public golf courses, and ongoing highway maintenance operations. The major industrial categories that require stormwater pollution prevention plans were described in Table 2-3. Both industrial and municipal operations must develop a detailed stormwater pollution prevention plan, train employees, and submit reports to regulators. Compliance has been a significant issue with this program in the past, particularly for small businesses (Duke and Augustenberg, 2006; Cross and Duke, 2008) Recently filed investigations of stormwater hotspots indicate many of these operations are not fully implementing their stormwater pollution prevention plans, and a recent GAO report (2007) indicates that state inspections and enforcement actions are extremely rare.

The goal of pollution prevention is to prevent contact of rainfall or stormwater runoff with pollutants, and it is an important element of the post-construction stormwater plan. However, with the exception of a few industries such as auto salvage yards (Swamikannu, 1994), basic research is lacking on how much greater event mean concentrations are at municipal and industrial stormwater hotspots compared to other urban land uses. In addition, little is presently known about whether aggressive implementation of stormwater pollution prevention plans actually can reduce stormwater pollutant concentrations at hot spots.

Runoff Volume Reduction—Rainwater Harvesting

A primary goal of stormwater management is to reduce the volume of runoff from impervious surfaces. There are several classes of SCMs that can achieve this goal, including rainwater harvesting systems, vegetated SCMs that evapotranspirate part of the volume, and infiltration SCMs. For all of these measures, the amount of runoff volume to be captured depends on watershed goals, site conditions including climate, upstream nonstructural practices employed, and whether the chosen SCM is the sole management measure or part of a treatment train. Generally, runoff-volume-reduction SCMs are designed to handle at least the first flush from impervious surfaces (1 inch of rainfall). In Pennsylvania, control of the 24-hour, two-year storm volume (about 8 cm) is considered the standard necessary to protect stream-channel geomorphology, while base flow recharge and the first flush can be addressed by capturing a much smaller volume of rain (1–3 cm). Where both goals must be met, the designer is permitted to either oversize the volume reduction device to control the larger volume, or build a smaller device and use it in series with an extended detention basin to protect the stream geomorphology (PaDEP, 2006). Some designers have reported that in areas with medium to lower percentage impervious surfaces they are able to control up to the 100-year storm by enlarging runoff-volume-reduction SCMs and using the entire site. In retrofit situations, capture amounts as small as 1 cm are a distinct improvement. It should be noted that there are important, although indirect, water quality benefits of all runoff-volume-reduction SCMs—(1) the reduction in runoff will reduce streambank erosion downstream and the concomitant increases in sediment load, and (2) volume reductions lead to pollutant load reductions, even if pollutant concentrations in stormwater are not decreased.

Rainwater harvesting systems refer to use of captured runoff from roof tops in rain barrels, tanks, or cisterns (Figures 5-14 and 5-15). This SCM treats runoff as a resource and is one of the few SCMs that can provide a tangible economic benefit through the reduction of treated water usage. Rainwater harvesting systems have substantial potential as retrofits via the use of rain barrels or cisterns that can replace lawn or garden sprinkling systems. Use of this SCM to provide gray water within buildings (e.g., for toilet flushing) is considerably more complicated due to the need to construct new plumbing and obtain the necessary permits.

FIGURE 5-14 Rainwater harvesting tanks at a Starbucks in Austin, Texas. SOURCE: Laura Ehlers, National Research Council.

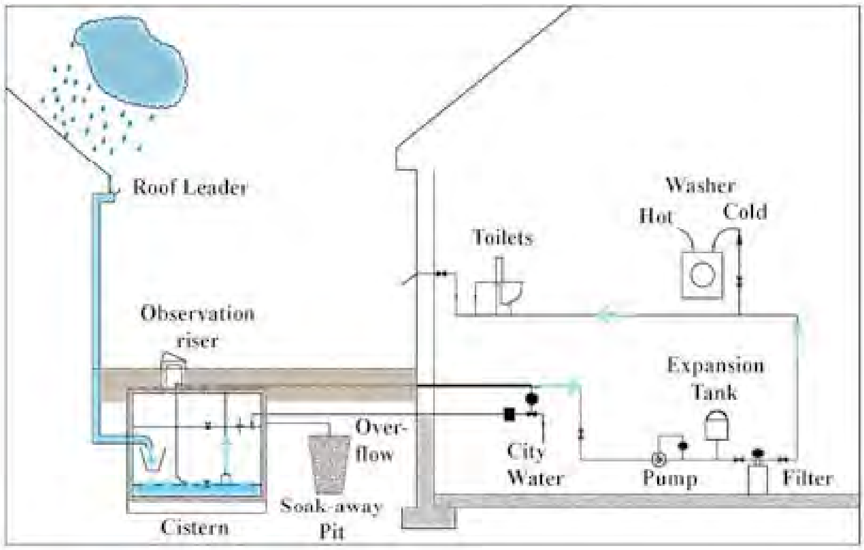

FIGURE 5-15 A Schematic of rainwater harvesting. SOURCE: PaDEP (2006).

The greatest challenge with these systems is the need to use the stored water and avoid full tanks, since these cannot be responsive in the event of a storm. That is, these SCMs are effective only if the captured runoff can be regularly used for some grey water usage, like car washing, toilet flushing, or irrigation systems (golf courses, landscaping, nurseries). In some areas it might be possible to use the water for drinking, showering, or washing, but treatment to potable water quality would be required. Sizing of the required storage is dependent on the climate patterns, the amount of impervious cover, and the frequency of water use. Areas with frequent rainfall events require less storage as long as the water is used regularly, while areas with cold weather will not be able to utilize the systems for irrigation in the winter and thus require larger storage.

One substantial advantage of these systems is their ability to reduce water costs for the user and the ability to share needs. An example of this interaction is the Pelican Hill development in Irvine, California, where excess runoff from the streets and houses is collected in enormous cisterns and used for watering of a nearby golf course. Furthermore, compared to other SCMs, the construction of rainwater harvesting facilities provide a long-term benefit with minimal maintenance cost, although they do require an upfront investment for piping and storage tanks.

Coombes et al. (2000) found that rainwater harvesting achieved a 60 to 90 percent reduction in runoff volume; in general, few studies have been conducted to determine the performance of these SCMs. It should be noted that rainwater harvesting systems do collect airborne deposition and acid rain.

Runoff Volume Reduction—Vegetated

A large and very promising class of SCMs includes those that use infiltration and evapotranspiration via vegetation to reduce the volume of runoff. These SCMs also directly address water quality of both surface water and groundwater by reducing streambank erosion, capturing suspended solids, and removing other pollutants from stormwater during filtration through the soil (although the extent to which pollutants are removed depends on the specific pollutant and the local soil chemistry). Depending on their design, these SCMs can also reduce peak flows and recharge groundwater (if they infiltrate). These SCMs can often be added as retrofits to developed areas by installing them into existing lawns, rights of way, or traffic islands. They can add beauty and property value.

Flow volume is addressed by this SCM group by first capturing runoff, creating a temporary holding area, and then removing the stored volume through infiltration and evapotranspiration. Examples include bioswales, bioretention, rain gardens, green roofs, and bioinfiltration. Swales refer to grassy areas on the side of the road that convey drainage. These were first designed to move runoff away from paved areas, but can now be designed to achieve a certain contact time with runoff so as to promote infiltration and pollutant removal (see Figure 5-16). Bioretention generally refers to a constructed sand filter with soil and vegetation growing on top to which stormwater runoff from impervious surfaces is directed (Figure 5-17). The original rain garden or bioretention facilities were constructed with a fabric at the bottom of the prepared soil to prevent infiltration and instead had a low-level outflow at the bottom. Green roofs (Figure 5-18) are very similar to bioretention SCMs. They tend to be populated with a light expanded shale-type soil and succulent plants chosen to survive wet and dry periods. Finally, bioinfiltration is similar to bioretention but is better engineered to achieve greater infiltration (Figure 5-19). All of these devices are usually at the upper end of a treatment train and designed for smaller storms, which minimizes their footprint and allows for incorporation within existing infrastructure (such as traffic control devices and median strips). This allows for distributed treatment of the smaller volumes and distributed volume reduction.

These SCMs work by capturing water in a vegetated area, which then infiltrates into the soil below. They are primarily designed to use plant material and soil to evapotranspirate the runoff over several days. A shallow depth of ponding is required, since the inflows may exceed the possible infiltration ability of the native soil. This ponding is maintained above an engineered sandy soil mixture and is a surface-controlled process (Hillel, 1998). Early in the storm, the soil moisture potential creates a suction process that helps draw water into the SCM. This then changes to a steady rate that is "practically equal to the saturated hydraulic conductivity" of the subsurface (Hillel, 1998). The hydrologic design goal should be to maximize the volume of water that can be held in the soil, which necessitates consideration of the soil hydraulic conductivity (which varies with temperature), climate, depth to groundwater, and time to drain.

FIGURE 5-16 Vegetated swale. SOURCE: PaDEP (2006).

FIGURE 5-17 Bioretention during a storm event at the University of Maryland. SOURCE: Reprinted, with permission, from Davis et al. (2008). Copyright 2008 by the American Society of Civil Engineers.

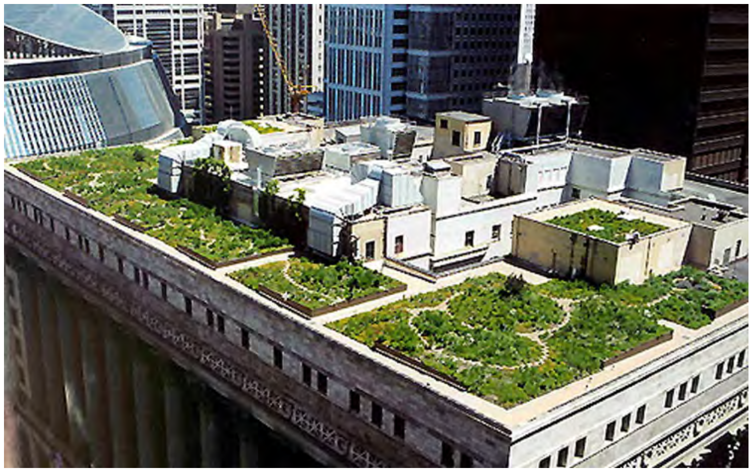

FIGURE 5-18 City Hall in the center of Chicago's downtown was retrofitted with a green roof to reduce the heat island effect, remove airborne pollutants, and attenuate stormwater flows as a demonstration of innovative stormwater management in an ultra-urban setting. SOURCE: Courtesy of the Conservation Design Forum.

FIGURE 5-19 Retrofit bioinfiltration at Villanova University immediately following a storm event. SOURCE: Robert Traver, Villanova University.

Usually these devices are designed to empty between 24 and 72 hours after a storm event. In some cases (usually bioretention), these SCMs have an underdrain.

The choice of vegetation is an important part of the design of these SCMs. Many sites where infiltration is desirable have highly sandy soils, and the vegetation has to be able to endure both wet and dry periods. Long root growths are desired to promote infiltration (Barr Engineering Co., 2001), and plants that attract birds can reduce the insect population. Bioretention cells may be wet for longer periods than bioinfiltration sites, requiring different plants. Denser plantings or "thorns" may be needed to avoid the destruction caused by humans and animals taking shortcuts through the beds.

The pollutant removal mechanism operating for volume-reduction SCMs are different for each pollutant type, soil type, and volume-reduction mechanism. For bioretention and SCMs using infiltration, the sedimentation and filtration of suspended solids in the top layers of the soil are extremely efficient. Several studies have shown that the upper layers of the soil capture metals, particulate nutrients, and carbon (Pitt, 1996; Deschesne et al., 2005; Davis et al., 2008). The removal of dissolved nutrients from stormwater is not as straightforward. While ammonia is caught by the top organic layer, nitrate is mobile in the soil column. Some bioretention systems have been built to hold water in the soil for longer periods in order to create anaerobic conditions that would promote denitrification (Hunt and Lord, 2006a). Phosphorus removal is related to the amount of phosphorus in the original soil. Some studies have shown that bioretention cells built with agricultural soils increased the amount of phosphorus released. Chlorides pass through the system unchecked (Ermilio and Traver, 2006), while oils and greases are easily removed by the organic layer. Hunt et al. (2008) have reported in studies in North Carolina that the drying cycle appears to kill off bacteria. Temperature is not usually a concern as most storms do not overflow these devices. Green roofs collect airborne deposition and acid rain and may export nutrients when they overflow. However, this must be tempered by the fact that in larger storms, most natural lands would produce nutrients.

A group of new research studies from North America and Australia have demonstrated the value of many of these runoff-volume-reduction practices to replicate predevelopment hydrology at the site. The results from 10 recent studies are given in Table 5-3, which shows the runoff reduction capability of bioretention. As can be seen, the reduction in runoff volume achieved by these practices is impressive—ranging from 20 to 99 percent with a median reduction of about 75 percent. Box 5-5 discusses the excellent performance of the bioswales installed during Seattle's natural drainage systems project (see also Horner et al., 2003; Jefferies, 2004; Stagge, 2006). Bioinfiltration has been less studied, but one field study concluded that close to 30 percent of the storm volume was able to be removed by bioinfiltration (Sharkey, 2006). A very recent case study of bioinfiltration is provided in Box 5-6, which demonstrates that the capture of small storms through these SCMs is extremely effective in areas where the majority of the rainfall falls in smaller storms.

The strengths of vegetated runoff-volume-reduction SCMs include the flexibility to utilize the drainage system as part of the treatment train. For example, bioswales can replace drainage pipes, green roofs can be installed on buildings, and bioretention can replace parking borders (Figure 5-27), thereby reducing the footprint of the stormwater system. Also, through the use of swales and reducing pipes and inlets, costs can be offset. Vegetated systems are more tolerant of the TSS collected, and their growth cycle maintains pathways for

TABLE 5-3 Volumetric Runoff Reduction Achieved by Bioretention

Bioretention Design	Location	Runoff Reduction	Reference
Infiltration	CT	99%	Dietz and Clausen (2006)
	PA	86%	Ermilio and Traver (2006)
	FL	98%	Rushton (2002)
	AUS	73%	Lloyd et al. (2002)
Underdrain	ONT	40%	Van Seters et al. (2006)
	Model	30%	Perez-Perdini et al. (2005)
	NC	40 to 60%	Smith and Hunt (2007)
	NC	20 to 29%	Sharkey (2006)
	NC	52 to 56%	Hunt et al. (2008)
	MD	52 to 65%	Davis et al. (2008)

BOX 5-5
Bioswale Case Study 110th Street Cascade, Seattle, Washington

A recent example of the ability of SCMs to accomplish a variety of goals was illustrated for water quality swales in Seattle, Washington. As part of its Natural Drainage Systems Project, the City of Seattle retrofitted several blocks of an urban residential neighborhood with curbside vegetated swales. On NW 110th Street, the two-block-long system was developed as a cascade, due to the steep slope (6 percent). Twelve stepped, in-series biofilters were installed between properties and the road, each of which contains a storage area and an overflow weir. During rain events, the cells were designed to fill before emptying into the cell downstream. The soils in the bottom of each cell were over one foot thick and consisted of river rocks overlain by a swale mix. Native plants were chosen to vegetate the sides of the swale.

Extensive flow and water quality sampling occurred during 2003–2006 at the inflow and outflow of the biofilters as well as at references points elsewhere in the neighborhood that are not served by the new SCMs. Perhaps the most profound observation was that almost 50 percent of all rainfall flowing into the cascade was infiltrated, resulting in a corresponding reduction in runoff. Indeed, the cascade discharged measurable flow only during 49 of 235 storm events during the period. Depending on preceding conditions, the cascade was able to retain all of the flow for storms up to 1 inch in magnitude. In addition to the reduction in runoff affected by the swales, they also achieved significant peak flow reduction, as shown in Figure 5-20. Many peak flow rates were entirely dampened, even those where the inflow peak rate was as high as 0.7 cfs.

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BOX 5-5 Continued

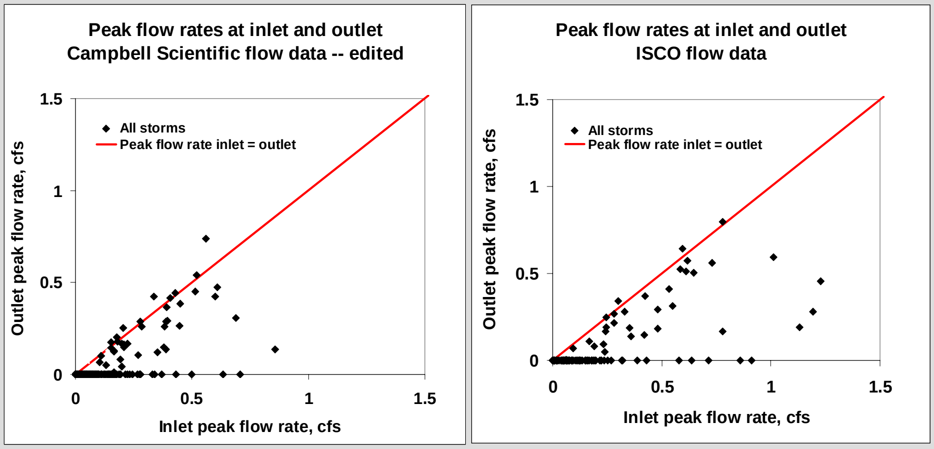

FIGURE 5-20 Peak flow rates at the inlet and outlet of the cascade, as measured by two different devices: Campbell Scientific (left) and ISCO (right). SOURCE: Horner and Chapman (2007).

Water quality data were also extremely encouraging, as shown in Table 5-4. For total suspended solids, influent concentration of 94 mg/L decreased to 29 mg/L at the outlet of the cascade. Similar percent removals were observed for total copper, total phosphorus, total zinc, and total lead (see Table 5-4). Soluble phosphorus concentrations tended to increase from the inflow of the cascade to the outflow.

TABLE 5-4 Typical Outflow Quality from the 110th Street Cascade.

Pollutant	Range (mg/L)
Total Suspended Solids	10–40
Total Nitrogen	0.6–1.4
Total Phosphorus	0.09–0.23
Soluble Reactive Phosphorus	0.02–0.05
Total Copper	0.004–0.008
Dissolved Copper	0.002–0.005
Total Zinc	0.04–0.11
Dissolved Zinc	0.02–0.06
Total Lead	0.002–0.007
Dissolved Lead	<0.001
Motor Oil	0.11–0.33

SOURCE: Horner and Chapman (2007).

Taking both measured concentrations and volume reduction into account, the cascade reduced the mass loadings for the contaminants by 60 percent to greater than 90 percent. As shown in Table 5-5, pollutants associated with sediments were reduced to the greatest extent, while dissolved pollutants were less readily removed.

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BOX 5-5 Continued

TABLE 5-5 Pollutant Mass Loading Reductions at 110th Street Cascade.

Pollutant	Percent Reduction (90% Confidence Interval)
Total Suspended Solids	84 (72–92)
Total Nitrogen	63 (53–74)
Total Phosphorus	63 (49–74)
Total Copper	83 (77–88)
Dissolved Copper	67 (50–78)
Total Zinc	76 (46–85)
Dissolved Zinc	55 (21–70)
Total Lead	90 (84–94)
Motor Oil	92 (86–97)

SOURCE: Horner and Chapman (2007).

This level of performance was compared to other parts of the neighborhood treated with conventional ditch and pipe systems. The concentrations of almost all pollutants at the outlet of the 100th Cascade was significantly lower than a corresponding outlet at 120th Street. Furthermore, the ability of this SCM to attenuate peak flows and reduce runoff was remarkable.

BOX 5-6
SCM Evaluation Through Monitoring: Villanova Bioinfiltration SCM

The Bioinfiltration Traffic Island located on the campus of Villanova University in Southeastern Pennsylvania is part of the Villanova Urban Stormwater Partnership (VUSP) BMP Demonstration Park (see Figure 5-21). Originally funded through the Pennsylvania Growing Greener Program, and now through the State's 319 nonpoint source monitoring program, the site has been monitored continuously since soon after it was constructed in 2001. This monitoring has lead to a wealth of information about the performance and monitoring needs of infiltration SCMs.

FIGURE 5-21 Villanova Bioinfiltration Traffic Island SCM. SOURCE: Reprinted, with permission, from VUSP. Copyright by Villanova Urban Stormwater Partnership.

The SCM is a retrofit of an existing curb-enclosed traffic island in the parking lot of a university dormitory complex. The original grass area was dug out to approximately six feet. The soil removed during the excavation was then mixed with sand onsite to create a 50 percent sand–soil mixture. This soil mixture was then placed back into the excavation to

continues next page

BOX 5-6 Continued

a depth of approximately four feet, leaving a surface depression that is an average of two feet deep. Care was taken during construction to prevent any compaction of either the soil mixture or the undisturbed soil below. Placement of the mixed soil is shown in Figure 5-22.

FIGURE 5-22 Placement of the mixed soil in the basin. Notice the construction equipment being kept away from the basin to avoid potential compaction of the sub-base. SOURCE: Reprinted, with permission, from VUSP. Copyright by Villanova Urban Stormwater Partnership.

During construction two curb cuts were created to direct runoff into the SCM. Creation of one of the cuts entailed filling and paving over an existing stormwater inlet to redirect the runoff that previously entered the stormwater drainage system of the parking lot. Another existing inlet was used to collect and redirect runoff into the SCM. Plants were chosen based on their ability to thrive in both extreme wet and dry conditions; the species chosen are commonly found on sand dunes where similar wet/dry conditions may exist.

The contributing watershed is approximately 50,000 square feet and is 52 percent impervious surfaces. The design goal of the SCM was for it to temporarily store the first inch of runoff. The one-inch capture depth is based on an analysis of local historical rainfall data showing that capture of the first inch of each storm would account for approximately 96 percent of the annual rainfall. This capture depth would therefore also account for the majority of the annual pollutant load coming from the drainage area.

Continuous monitoring over multiple years has increased our understanding of how this type of structure operates and its benefits. For example, Heasom et al. (2006) was able to produce a continuous hydrologic flow model of the site based on season. Figure 5-23 shows the variability of the infiltration rate on a seasonal basis, and the relationship between infiltration and temperature (Emerson and Traver, 2008). This work has also shown no statistical change in performance over the five-year monitoring period.

When examining the yearly performance of the site from a surface water standpoint, it is easily shown that on a regular basis approximately 50 to 60 percent of the runoff that reaches the site is removed from the surface waters, and 80 to 85 percent of the rainfall is infiltrated (Figure 5-24).

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BOX 5-6 Continued

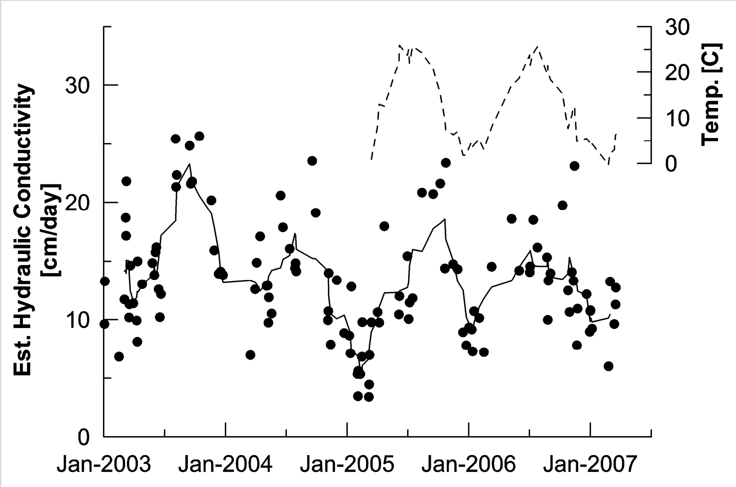
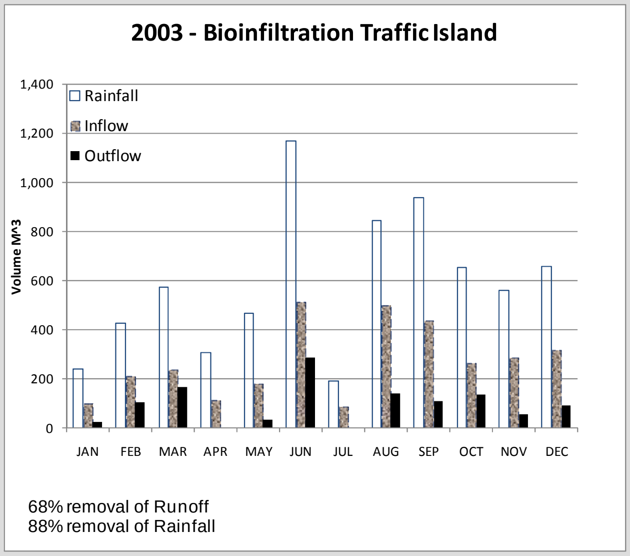


FIGURE 5-23 Seasonal Infiltration Rate. SOURCE: Reprinted, with permission, from Emerson and Traver (2008). Copyright 2008 by Journal of Irrigation and Drainage Engineering.

The performance of the SCM during individual storm events was examined in 2005. Out of 77 rainfall events, overflow was recorded for only seven events. Generally overflow did not occur for rainfalls less than 1.95 inches except for one occasion. As the bowl volume is much less than this value, substantial infiltration must be occurring during the storm event. When one extreme 6-inch storm was recorded (Figure 5-25), it was surprising to note that infiltration occurred all during the storm event, as did some unexpected peak flow reduction. What is even more impressive is to examine the reduction in the duration of flows, which is directly related to downstream channel erosion (Figure 5-26). Clearly the bioinfiltration SCM exceeded its design goals.

Research on this site is currently examining water quality benefits and groundwater interactions. When evaluating the pollutant removal of bioinfiltration, it is critical to consider flow volumes and pollutant levels together. For example, during many of the overflow events, there were higher nutrient levels leaving the SCM than entering due to the plants contained within the SCM. However, when the runoff volume reduction is considered, the total nitrogen and phosphorus removed from the influent is impressive (Davis et al., 2008). Water quality studies of the infiltrated water are still incomplete but generally show some conversion of nitrate to nitrite, and high chlorides from snow melt chemicals moving through the system. Nutrient levels are relatively low in the samples at the 8-foot depth.



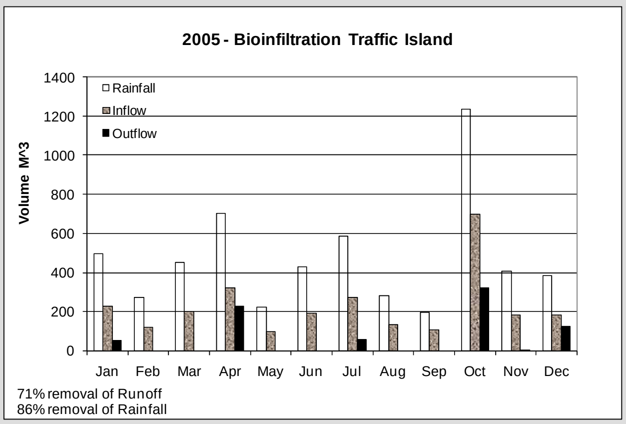


FIGURE 5-24 2003 Performance and 2005 Performance. SOURCE: Reprinted, with permission, from VUSP. Copyright by Villanova Urban Stormwater Partnership.

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BOX 5-6 Continued

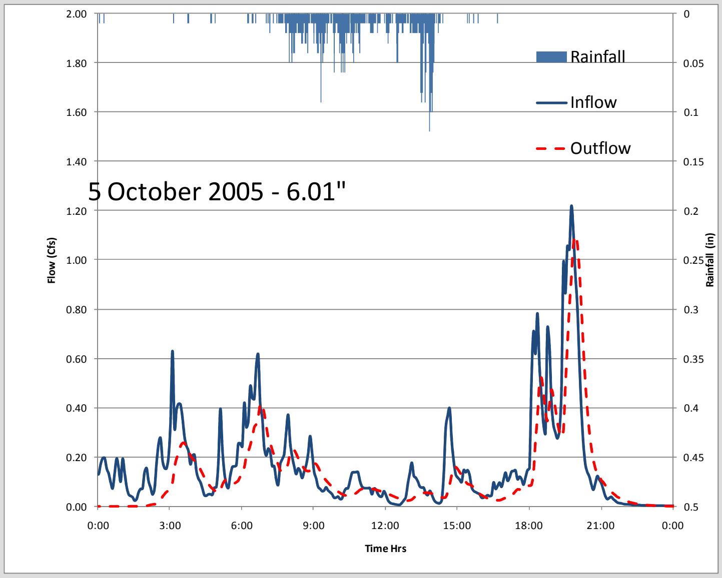

FIGURE 5-25 October 2005 extreme storm event. SOURCE: Reprinted, with permission, from VUSP. Copyright by Villanova Urban Stormwater Partnership.

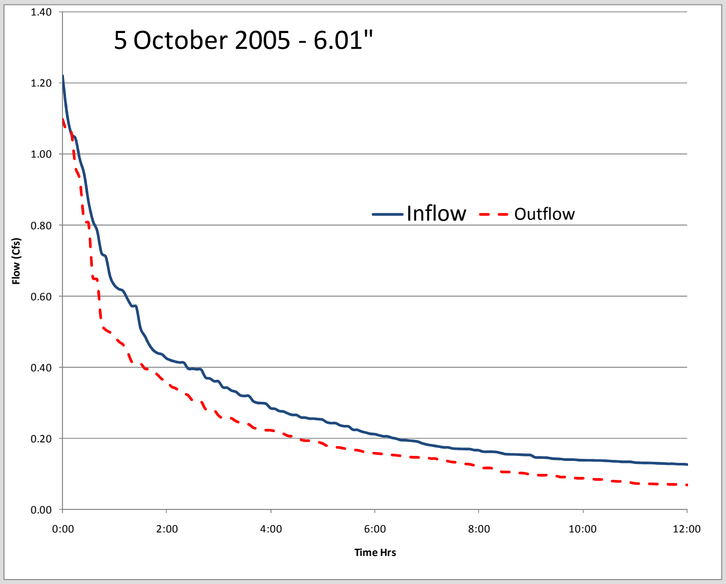

FIGURE 5-26 Flow duration curves, October 2005. SOURCE: Reprinted, with permission, from VUSP. Copyright by Villanova Urban Stormwater Partnership.

FIGURE 5-27 North Carolina Retrofit Bioretention SCMs. SOURCE: Robert Traver, Villanova University.

infiltration and prevents clogging. Freeze–thaw cycles also contribute to pathway maintenance. The aesthetic appeal of vegetated SCMs is also a significant strength.

Weaknesses include the dependence of these SCMs on native soil infiltration and the need to understand groundwater levels and karst geology, particularly for those SCMs designed to infiltrate. For bioinfiltration and bioretention, most failures occur early on and are caused by sedimentation and construction errors that reduce infiltration capacity, such as stripping off the topsoil and compacting the subsurface. Once a good grass cover is established in the contributing area, the danger of sedimentation is reduced. Nonetheless, the need to prevent sediment from overwhelming these structures is critical. The longevity of these SCMs and their vulnerability to toxic spills are a concern (Emerson and Traver, 2008), as is their failure to reduce chlorides. Finally, in areas where the land use is a hot spot, or where the SCM could potentially contaminate the groundwater supply, bioretention, non-infiltrating bioswales, and green roofs may be more suitable than infiltration SCMs.

The role of infiltration SCMs in promoting groundwater recharge deserves additional consideration. Although this is a benefit of infiltration SCMs in regions where groundwater levels are dropping, it may be undesirable in a few limited scenarios. For example, in the arid southwest contributions to base flow from irrigation have turned some dry ephemeral stream systems into perennial streams that support the growth of dense vegetation, which may be less desirable habitat for certain riparian species (like the Arroyo toad in Southern California). Infiltration SCMs could contribute to changing the flow regime in cases such as these. In most urban areas, there is so much impervious cover that it would be difficult to "overinfiltrate." Nonetheless, the use of infiltration SCMs will change local subsurface hydrology, and the ramifications of this—good and bad—should be considered prior to their installation.

Maintenance of vegetated runoff-volume-reduction SCMs is relatively simple. A visit after a rainstorm to check for plant health, to check sediment buildup, and to see if the water is ponded can answer many questions. Maintenance includes trash pickup and seasonal removal of dead grasses and weeds. Sediment removal from pretreatment devices is required. Depending on the pollutant concentrations in the influent, the upper layer of organic matter may need to be removed infrequently to maintain infiltration and to prevent metal and nutrient buildup.

At the site level, the chief factors that lead to uncertainty are the infiltration performance of the soil, particular for the limiting subsoil layer, and how to predict the extent of pollutant removal. Traditional percolation tests are not effective to estimate the infiltration performance; rather, testing hydraulic conductivity is required. Furthermore, the infiltration rate varies depending on temperature and season (Emerson and Traver, 2008). Basing measurements on percent removal of pollutants is extremely misleading, since every site and storm generates different levels of pollutants. The extent of pollutant removal depends on land use, time between storms, seasons, and so forth. These factors should be part of the design philosophy for the site. Finally, it should also be pointed out that climate is a factor determining the effectiveness of some of these SCMs. For example, green roofs are more likely to succeed in areas having smaller, more frequent storms (like the Pacific Northwest) compared to areas subjected to less frequent, more intense storms (like Texas).

Runoff Volume Reduction—Subsurface

Infiltration is the primary runoff-volume-reduction mechanism for subsurface SCMs, such that much of the previous discussion is relevant here. Thus, like vegetated SCMs, these SCMs provide benefits for groundwater recharge, water quality, stream channel protection, peak flow reduction, capture of the suspended solids load, and filtration through the soil (Ferguson, 2002). Because these systems can be built in conjunction with paved surfaces (i.e., they are often buried under parking lots), the amount of water captured, and thus stream protection, may be higher than for vegetated systems. They also have lower land requirements than vegetated systems, which can be an enormous advantage when using these SCMs during retrofitting, as long as the soil is conducive to infiltration.

Similar to vegetated SCMs, this SCM group works primarily by first capturing runoff and then removing the stored volume through infiltration. The temporary holding area is made either of stone or using manufactured vaults. Examples include pervious pavement, infiltration trenches, and seepage pits (see Figures 5-28, 5-29, 5-30, 5-31, and 5-32). As with vegetated SCMs, a shallow

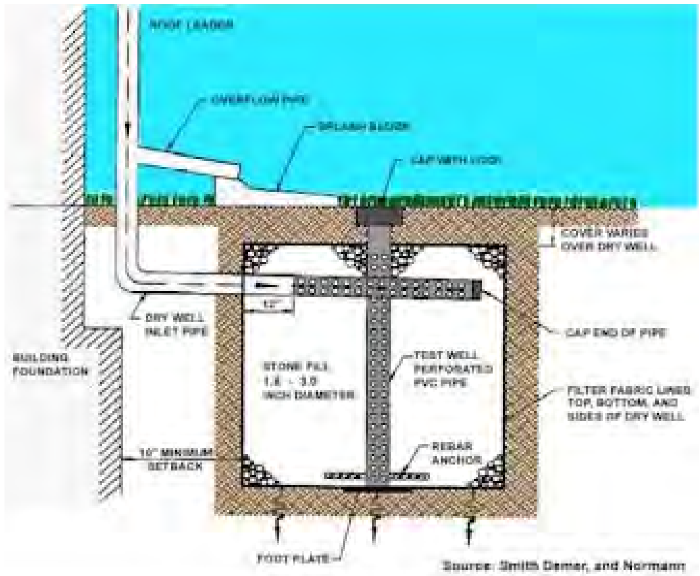

FIGURE 5-28 Schematic of a seepage pit. SOURCE: PaDEP (2006).

FIGURE 5-29 Porous asphalt. SOURCE: PaDEP (2006).

FIGURE 5-30 A retrofitted infiltration trench at Villanova University. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.

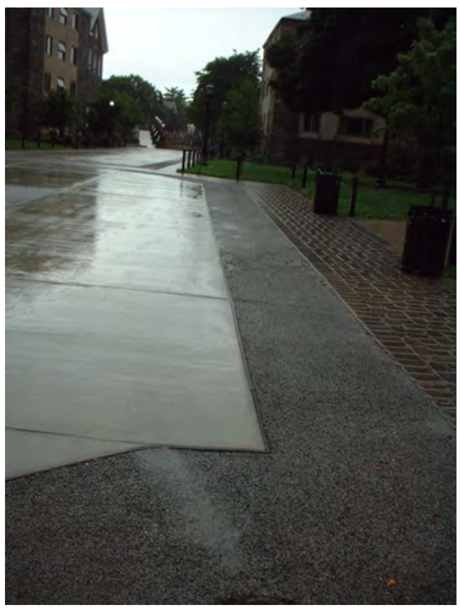

FIGURE 5-31 Pervious concrete at Villanova University. SOURCE: Reprinted, with permission from Villanova University. Copyright by VUSP.

FIGURE 5-32 A small office building conversion at the edge of downtown Denver included the replacement of a portion of the site's parking with modular block porous pavement underlain by an 18-inch layer of crushed rock. Rainfall on the porous pavement and roof runoff for most storm events are contained in the reservoir created by the crushed rock. The pavement infiltrates runoff from most storm events for one-third of the impervious area on the half-acre site. SOURCE: Courtesy of Wenk Associates.

depth of ponding is required, since the inflows may exceed the possible infiltration ability of the native soil. In this case, the ponding is maintained within a rock bed under a porous pavement or in an infiltration trench. These devices are usually designed to empty between 24 and 72 hours after the storm event.

The infiltration processes operating for these subsurface SCMs are similar to those for the vegetated devices previously discussed. Thus, much like for vegetated systems, the level of control achieved depends on the infiltration ability of the native soils, the percent of impervious surface area in the contributing watershed, land use contributing to the pollutant loadings, and climate. A large number of recent studies have found that permeable pavement can reduce runoff volume by anywhere from 50 percent (Rushton, 2002; Jefferies, 2004; Bean et al., 2007) to as much as 95 percent or greater (van Seters et al., 2006; Kwiatkowski et al., 2007). Box 5-7 describes the success of a recent retrofitting of asphalt with pervious pavement at Villanova University.

The strengths of subsurface runoff-volume-reduction SCMs are similar to those of their vegetated counterparts. Additional attributes include their ability to be installed under parking areas and to manage larger volumes of rainfall. These SCMs typically have few problems with safety or vector-borne diseases because of their subsurface location and storage capacity, and they can be very aesthetically pleasing. The potential of permeable pavement could be particularly far-reaching if one considers the amount of impervious surface in urban areas that is comprised of roads, driveways, and parking lots.

The weaknesses of these SCMs are also similar to those of vegetated systems, including their dependence on native soil infiltration and the need to understand groundwater levels and karst geology. Simply estimating the soil hydraulic conductivity can have an error rate of an order of magnitude. Specifically for subsurface systems that use geotextiles (not permeable pavement), there is a danger of TSS being compressed against the bottom of the geotextile, preventing infiltration. There are no freeze–thaw cycles or vegetated processes that can reopen pathways, so the control of TSS is even more critical to their life span. In most cases (permeable pavement is an exception), pretreatment is required, except for the cleanest of sources (like a slate roof). Typically, manufactured devices, sediment forebays, or grass strips are part of the design of subsurface SCMs to capture the larger sediment particles.

The maintenance of subsurface runoff-volume-reduction SCMs is relatively simple but critical. If inspection wells are installed, a visit after a rainstorm will check that the volume is captured, and later that it has infiltrated. Porous surfaces should undergo periodic vacuum street sweeping when a sediment source is present. Pretreatment devices require sediment removal. The difficulty with this class of SCMs is that, if a toxic spill occurs or maintenance is not proactive, there are no easy corrective measures other than replacement.

Low-Impact Development. LID refers primarily to the use of small, engineered, on-site stormwater practices to treat the quality and quantity of runoff at its source. It is discussed here because the SCMs that are thought of as LID—particularly vegetated swales, green roofs, permeable pavement, and rain gardens—are all runoff-volume-reduction SCMs. They are designed to capture the first portion of a rainfall event and to treat the runoff from a few hundred square meters of impervious cover.

BOX 5-7
Evaluation Through Monitoring: Villanova Pervious Concrete SCM

Villanova University's Stormwater Research and Demonstration Park is home to a pervious concrete infiltration site (Figure 5-33). The site, formerly a standard asphalt paved area, is located between two dormitories. The area was reconstructed in the summer of 2002 and outfitted with three infiltration beds overlain with pervious concrete. Usage of the site consists primarily of pedestrian traffic with some light automobile traffic. The pervious concrete site is designed to infiltrate small-volume storms (1 to 2 inches). Roof top runoff is directly piped to the rock bed under the concrete. For these smaller events, there is essentially no runoff from the site.

FIGURE 5-33 Villanova University pervious concrete retrofit site. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.

The pervious concrete is outlined with decorative pavers that divide the pervious concrete into three separate sections as seen in Figure 5-33. Underneath these three sections are individual storage beds. Since the site lies on a significant slope it was necessary to create earthen dams that isolate each storage area. At the top of each dam there is an overflow pipe which connects the storage area with the next one downstream. The final storage bed has an overflow that connects to the existing storm sewer. The beds are approximately 4 feet deep and are filled with stone, producing about 40 percent void space within the beds. A geotextile pervious liner was laid down to separate the storage beds from the undisturbed soil below (Figure 5-34). The primary idea was to avoid any upward migration of the in-situ soil, which could possibly reduce the capacity of the beds over time.

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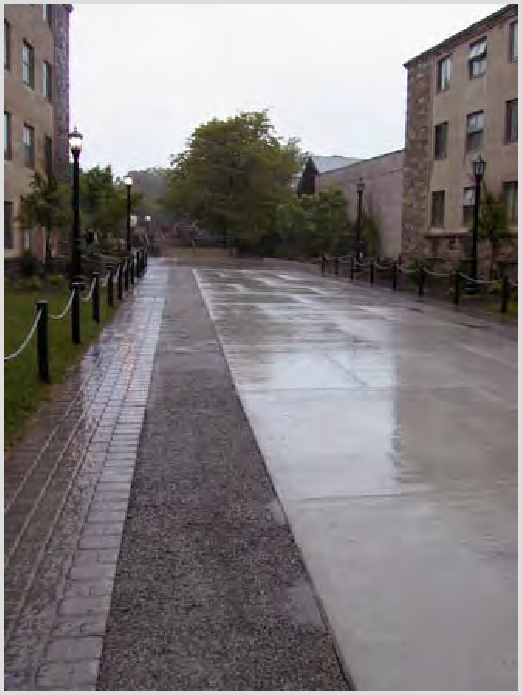
BOX 5-7 Continued

FIGURE 5-34 Infiltration bed under construction. Pervious concrete has functionality and workability similar to that of regular concrete. However, the pervious concrete mix lacks the sand and other fine particles found in regular concrete. This creates a significant amount of void space which allows water to flow relatively unobstructed through the concrete. This site was the first attempt at creating a pervious concrete SCM in the area, and there were construction and material problems. Since that time the industry has matured, and a second site on campus constructed in 2007 has not had any significant difficulties. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.



Note the runoff from impervious concrete spilling over to the pervious concrete. SOURCE: Robert Traver, Villanova University

Continuous monitoring of the site over a number of years has considerably increased our understanding of infiltration. Similar to the bioinfiltration site (Box 5-6), the infiltration rate of permeable concrete does vary as a function of temperature (Braga et al., 2007; Emerson and Traver, 2008), and the SCM volume reduction is impressive. As shown in Figure 5-35, over 95 percent of the yearly rainfall was infiltrated with minimal overflow. Besides hydrologic plots, water quality plots also show the benefits of permeable concrete (Kwiatkowski et al., 2007). Because over 95 percent of the runoff is infiltrated, well over 95 percent of the pollutant mass is also removed. Figure 5-36 shows the level of copper extracted from lysimeters buried under the rock bed and surrounding grass. The plot is arranged in quartiles, with readings in milligrams per liter. Lysimeter samples from under the surrounding grass and one foot and four feet under the infiltration bed all report almost no copper, compared to samples taken from the port in the rock bed and from the gutters draining the roof tops.

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BOX 5-7 Continued

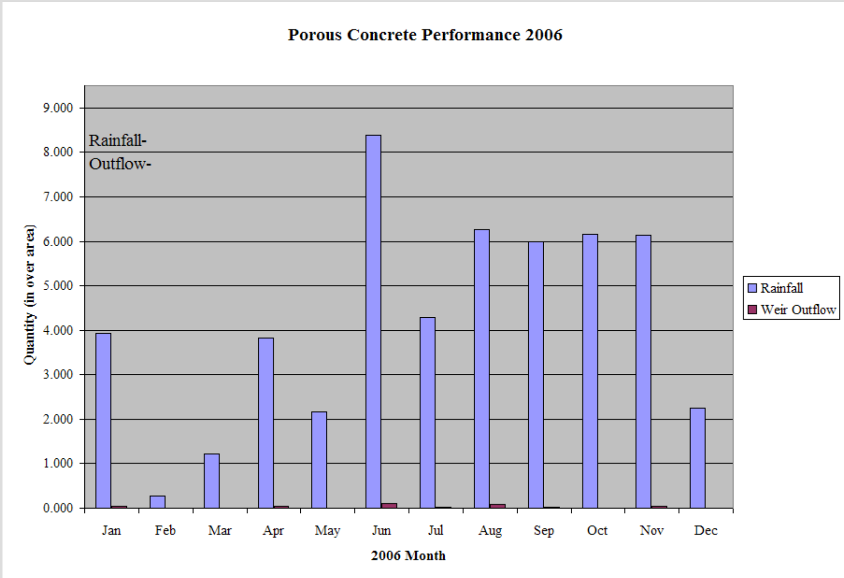

FIGURE 5-35 Rainfall and corresponding outflow from the weir of the SCM. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.

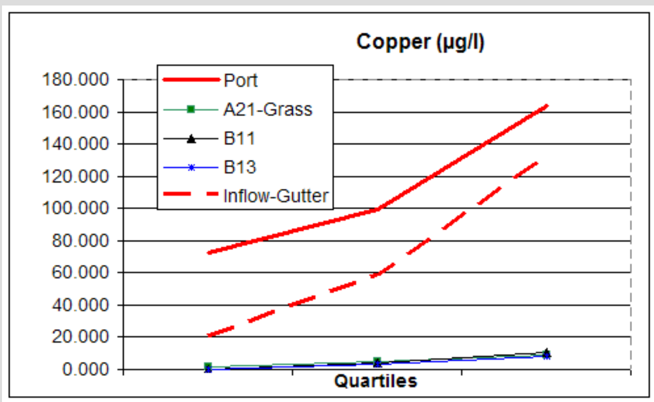

FIGURE 5-36 Copper measured at various locations. The three quartiles correspond to the 25th, 50th, and 75th percentile value of all data collected. A21 is a lysimeter location under the surrounding grass, while B11 and B13 refer to locations that are one foot and four feet under the infiltration bed, respectively. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.

As discussed earlier, several studies have measured the runoff volume reduction of individual LID practices. Fewer studies are available on whether multiple LID practices, when used together, have a cumulative benefit at the neighborhood or catchment scale. Four monitoring studies have clearly documented a major reduction in runoff from developments that employ LID and Better Site Design (see Box 5-8) compared to those that do not. In addition, six studies have documented the runoff reduction benefits of LID at the catchment or watershed scale using a modeling approach (Alexander and Heaney, 2002; Stephens et al., 2002; Holman-Dodds et al., 2003; Coombes, 2004; Hardy et al., 2004; Huber et al., 2006).

Peak Flow Reduction and Runoff Treatment

After efforts are made to prevent the generation of pollutants and to reduce the volume of runoff that reaches stormwater systems, stormwater management focuses on the reduction of peak flows and associated treatment of polluted runoff. The main class of SCMs used to accomplish this is extended detention basins, versions of which have dominated stormwater management for decades. These include a wide variety of ponds and wetlands, including wet ponds (also known as retention basins), dry extended detention ponds (as known as detention basins), and constructed wetlands. By holding a volume of stormwater runoff for an extended period of time, extended detention SCMs can achieve both water quality improvement and reduced peak flows. Generally the goal is to hold the flows for 24 hours at a minimum to maximize the opportunity of settling, adsorption, and transformation of pollutants (based on past pollutant removal studies) (Rea and Traver, 2005). For smaller storm events (one- to two-year storms), this added holding time also greatly reduces the outflows from the SCM to a level that the stream channel can handle. Most wet ponds and stormwater wetlands can hold a “water quality” volume, such that the flows leaving in smaller storms have been held and “treated” for multiple days. Extended detention dry ponds greatly reduce the outflow peaks to achieve the required residence times.

Usually extended detention devices are lower in the treatment train of SCMs, if not at the end. This is both due to their function (they are designed for larger events) and because the required water sources and less permeable soils needed for these SCMs are more likely to be found at the lower areas of the site. Some opportunities exist to naturalize dry ponds or to retrofit wet ponds into stormwater wetlands but it depends on their site configuration and hydrology. Stormwater wetlands are shown in Figures 5-40 and 5-41. A wet pond and a dry extended detention basin are shown in Figures 5-42 and 5-43.

Simple ponds are little more than a hole in the ground, in which stormwater is piped in and out. Dry ponds are meant to be dry between storms, whereas wet ponds have a permanent pool throughout the year. Detention basins reduce peak flows by restricting the outflows and creating a storage area. Depending on the

BOX 5-8
Jordan Cove—An LID Watershed Project

LID refers to the use of a system of small, on-site SCMs to counteract increases in flow and pollution following development and to control smaller runoff events. Although some studies are available that measure the runoff volume reduction of individual LID practices, fewer studies are available on whether multiple LID practices, when used together, have a cumulative benefit at the neighborhood or catchment scale. Of those listed in Table 5-6, Jordan Cove is the most extensively studied, as it was monitored for ten years as part of a paired watershed study that included a site with no SCMs and a site with traditional (detention) SCMs. The watersheds were monitored during calibration, construction, and post-construction periods. The project consisted of 12 lots, and the SCMs used were bioretention, porous pavements, no-mow areas, and education for the homeowners (Figure 5-37).

TABLE 5-6 Review of Recent LID Monitoring Research on a Catchment Scale

Location	Practices	Runoff Reduction
Jordan Cove, USA Dietz and Clausen (2008)	Permeable pavers, bioretention, grass swales, education	84%
Somerset Heights, USA Cheng et al. (2005)	Grass swale, bioretention, and rooftop disconnection	45%
Figtree Place, Australia Coombes et al. (2000)	Rain tanks, infiltration trenches, swales	100%

FIGURE 5-37 Jordan Cove LID subdivision. SOURCE: Reprinted, with permission, from Clausen (2007). Copyright 2007 by John Clausen.

Figure 5-38 (right panel) displays the hydrograph from a post-construction storm comparing the LID, traditional, and control watersheds. Note that the traditional watershed shows the delay and peak reduction from the detention basins, while the LID watershed has almost no runoff. The LID watershed was found to reduce runoff volume by 74 percent by increasing infiltration over preconstruction levels.

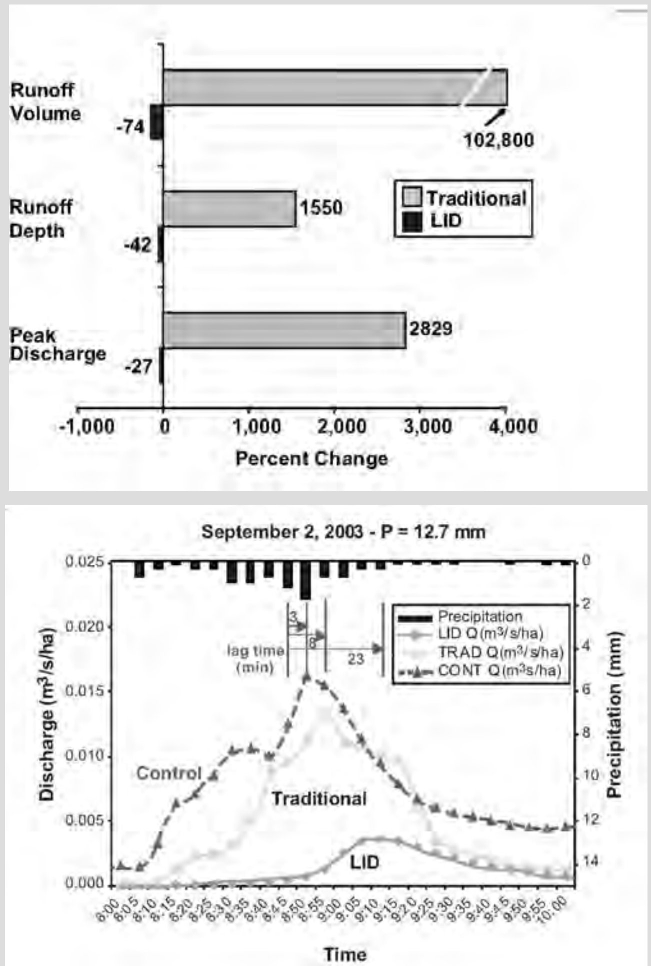

FIGURE 5-38. Significant changes in runoff volume (m^3/week), runoff depth (cm/week) and peak discharge (m^3/sec/week) after construction was completed (top panel). Hydrograph of all three subdivisions in the project, showing the larger volume and rate of runoff from the traditional and control subdivisions, as compared to the LID (bottom panel). SOURCE: Reprinted, with permission, from Clausen (2007). Copyright 2007 by John Clausen.

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BOX 5-8 Continued

Comparisons of nutrient and metal concentrations and total export in the surface water shows the value of the LID approach as well as the significance of the reduction in runoff volume. Figure 5-39 shows the changes in pollutant concentration and mass export before and after construction for the traditional and LID subdivisions. Note that concentrations of TSS and nutrients are increased in the LID subdivision (left-hand panel); this is because swales and natural systems are used in place of piping as a "green" drainage system and because only larger storms leave the site. The right-hand panel shows how the large reduction in runoff achieved through infiltration can dramatically reduce the net export of pollutants from the LID watershed.

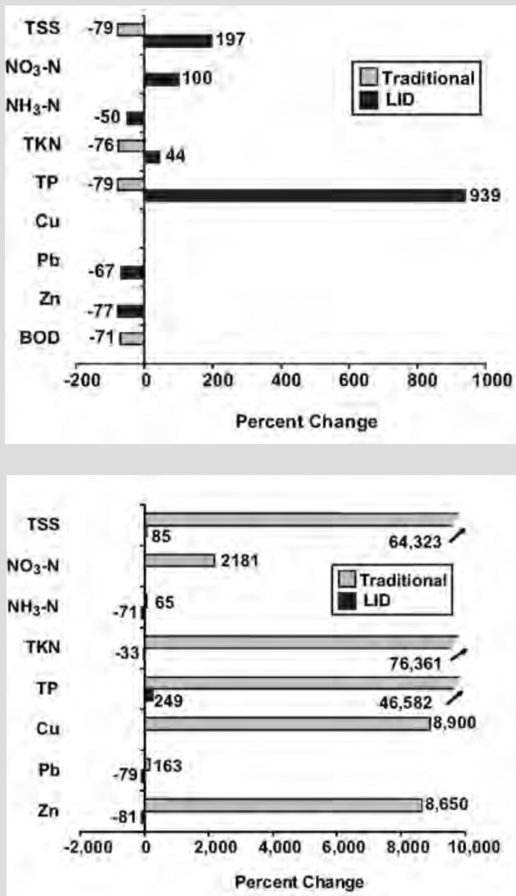

FIGURE 5-39 Significant changes in pollutant concentration, after construction was completed (top). Units are mg/L for NO_3-N, NH_3-N, TKN, TP, and BOD, and µg/L for Cu, Pb, and Zn. Significant changes in mass export (kg/ha/year) after construction was completed (bottom). SOURCE: Reprinted, with permission, from Clausen (2007). Copyright 2007 by John Clausen.

FIGURE 5-40 Constructed wetland. SOURCE: PaDEP (2006).

FIGURE 5-41 Retrofitted stormwater wetland at Villanova University. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.

FIGURE 5-42 Wet pond. SOURCE: PaDEP (2006).

FIGURE 5-43 Dry extended detention pond. SOURCE: PaDEP (2006).

detention time, outflows can be reduced to levels that do not accelerate erosion, that protect the stream channel, and that reduce flooding.

The flow normally enters the structure through a sediment forebay (Figure 5-44), which is included to capture incoming sediment, remove the larger particles through settling, and allow for easier maintenance. Then a meandering path or cell structure is built to "extend" and slow down the flows. The main basin is a large storage area (sometimes over the meandering flow paths). Finally, the runoff exits through an outflow control structure built to retard flow.

Wet ponds, stormwater wetlands, and (to a lesser extent) dry extended detention ponds provide treatment. The first step in treatment is the settling of larger particles in the sediment forebay. Next, for wet ponds a permanent pool of water is maintained so that, for smaller storms, the new flows push out a volume that has had a chance to interact with vegetation and be "treated." This volume is equivalent to an inch of rain over the impervious surfaces in the drainage area. Thus, what exits the SCM during smaller storm events is baseflow contributions and runoff that entered during previous events. For dry extended detention ponds, there is no permanent pool and the outlet is instead greatly restricted. For all of these devices, vegetation is considered crucial to pollutant removal. Indeed, wet ponds are designed with an aquatic bench around the edges to promote contact with plants. The vegetation aids in reduction of flow velocities, provides growth surfaces for microbes, takes up pollutants, and provides filtering (Braskerud, 2001).

The ability of detention structures to achieve a certain level of control is size related—that is, the more peak flow reduction or pollutant removal required, the more volume and surface area are needed in the basin. Because it is not simply the peak flows that are important, but also the duration of the flows that cause damage to the stream channels (McCuen, 1979; Loucks et al., 2005),

FIGURE 5-44 Villanova University sediment forebay. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.

some detention basins are currently sized and installed in series with runoff-volume-reduction SCMs.

The strength of extended detention devices is the opportunity to create habitats or picturesque settings during stormwater management. The weaknesses of these measures include large land requirements, chloride buildup, possible temperature effects, and the creation of habitat for undesirable species in urban areas. There is a perception that these devices promote mosquitoes, but that has not been found to be a problem when a healthy biological habitat is created (Greenway et al., 2003). Another drawback of this class of SCMs is that they often have limited treatment capacity, in that they can reduce pollutants in stormwater only to a certain level. These so-called irreducible effluent concentrations have been documented mainly for ponds and stormwater wetlands, as well as sand filters and grass channels (Schueler, 1998). Finally, it should be noted that either a larger watershed (10–25 acres; CWP, 2004) or a continuous water source is needed to sustain wet ponds and stormwater wetlands.

Maintenance requirements for extended detention basins and wetlands include the removal of built-up sediment from the sediment forebay, harvesting of grasses to remove accumulated nutrients, and repair of berms and structures after storm events. Inspection items relate to the maintenance of the berm and sediment forebay.

While the basic hydrologic function of extended detention devices is well known, their performance on a watershed basis is not. Because they do not significantly reduce runoff volume and are designed on a site-by-site basis using synthetic storm patterns, their exclusive use as a flood reduction strategy at the watershed scale is uncertain (McCuen, 1979; Traver and Chadderton, 1992). Much of this variability is reduced when they are coupled with volume reduction SCMs at the watershed level. Pollutant removal is effected by climate, short-circuiting, and by the schedule of sediment removal and plant harvesting. Extreme events can resuspend captured sediments, thus reintroducing them into the environment. Although there is debate, it seems likely that plants will need to be harvested to accomplish nutrient removal (Reed et al., 1998).

Runoff Treatment

As mentioned above, many SCMs associated with runoff volume reduction and extended detention provide a water quality benefit. There are also some SCMs that focus primarily on water quality with little peak flow or volume effect. Designed for smaller storms, these are usually based on filtration, hydrodynamic separation, or small-scale bioretention systems that drain to a subsequent receiving water or other device. Thus, often these SCMs are used in conjunction with other devices in a treatment train or as retrofits under parking lots. They can be very effective as pretreatment devices when used “higher up” in the watershed than infiltration structures. Finally, in some cases these SCMs are specifically designed to reduce peak flows in addition to providing water quality benefits by introducing elements that make them similar to detention basins; this is particularly the case for sand filters.

The sand filter is relied on as a treatment technology in many regions, particular those where stream geomorphology is less of a concern and thus peak flow control and runoff volume reduction are not the primary goals. These devices can be effective at removing suspended sediments and can extend the longevity and performance of runoff-volume-reduction SCMs. They are also one of the few urban retrofits available, due to the ability to implement them within traditional culvert systems. Figures 5-45 and 5-46 show designs for the Austin sand filter and the Delaware sand filter.

Filters use sand, peat, or compost to remove particulates, similar to the processes used in drinking water plants. Sand filters primarily remove suspended solids and ammonia nitrogen. Biological material such as peat or compost provides adsorption of contaminants such as dissolved metals, hydrocarbons, and other organic chemicals. Hydrodynamic devices use rotational forces to separate the solids from the flow, allowing the solids to settle out of the flow stream. There is a recent class of bioretention-like manufactured devices that combine inlets with planters. In these systems, small volumes are directed to a soil planter area, with larger flows bypassing and continuing down the storm sewer system. In any event, for manufactured items the user needs to look to the manufacturer’s published and reviewed data to understand how the device should be applied.

FIGURE 5-45 Austin sand filter. SOURCE: Robert Traver, Villanova University.

FIGURE 5-46 Delaware sand filter. SOURCE: Tom Schueler, Chesapeake Stormwater Network.

The level of control that can be achieved with these SCMs depends entirely on sizing of the device based on the incoming flow and pollutant loads. Each unit has a certified removal rate depending on inflow to the SCM. Also all units have a maximum volume or rate of flow they can treat, such that higher flows are bypassed with no treatment. Thus, the user has to determine what size unit is needed and the number to use based on the area's hydrologic cycle and what criteria are to be met.

With the exception of some types of sand filters, the strengths of water quality SCMs are that they can be placed within existing infrastructure or under parking lots, and thus do not take up land that may be used for other purposes. They make excellent choices for retrofit situations. For filters, there is a wealth of experience from the water treatment community on their operations. For all manufactured devices there are several testing protocols that have been set up to validate the performance of the manufactured devices (the sufficiency of which is discussed in Box 5-9). Weaknesses of these devices include their cost and maintenance requirements. Regular maintenance and inspection at a high level are required to remove captured pollutants, to replace mulch, or to rake and remove the surface layer to prevent clogging. In some cases specialized equipment (vacuum trucks) is required to remove built-up sediment. Although the underground placement of these devices has many benefits, it makes it easy to neglect their maintenance because there are no signs of reduced performance on the surface. Because these devices are manufactured, the unit construction cost is usually higher than for other SCMs. Finally, the numerous testing protocols are confusing and prevent more widespread applications.

The chief uncertainty with these SCMs is due to the lack of certification of some manufactured devices. There is also concern about which pollutants are removed by which class of device. For example, hydrodynamic devices and sand filters do not address dissolved nutrients, and in some cases convert suspended pollutants to their dissolved form. Both issues are related to the false perception that a single SCM must be found that will comprehensively treat stormwater. Such pressures often put vendors in a position of trying to certify that their devices can remove all pollutants. Most often, these devices can serve effectively as part of a treatment train, and should be valued for their incremental contributions to water quality treatment. For example, a filter that removes sediment upstream of a bioinfiltration SCM can greatly prolong the life of the infiltration device.

Aquatic Buffers and Managed Floodplains

Aquatic buffers, sometimes also known as stream buffers or riparian buffers, involve reserving a vegetated zone adjacent to streams, shorelines, or wetlands as part of development regulations or as an ordinance. In most regions of the country, the buffer is managed as forest, although in arid or semi-arid

BOX 5-9
Insufficient Testing of Proprietary Stormwater Control Measures

Manufacturers of proprietary SCMs offer a service that can save municipalities time and money. Time is saved by the ability of the manufactures to quickly select a model matching the needs of the site. A city can minimize the cost of buying the product by requiring the different manufacturers to submit bids for the site. All the benefits of the service will have no meaning, however, if the cities cannot trust the performance claims of the different products. Because the United States does not have, at this time, a national program to verify the performance of proprietary SCMs, interested municipalities face a high amount of uncertainty when they select a product. Money could be wasted on products that might have the lowest bid, but do not achieve the water quality goals of the city or state.

The EPA's Environmental Technology Verification (ETV) program was created to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The Wet Weather Flow Technologies Pilot was established as part of the ETV program to verify commercially available technologies used in the abatement and control of urban stormwater runoff, combined sewer overflows, and sanitary sewer overflows. Ten proprietary SCMs were tested under the ETV program (see Figure 5-47), and the results of the monitoring are available on the National Sanitation Foundation International website. Unfortunately, the funding for the ETV program was discontinued before all the stormwater products could be tested. Without a national testing program some states have taken a more regional approach to verifying the performance of proprietary practices, while most states do not have any type of verification or approval program.

The Washington Department of Ecology has supported a testing protocol called Technology Assessment Protocol–Ecology that describes a process for evaluating and reporting on the performance and appropriate uses of emerging SCMs. California, Massachusetts, Maryland, New Jersey, Pennsylvania, and Virginia have sponsored a testing program called Technology Acceptance and Reciprocity Partnership (TARP), and a number of products are being tested in the field. The State of Wisconsin has prepared a draft technical standard (1006) describing methods for predicting the site-specific reduction efficiency of proprietary sedimentation devices. To meet the criteria in the standard the manufacturers can either use a model to predict the performance of the practice or complete a laboratory protocol designed to develop efficiency curves for each product. Although none of these state or federal verification efforts have produced enough information to sufficiently reduce the uncertainty in selection and sizing of proprietary SCMs, many proprietary practices are being installed around the country, because of the perceived advantage of the service being provided by the manufacturers and the sometimes overly optimistic performance claims.

All those involved in stormwater management, including the manufacturers, will have a much better chance of implementing a cost-effective stormwater program in their cities if the barriers to a national testing program for proprietary SCMs are eliminated. Two of the barriers to the ETV program were high cost and the transferability of the results. Also, the ETV testing did not produce results that could be used in developing efficiency curves for the product. A new national testing program could reduce the cost by using laboratory testing instead of field testing. Each manufacturer would only have to do one series of tests in the lab and the results would be applicable to the entire country. The laboratory

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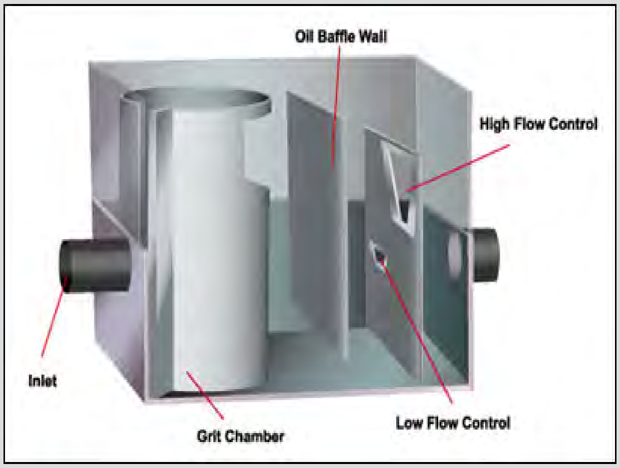
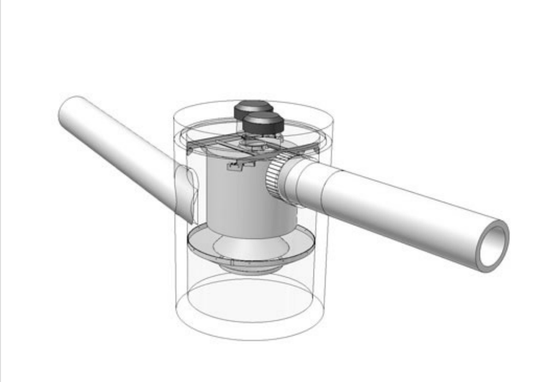
BOX 5-9 Continued

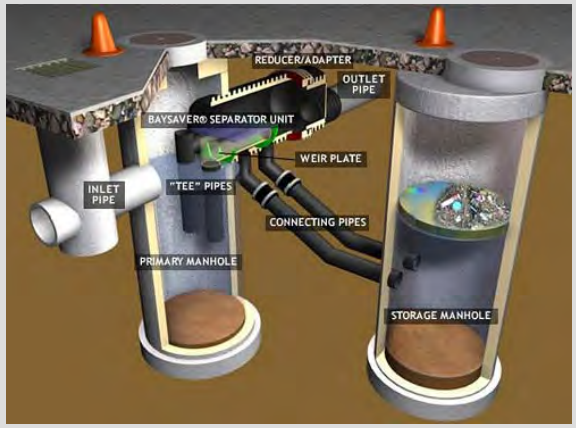
protocol in the Wisconsin Technical Standard 1006 provides a good example of what should be included to evaluate each practice over a range of particle sizes and flows. These types of laboratory data could also be used to produce efficiency curves for each practice. It would be relatively easy for state and local agencies to review the benefits of each installation if the efficiency curves were incorporated into urban runoff models, such as WinSLAMM or P8.



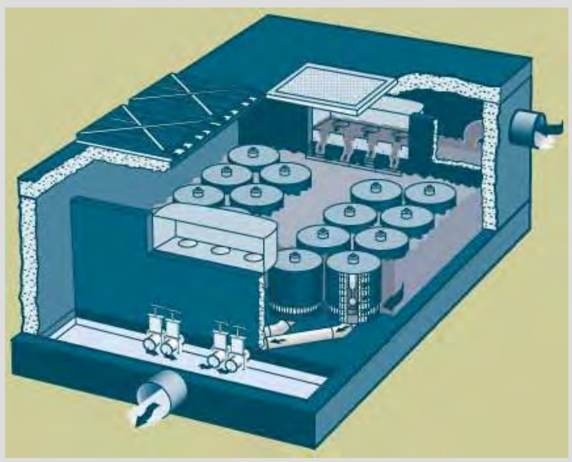
Stormwater 360 Hydrodynamic Separator. SOURCE: EPA (2005c).



Downstream Defender. SOURCE: Available online at http://epa.gov/Region1/assistance/ ceitts/stormwater/techs/downstreamdefender.html



Bay Seperator. SOURCE: EPA (2005a).



Stormfilter. SOURCE: EPA (2005b).

FIGURE 5-47 Proprietary Manufactured Devices tested by the ETV Program.

regions it may be managed as prairie, chapparal, or other cover. When properly designed, buffers can both reduce runoff volumes and provide water quality treatment to stormwater.

The performance of urban stream buffers cannot be predicted from studies of buffers installed to remove sediment and nutrients from agricultural areas (Lowrance and Sheridan, 2005). Agricultural buffers have been reported to have high sediment and nutrient removal because they intercept sheet flow or shallow groundwater flow in the riparian zone. By contrast, urban stream buffers often receive concentrated surface runoff or may even have a storm-drain pipe that short-circuits the buffer and directly discharges into the stream. Consequently, the pollutant removal capability of urban stream buffers is limited, unless they are specifically designed to distribute and treat stormwater runoff (NRC, 2000). This involves the use of level spreaders, grass filters, and berms to transform concentrated flows into sheet flow (Hathaway and Hunt, 2006). Such designed urban stream buffers have been applied widely in the Neuse River basin to reduce urban stormwater nutrient inputs to this nitrogen-sensitive waterbody.

The primary benefit of buffers is to help maintain aquatic biodiversity within the stream. Numerous researchers have evaluated the relative impact of riparian forest cover and impervious cover on stream geomorphology, aquatic insects, fish assemblages, and various indexes of biotic integrity. As a group, the studies suggest that indicator values for urban stream health increase when riparian forest cover is retained over at least 50 to 75 percent of the length of the upstream network (Goetz et al., 2003; Wang et al., 2003b; McBride and Booth, 2005; Moore and Palmer, 2005). The width of the buffer is also important for enhancing its stream protection benefits, and it ranges from 25 to 200 feet depending on stream order, protection objectives, and community ordinances. At the present time, there are no data to support an optimum width for water quality purposes. The beneficial impact of riparian forest cover is less detectable when watershed impervious cover exceeds 15 percent, at which point degradation by stormwater runoff overwhelms the benefits of the riparian forest (Roy et al., 2005, 2006; Walsh et al., 2007).

Maintenance, inspection, and compliance for buffers can be a problem. In most communities, urban stream buffers are simply a line on a map and are not managed in any significant way after construction is over. As such, urban stream buffers are prone to residential encroachment and clearing, and to colonization by invasive plants. Another important practice is to protect, preserve, or otherwise manage the ultimate 100-year floodplain so that vulnerable property and infrastructure are not damaged during extreme floods. Federal Emergency Management Agency (FEMA), state, and local requirements often restrict or control development on land within the floodway or floodplain. In larger streams, the floodway and aquatic buffer can be integrated together to achieve multiple social objectives.

Stream Rehabilitation

While not traditionally considered an SCM, certain stream rehabilitation practices or approaches can be effective at recreating stream physical habitat and ecosystem function lost during urbanization. When combined with effective SCMs in upland areas, stream rehabilitation practices can be an important component of a larger strategy to address stormwater. From the standpoint of mitigating stormwater impacts, four types of urban stream rehabilitation are common:

- Practices that stabilize streambanks and/or prevent channel incision/enlargement can reduce downstream delivery of sediments and attached nutrients (see Figure 5-48). Although the magnitude of sediment delivery from urban-induced stream-channel enlargement is well documented, there are very few published data to quantify the potential reduction in sediment or nutrients from subsequent channel stabilization.

- Streams can be hydrologically reconnected to their floodplains by building up the profile of incised urban streams using grade controls so that the channel and floodplain interact to a greater degree. Urban stream reaches that have been so rehabilitated have increased nutrient uptake and processing rates, and in particular increased denitrification rates, compared to degraded urban streams prior to treatment (Bukavecas, 2007; Kaushal et al., 2008). This suggests that urban stream rehabilitation may be one of many elements that can be considered to help decrease loads in nutrient-sensitive watersheds.

- Practices that enhance in-stream habitat for aquatic life can improve the expected level of stream biodiversity. However, Konrad (2003) notes that improvement of biological diversity of urban streams should still be considered an experiment, since it is not always clear what hydrologic, water quality, or habitat stressors are limiting. Larson et al. (2001) found that physical habitat improvements can result in no biological improvement at all. In addition, many of the biological processes in urban stream ecosystems remain poorly understood, such as carbon processing and nutrient uptake.

- Some stream rehabilitation practices can indirectly increase stream biodiversity (such as riparian reforestation, which could reduce stream temperatures, and the removal of barriers to fish migration).

It should be noted that the majority of urban stream rehabilitation projects undertaken in the United States are designed for purposes other than mitigating the impacts of stormwater or enhancing stream biodiversity or ecosystem function (Bernhardt et al., 2005). Most stream rehabilitation projects have a much narrower design focus, and are intended to protect threatened infrastructure,

FIGURE 5-48 Three photographs illustrate stream rehabilitation in Denver. The top picture is a creek that has eroded in its bed due to urbanization. The middle picture shows a portion of the stabilized creek immediately after construction. Check structures, which keep the creek from cutting its bed, are visible in the middle distance. The bottom image shows the creek just upstream of one of the check structures two years after stabilization. The thickets of willows established themselves naturally. The only revegetation performed was to seed the area for erosion control. SOURCE: Courtesy of Wenk Associates.

naturalize the stream corridor, achieve a stable channel, or maintain local bank stability (Schueler and Brown, 2004). Improvements in either biological health or the quality of stormwater runoff have rarely been documented.

Unique design models and methods are required for urban streams, compared to their natural or rural counterparts, given the profound changes in hydrologic and sediment regime and stream–floodplain interaction that they experience (Konrad, 2003). While a great deal of design guidance on urban stream rehabilitation has been released in recent years (FISRWG, 2000; Doll and Jennings, 2003; Schueler and Brown, 2004), most of the available guidance has not yet been tailored to produce specific outcomes for stormwater mitigation, such as reduced sediment delivery, increased nutrient processing, or enhanced stream biodiversity. Indeed, several researchers have noted that many urban stream rehabilitation projects fail to achieve even their narrow design objectives, for a wide range of reasons (Bernhardt and Palmer, 2007; Sudduth et al., 2007). This is not surprising given that urban stream rehabilitation is relatively new and rarely addresses the full range of in-stream alteration generated by watershed-scale changes. This shortfall suggests that much more research and testing are needed to ensure urban stream habilitation can meet its promise as an emerging SCM.

Municipal Housekeeping (Street Sweeping and Storm-Drain Cleanouts)

Phase II NPDES stormwater permits specifically require municipal good housekeeping as one of the six minimum management measures for MS4s. Although EPA has not presented definitive guidance on what constitutes "good housekeeping", CWP (2008) outlines ten municipal operations where housekeeping actions can improve the quality of stormwater, including the following:

- municipal hotspot facility management,
- municipal construction project management,
- road maintenance,
- street sweeping,
- storm-drain maintenance,
- stormwater hotline response,
- landscape and park maintenance ,
- SCM maintenance, and
- employee training.

The overarching theme is that good housekeeping practices at municipal operations provide source treatment of pollutants before they enter the storm-drain system. The most frequently applied practices are street sweeping (Figure 5-49) and sediment cleanouts of sumps and storm-drain inlets. Most communities

FIGURE 5-49 Vacuum street sweeper at Villanova University. SOURCE: Robert Traver, Villanova University.

conduct both operations at some frequency for safety and aesthetic reasons, although not specifically for the sake of improving stormwater quality (Law et al., 2008).

Numerous performance monitoring studies have been conducted to evaluate the effect of street sweeping on the concentration of stormwater pollutants in downstream storm-drain pipes (see Pitt, 1979; Bender and Terstriep, 1994; Brinkman and Tobin, 2001; Zarrielo et al., 2002; Chang et al., 2005; USGS, 2005; Law et al., 2008). The basic finding is that regular street sweeping has a low or limited impact on stormwater quality, depending on street conditions, sweeping frequency, sweeper technology, operator training, and on-street parking. Sweeping will always have a limited removal capability because rainfall events frequently wash off pollutants before the sweeper passes through, and only some surfaces are accessible to the sweeper, thus excluding sidewalk, driveways, and landscaped areas. Frequent sweeping (i.e., weekly or monthly) has a moderate capability to remove sediment, trash and debris, coarse solids, and organic matter.

Fewer studies have been conducted on the pollutant removal capability of frequent sediment cleanout of storm-drain inlets, most in regions with arid climates (Lager et al., 1977; Mineart and Singh, 1994; Morgan et al., 2005). These studies have shown some moderate pollutant removal if cleanouts are done on a monthly or quarterly basis. Most communities, however, report that they clean out storm drains on an annual basis or in response to problems or drainage complaints (Law, 2006).

Frequent sweeping and cleanouts conducted on the dirtiest streets and storm drains appear to be the most effective way to include these operations in the stormwater treatment train. However, given the uncertainty associated with the expected pollutant removal for these practices, street sweeping and storm-drain cleanout cannot be relied on as the sole SCMs for an urban area.

Illicit Discharge Detection and Elimination

MS4 communities must develop a program to detect and eliminate illicit discharges to their storm-drain system as a stormwater NPDES permit condition. Illicit discharges can involve illegal cross-connections of sewage or washwater into the storm-drain system or various intermittent or transitory discharges due to spills, leaks, dumping, or other activities that introduce pollutants into the storm-drain system during dry weather. National guidance on the methods to find and fix illicit discharges was developed by Brown et al. (2004). Local illicit discharge detection and elimination (IDDE) programs represent an ongoing and perpetual effort to monitor the network of pipes and ditches to prevent pollution discharges.

The water quality significance of illicit discharges has been difficult to define since they occur episodically in different parts of a municipal storm drain system. Field experience in conducting outfall surveys does indicate that illicit discharges may be present at 2 to 5 percent of all outfalls at any given time. Given that pollutants are being introduced into the receiving water during dry weather, illicit discharges may have an amplified effect on water quality and biological diversity.

Many communities indicate that they employ a citizen hotline to report illicit discharges and other water quality problems (Brown et al., 2004), which sharply increases the number of illicit discharge problems observed.

Stormwater Education

Like IDDE, stormwater education is one of the six minimum management measures that MS4 communities must address in their stormwater NPDES permits. Stormwater education involves municipal efforts to make sure individuals understand how their daily actions can positively or negatively influence water quality and work to change specific behaviors linked to specific pollutants of concern (Schueler, 2001c). Targeted behaviors include lawn fertilization, littering, car fluid recycling, car washing, pesticide use, septic system maintenance, and pet waste pickup. Communities may utilize a wide variety of messages to make the public aware of the behavior and more desirable alternatives through radio, television, newspaper ads, flyers, workshops, or door-to-door outreach. Several communities have performed before-and-after surveys to assess both the penetration rate for these campaigns and their ability to induce changes in actual behaviors. Significant changes in behaviors have been recorded (see Schueler, 2002), although few studies are available to link specific stormwater quality improvements to the educational campaigns (but see Turner, 2005; CASQA, 2007).

Residential Stewardship

This SCM involves municipal programs to enhance residential stewardship to improve stormwater quality. Residents can undertake a wide range of activities and practices that can reduce the volume or quality of runoff produced on their property or in their neighborhood as a whole. This may include installing rain barrels or rain gardens, planting trees, xeriscaping, downspout disconnection, storm-drain marking, household hazardous waste pickups, and yard waste composting (CWP, 2005). This expands on stormwater education in that a municipality provides a convenient delivery service to enable residents to engage in positive watershed behavior. The effectiveness of residential stewardship is enhanced when carrots are provided to encourage the desired behavior, such as subsidies, recognition, discounts, and technical assistance (CWP, 2005). Consequently, communities need to develop a targeted program to educate residents and help them engage in the desired behavior.

SCM Performance Monitoring and Modeling

Stormwater is characterized by widely fluctuating flows. In addition, inflow pollutant concentrations vary over the course of a storm and can be a function of time since the last storm, watershed, size and intensity of rainfall, season, amount of imperviousness, pollutant of interest, and so forth. This variability of the inflow to SCMs along with the very nature of SCMs makes performance monitoring a complex task. Most SCMs are built to manage stormwater, not to enable flow and water quality monitoring. Furthermore, they are incorporated into the collection system and spread throughout developments. Measurement of multiple inflows, outflows, evapotranspiration, and infiltration are simply not feasible for most sites. Many factors, such as temperature and climate, play a role in how well SCMs function. Infiltration rates can vary by an order of magnitude as a function of temperature (Braga et al., 2007; Emerson and Traver, 2008), such that a reading in late summer might be twice that of a winter reading. Determining performance can be further complicated because, e.g., at the start of a storm a detention basin could still be partially full from a previous storm, and removal rates for wetlands are a function of the growing season, not to mention snowmelt events.

Monitoring of SCMs is usually performed for one of two purposes: functionality or more intensive performance monitoring. Monitoring of functionality is primarily to establish that the SCM is functioning as designed. Performance monitoring is focused on determining what level of performance is achieved by the SCM.

Functionality Monitoring

Functionality monitoring, in a broad sense, involves checking to see whether the SCM is functioning and screening it for potential problems. Both the federal and several state industrial and construction stormwater general permits have standard requirements for visual inspections following a major storm event. Visual observations of an SCM by themselves do not provide information on runoff reduction or pollutant removal, but rather only that the device is functioning as designed. Adding some grab samples for laboratory analysis can act as a screening tool to determine if a more complex analysis is required.

The first step of functionality monitoring for any SCM is to examine the physical condition of the device (piping, pervious surfaces, outlet structure, etc.). Visual inspection of sediments, eroded berms, clogged outlets, and other problems are good indications of the SCM's functionality (see Figure 5-50). For infiltration devices, visiting after a storm event will show whether or not the device is functioning. A simple staff gauge (Figure 5-51) or a stilling well in pervious pavement can be used to measure the amount of water-level change over several days to estimate infiltration rates. Minnesota suggests the use of fire equipment or hydrants to fill infiltration sites with a set volume of water to measure the rate of infiltration. For sites that are designed to capture a set volume, for example a green roof, a visit could be coordinated with a rainfall event of the appropriate size to determine whether there is overflow during the event. If so, then clearly further investigation is required.

FIGURE 5-50 Rusted outlet structure. SOURCE: Reprinted, with permission, from Emerson. Copyright by Clay Emerson.

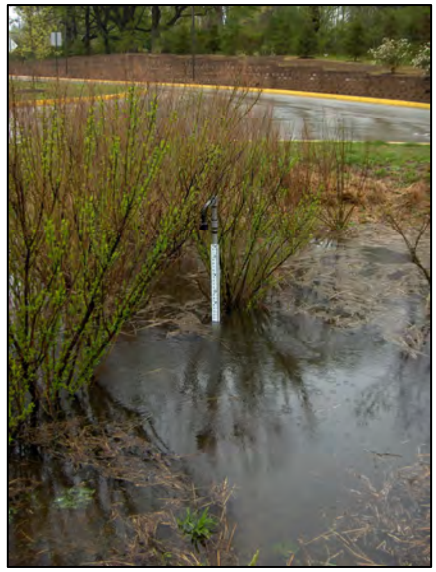


FIGURE 5-51 Staff gauge attached to ultrasonic sensor after a storm. SOURCE: Reprinted, with permission, from VUSP. Copyright by VUSP.

For extended detention and stormwater wetlands, the depth of water during an event is an indicator of how well the SCM is functioning. Usually high-water marks are easy to determine due to debris or mud marks on the banks or the structures. If the size of the storm event is known, the depths can be compared to what was expected for the structure. Other indicators of problems would include erosion downstream of the SCM, algal blooms, invasive species, poor water clarity, and odor.

For water quality and manufactured devices, visual inspections after a storm event can determine whether the SCM is functioning properly. Standing water over a sand or other media filter 48 hours after a storm is a sign of problems. Odor and lack of flow clarity could be a sign of filter breakthrough or other problems. For manufactured devices, literature about the device should specify inspection and maintenance procedures.

Monitoring of nonstructural SCMs is almost exclusively limited to visual observation due to the difficulty in applying numerical value to their benefits. Visual inspection can identify eroded stream buffers, additional paved areas, or denuded conservation areas (see Figure 5-52).

Performance Monitoring

Performance monitoring is an extremely intensive effort to determine the performance of an SCM over either an individual storm event or over a series of

FIGURE 5-52 Wooded conservation area stripped of trees. Note pile of sawdust. SOURCE: Robert Traver, Villanova University.

storms. It requires integration of flow and water quality data creating both a hydrograph and a polutograph for a storm event as shown in Figure 5-53. The creation of these graphs requires continuous monitoring of the hydrology of the site and multiple water quality samples of the SCM inflow and outflow, the vadose zone, and groundwater. Event mean concentrations can then be determined from these data. There should be clear criteria for the number and type of storms to be sampled and for the conditions preceding a storm. For example, for most SCMs it would be improper to sample a second storm event in series, as the inflow may be free of pollutants and the soil moisture filled, resulting in a poor or negative performance. (Extended detention basins are an exception because the outflow during a storm event may include inflows from previous events.) The size of the sampled storm is also important. If the water quality goal is focused on smaller events, the 100-year storm would not give a proper picture of the performance because the occurrence is so rare that it is not a water quality priority.

For runoff-volume-reduction SCMs, performance monitoring can be extremely difficult because these systems are spread over the project site. The monitoring program must consider multiple-size storms because these SCMs are designed to remove perhaps the first inch of runoff. Therefore, for storms of less than an inch, there is no surface water release, so the treatment is 100

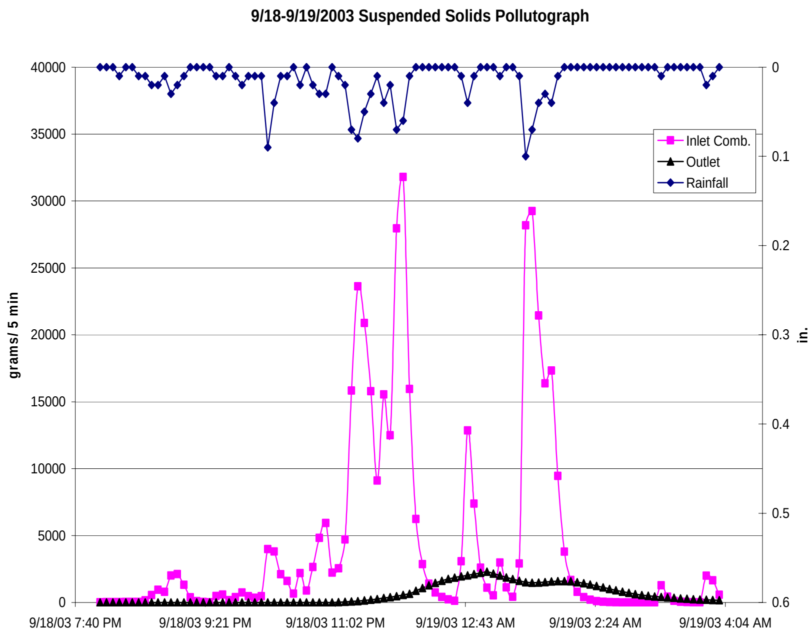


FIGURE 5-53 Example polutograph that displays inflow and outflow TSS during a storm event from the Villanova wetland stormwater SCM. SOURCE: Reprinted, with permission, Rea and Traver (2005). Copyright 2005 by the American Society of Civil Engineers.

percent effective for surface discharges. During larger events, a bioretention SCM or green roof may export pollutants. When viewed over the entire spectrum of storms, these devices are an outstanding success; however, this may not be evident during a hurricane.

Through the use of manufactured weirs (Figure 5-54), it is possible to develop flow-depth criteria based on hydraulic principles for surface flows entering or leaving the SCM. Where this is not practical, various manufacturers have Doppler velocity sensors that, combined with geometry and depth, provide a reasonable continuous record of flow. Measurement of depth within a device can be accomplished through use of pressure transducers, bubblers, float gauges, and ultrasonic sensors. Other common measures would include rainfall and temperature. One advantage of these data recording systems is that they can be connected to water quality probes and automated samplers to provide a flow-weighted sample of the event for subsequent laboratory analysis. Field calibration and monitoring of these systems is required.

Groundwater sampling for infiltration SCMs is a challenge. Although the rate of change in water depth can indicate volume moving into the soil mantle, it is difficult to establish whether this flow is evapotranspirated or ends up as baseflow or deep groundwater input. Sampling in the vadose zone can be established

FIGURE 5-54 Weir flow used to measure flow rate. SOURCE: Robert Traver, Villanova University.

through the use of lysimeters that, through a vacuum, draw out water from the soil matrix. Soil moisture probes can give a rough estimation of the soil moisture content, and weighing lysimeters can establish evapotranspiration rates. Finally groundwater wells can be used to establish the effect of the SCM on the groundwater depth and quality during and after storm events.

Performance monitoring of extended detention SCMs is difficult because the inflows and outflows are variable and may extend over multiple days. Hydrologic monitoring can be accomplished using weirs (Figure 5-54), flow meters, and level detectors. The new generation of temperature, dissolved oxygen, and conductivity probes allows for automated monitoring. (It should be noted that in many cases the conductivity probes are observing chlorides, which are not generally removed by SCMs.) In many cases monitoring of the downstream stream-channel geomorphology and stream habitat may be more useful than performance monitoring when assessing the effect of the SCM.

The performance monitoring of treatment devices is straightforward and involves determining the pollutant mass inflows and outflows. Performance monitoring of manufactured SCMs has been established through several protocols. An example is TARP, used by multiple states (*http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/tarp/*). This requires the manufacturer to test their units according to a set protocol of lab or field experiments to set performance criteria. Several TARP member and other states have published revised protocols for their use. These and other similar criteria are evolving and the subject of considerable effort by industry organizations that include the American Society of Civil Engineers.

Finally, much needs to be done to determine the performance of nonstructural SCMs, for which little to no monitoring data are available (see Table 5-2). Currently most practitioners expand upon current hydrologic modeling techniques to simulate these techniques. For example, disconnection of impervious surfaces is often modeled by adding the runoff from the roof or parking area as distributed "rainfall" on the pervious area. Experiments and long-term monitoring are needed for these SCMs.

More information on SCM monitoring is available through the International Stormwater BMP Database (*http://www.bmpdatabase.org*).

Modeling of SCM performance

Modeling of SCMs is required to understand their individual performance and their effect on the overall watershed. The dispersed nature of their implementation, the wide variety of possible SCM types and goals, and the wide range of rainfall events they are designed for makes modeling of SCMs extremely challenging. For example, to model multiple SCMs on a single site may require simulation of many hydrologic and environmental processes for each SCM in series. Modeling these effects over large watersheds by simulating each SCM is not only impractical, but the noise in the modeling may make the simulation results suspect. Thus, it is critical to understand the model's purpose, limitations, and applicability.

As discussed in Chapter 4, one approach to simulating SCM performance is through mathematical representation of the unit processes. The large volumes of data needed for process-based models generally restrict their use to smaller-scale modeling. For flow this would start with the hydrograph entering the SCM and include infiltration, evapotranspiration, routing through the system, or whatever flow paths were applicable. The environmental processes that would need to be represented could include settling, adsorption, biological transformation, and soil physics. Currently there are no environmental process models that work across the range of SCMs. Rather, the state of art is to use general removal efficiencies from publications such as the International Stormwater BMP Database (http://www.bmpdatabase.org) and the Center for Watershed Protection's National Pollutant Removal Database (CWP, 2000b, 2007b). Unfortunately, this approach has many limitations. The percent removal used on a site and storm basis does not include storm intensity, period between the storms, land use, temperature, management practices, whether other SCMs are upstream, and so forth. It also should be noted that percent removals are a surface water statistic and do not address groundwater issues or include any biogeochemistry.

Mechanistic simulation of the hydrologic processes within an SCM is much advanced compared to environmental simulation, but from a modeling scale it is still evolving. Indeed, models such as the Prince George's County Decision Support System are greatly improved in that the hydrologic simulation of the SCM includes infiltration, but they still do not incorporate the more rigorous soil physics and groundwater interactions. Some models, such as the Stormwater Management Model (SWMM), have the capability to incorporate mechanistic descriptions of the hydrologic processes occurring inside an SCM.

At larger scales, simulation of SCMs is done primarily using lumped models that do not explicitly represent the unit processes but rather the overall effects. For example, the goal may be to model the removal of 2 cm of rainfall from every storm from bioinfiltration SCMs. Thus, all that would be needed is how many SCMs are present and their configuration and what their capabilities are within your watershed. What is critical for these models is to represent the interrelated processes correctly and to include seasonal effects. Again, the pollutant removal capability of the SCM is represented with removal efficiencies derived from publications.

Regardless of the scale of the model, or the extent to which it is mechanistic or not, nonstructural SCMs are a challenge. Limiting impervious surface or maintenance of forest cover have been modeled because they can be represented as the maintenance of certain land uses. However, aquatic buffers, disconnected impervious surfaces, stormwater education, municipal housekeeping, and most other nonstructural SCMs are problematic. Another challenge from a watershed perspective is determining what volume of pollutants comes from streambank erosion during elevated flows versus from nonpoint source pollution. Most hydrologic models do not include or represent in-stream processes.

In order to move forward with modeling of SCMs, it will be necessary to better understand the unit processes of the different SCMs, and how they differ for hydrology versus transformations. Research is needed to gather performance numbers for the nonstructural SCMs. Until such information is available, it will be virtually impossible to predict that an individual SCM can accomplish a certain level of treatment and thus prevent a nearby receiving water from violating its water quality standard.

DESIGNING SYSTEMS OF STORMWATER CONTROL MEASURES ON A WATERSHED SCALE

Most communities have traditionally relied on stormwater management approaches that result in the design and installation of SCMs on a site-by-site basis. This has created a large number of individual stormwater systems and SCMs that are widely distributed and have become a substantial part of the contemporary urban and suburban landscape. Typically, traditional stormwater infrastructure was designed on a subdivision basis to reduce peak storm flow rates to predevelopment levels for large flood events (> 10-year return period). The problem with the traditional approach is that (1) the majority of storms throughout the year are small and therefore pass through the detention facilities uncontrolled, (2) the criterion of reducing storm flow does not address the need for reducing total storm volume, and (3) the facilities are not designed to work as a system on a watershed scale. In many cases, the site-by-site approach has exacerbated downstream flooding and channel erosion problems as a watershed is gradually built out. For example, McCuen (1979) and Emerson et al. (2005) showed that an unplanned system of site-based SCMs can actually increase flooding on a watershed scale owing to the effect of many facilities discharging into a receiving waterbody in an uncoordinated fashion—causing the very flooding problem the individual basins were built to solve.

With the relatively recent recognition of unacceptable downstream impacts and the regulation of urban stormwater quality has come a rethinking of the design of traditional stormwater systems. It is becoming rapidly understood that stormwater management should occur on a watershed scale to prevent flow control problems from occurring or reducing the chances that they might become worse. In this context, the "watershed scale" refers to the small local watershed to which the individual site drains (i.e., a few square miles within a single municipality). Together, the developer, designer, plan reviewer, owners, and the municipality jointly install and operate a linked and shared system of distributed practices across multiple sites that achieve small watershed objectives. Many metropolitan areas around the country have institutions, such as the Southeast Wisconsin Regional Planning Commission and the Milwaukee Metropolitan Sewage District, that are doing stormwater master planning to reduce flooding, bank erosion, and water quality problems on a watershed scale.

Designing stormwater management on a watershed scale creates the opportunity to evaluate a system of SCMs and maximize overall effectiveness based on multiple criteria, such as the incremental costs to development beyond traditional stormwater infrastructure, the limitations imposed on land area required for site planning, the effectiveness at improving water quality or attenuating discharges, and aesthetics. Because the benefits that accrue with improved water quality are generally not realized by those entities required to implement SCMs, greater value must be created beyond the functional aspects of the facility if there is to be wide acceptance of SCMs as part of the urban landscape. Stormwater systems designed on a watershed basis are more likely to be seen as a multi-functional resource that can contribute to the overall quality of the urban environment. Potential even exists to make the stormwater system a primary component of the civic framework of the community—elements of the public realm that serve to enhance a community's quality of life like public spaces and parks. For example, in central Minneapolis, redevelopment of a 100-acre area called Heritage Park as a mixed-density residential neighborhood was organized around two parks linked by a parkway that served dual functions of recreation and stormwater management.

Key elements of the watershed approach to designing systems of SCMs are discussed in detail below. They include the following:

1. Forecasting the current and future development types.

2. Forecasting the scale of current and future development.
3. Choosing among on-site, distributed SCMs and larger, consolidated SCMs.
4. Defining stressors of concern.
5. Determining goals for the receiving water.
6. Noting the physical constraints.
7. Developing SCM guidance and performance criteria for the local watershed.
8. Establishing a trading system.
9. Ensuring the safe performance of the drainage network, streams, and floodplains.
10. Establishing community objectives for the publically owned elements of stormwater infrastructure.
11. Establishing a maintenance plan.

Forecasting the Current and Future Development Types

Forecasting the type of current and future development within the local watershed will guide or shape how individual practices and SCMs are generally assembled at each individual site. The development types that are generally thought of include Greenfield development (small and large scales), redevelopment within established communities and on Brownfield sites, and retrofitting of existing urban areas. These development types range roughly from lower density to higher density impervious cover. Box 5-10 explains how the type of development can dictate stormwater management, discussing two main categories—*Greenfield* development and *redevelopment* of existing areas. The former refers to development that changes pristine or agricultural land to urban or suburban land uses, frequently low-density residential housing. Redevelopment refers to changing from an existing urban land use to another, usually of higher density, such as from single-family housing to multi-family housing. Finally, *retrofitting* as used in this report is not a development type but rather the upgrading of stormwater management within an existing land use to meet higher standards.

Table 5-7 shows which SCMs are best suited for Greenfield development (particularly low-density residential), redevelopment of urban areas, and intense industrial redevelopment. The last category is broken out because the suite of SCMs needed is substantially different than for urban redevelopment. Each type of development has a different footprint, impervious cover, open space, land cost, and existing stormwater infrastructure. Consequently, SCMs that are ideally suited for one type of development may be impractical or infeasible for another. One of the main points to be made is that there are more options during Greenfield development than during redevelopment because of existing infrastructure, limited land area, and higher costs in the latter case.

BOX 5-10
Development Types and their Relationship to the Stormwater System

Development falls into two basic types. Greenfield development requires new infrastructure designed according to contemporary design standards for roads, utilities, and related infrastructure. Redevelopment refers to developed areas undergoing land-use change. In contrast to Greenfields, infrastructure in previously developed areas is often in poor condition, was not built to current design standards, and is inadequate for the new land uses proposed. The stormwater management scenarios common to these types of development are described below.

Greenfield Development

At the largest scale, Greenfield development refers to planned communities at the developing edge of metropolitan areas. Communities of this type often vary from several hundred acres to very large projects that encompassed tens of thousands of acres requiring buildout over decades. They often include the trunk or primary stormwater system as well as open stream and river corridors. The most progressive communities of this type incorporate a significant portion of the area to stormwater systems that exist as surface elements. Such stormwater system elements are typically at the subwatershed scale and provide for consolidated conveyance, detention, and water quality treatment. These elements of the infrastructure can be multi-functional in nature, providing for wildlife habitat, trail corridors, and open-space amenities.

Greenfield development can also occur on a small scale—neighborhoods or individual sites within newly developing areas that are served by the secondary public and tertiary stormwater systems. This smaller-scale, incremental expansion of existing urban patterns is a more typical way for cities to grow. A more limited range of SCMs are available on smaller projects of this type, including LID practices.

Redevelopment of Existing Areas

Redevelopment within established communities is typically at the scale of individual sites and occasionally the scale of a small district. The area is usually served by private, on-site systems that convey larger storm events into preexisting stormwater systems that were developed decades ago, either in historic city centers or in "first ring," post-World War II suburbs adjacent to historic city centers. Redevelopment in these areas is typically much denser than the original use. The resulting increase in impervious area, and typically the inadequacy of existing stormwater infrastructure serving the site often results in significant development costs for on-site detention and water quality treatment. Elaborate vaults or related structures, or land area that could be utilized for development, must often be committed to on-site stormwater management to comply with current stormwater regulations.

Brownfields are redevelopments of industrial and often contaminated property at the scale of an individual site, neighborhood, or district. Secondary public systems and private stormwater systems on individual sites typically serve these areas. In many cases, especially in outdated industrial areas, little or no stormwater infrastructure exists, or it is so inadequate as to require replacement. Water quality treatment on contaminated sites may also be necessary. For these reasons, stormwater management in such developments presents special challenges. As an example, the most common methods of remediation of contaminated sites involve capping of contaminated soils or treatment of contaminants in situ, especially where removal of contaminated soils from a site is cost prohibitive. Given that contaminants are still often in place on redeveloped Brownfield sites and must not be disturbed, certain SCMs such as infiltration of stormwater into site soils, or excavation for stormwater piping and other utilities, present special challenges.

TABLE 5-7 Applicability of Stormwater Control Measures by Type of Development

Stormwater Control Measure	Low-Density Greenfield Residential	Urban Redevelopment	Intense Industrial Redevelopment
Product Substitution	○	●	●
Watershed and Land-Use Planning	■	■	○
Conservation of Natural Areas	■	♦	○
Impervious Cover Minimization	■	♦	♦
Earthwork Minimization	■	♦	♦
Erosion and Sediment Control	■	■	■
Reforestation and Soil Conservation	■	●	●
Pollution Prevention SCMs	♦	●	■
Runoff Volume Reduction—Rainwater Harvesting	■	■	●
Runoff Reduction—Vegetated	■	○	●
Runoff Reduction—Subsurface	■	○	♦
Peak Reduction and Runoff Treatment	■	♦	○
Runoff Treatment	●	●	■
Aquatic Buffers and Managed Floodplains	●	♦	○
Stream Rehabilitation	○	♦	♦
Municipal Housekeeping	○	○	NA
IDDE	○	○	○
Stormwater Education	●	●	●
Residential Stewardship	■	●	NA

NOTE: ■, always; ●, often; ○, sometimes; ♦, rarely; NA, not applicable.

Forecasting the Scale of Current and Future Development

The choice of what SCMs to use depends on the area that needs to be serviced. It turns out that some SCMs work best over a few acres, whereas others require several dozen acres or more; some are highly effective only for the smallest sites, while others work best at the stream corridor or subwatershed level. Table 5-1 includes a column that is related the scale at which individual SCMs can be applied ("where" column). The SCMs mainly applied at the site scale include runoff volume reduction—rainwater harvesting, runoff treatment like filtering, and pollution prevention SCMs for hotspots. As one goes up in scale, SCMs like runoff volume reduction—vegetated and subsurface, earthwork minimization, and erosion and sediment control take on more of a role. At the largest scales, watershed and land-use planning, conservation of natural areas, reforestation and soil conservation, peak flow reduction, buffers and managed floodplains, stream rehabilitation, municipal housekeeping, IDDE, stormwater education, and residential stewardship play a more important role. Some SCMs are useful at all scales, such as product substitution and impervious cover minimization.

Choosing Among On-Site, Distributed SCMs and Larger, Consolidated SCMs

There are distinct advantages and disadvantages to consider when choosing to use a system of larger, consolidated SCMs versus smaller-scale, on-site SCMs that go beyond their ability to achieve water quality or urban stream health. Smaller, on-site facilities that serve to meet the requirements for residential, commercial, and office developments tend to be privately owned. Typically, flows are directed to porous landscape detention areas or similar SCMs, such that volume and pollutants in stormwater are removed at or near their source. Quite often, these SCMs are relegated to the perimeter project, incorporated into detention ponds, or, at best, developed as landscape infiltration and parking islands and buffers. On-site infiltration of frequent storm events can also reduce the erosive impacts of stormwater volumes on downstream receiving waters. Maintenance is performed by the individual landowner, which is both an advantage because the responsibility and costs for cleanup of pollutants generated by individual properties are equitably distributed, and a disadvantage because ongoing maintenance incurs a significant expense on the part of individual property owners and enforcement of properties not in compliance with required maintenance is difficult. On the negative side, individual SCMs often require additional land, which increases development costs and can encourage sprawl. Monitoring of thousands of SCMs in perpetuity in a typical city creates a significant ongoing public expense, and special training and staffing may be required to maintain SCM effectiveness (especially for subgrade or in-building vaults used in ultra-urban environments). Finally, given that as much as 30 percent of the urban landscape is comprised of public streets and rights-of-way, there are limited opportunities to treat runoff from streets through individual on-site private SCMs. (Notable exceptions are subsurface runoff-volume-reduction SCMs like permeable pavement that require no additional land and promote full development density within a given land parcel because they use the soil areas below roads and the development site for infiltration.)

In contrast, publicly owned, consolidated SCMs are usually constructed as part of larger Greenfield and infill development projects in areas where there is little or no existing infrastructure. This type of facility—usually an infiltration basin, detention basin, wet/dry pond, or stormwater wetland—tends to be significantly larger, serving multiple individual properties. Ownership is usually by the municipality, but may be a privately managed, quasi-public special district. There must be adequate land available to accommodate the facility and a means of up-front financing to construct the facility. An equitable means of allocating costs for ongoing maintenance must also be identified. However, the advantage of these facilities is that consolidation requires less overall land area, and treatment of public streets and rights-of-way can be addressed. Monitoring and maintenance are typically the responsibility of one organization, allowing for effective ongoing operations to maintain the original function of the facility. If that entity is public, this ensures that the facility will be maintained in perpetuity, allowing for the potential to permanently reduce stormwater volumes and for reduction in the size of downstream stormwater infrastructure. Because consolidated facilities are typically larger than on-site SCMs, mechanized maintenance equipment allows for greater efficiency and lower costs. Finally, consolidated SCMs have great potential for multifunctional uses because wildlife habitat, recreational, and open-space amenities can be integrated to their design. Box 5-11 describes sites of various scales where either consolidated or distributed SCMs were chosen.

Defining Stressors of Concern

The primary pollutants or stressors of concern (and the primary source areas or stormwater hotspots within the watershed likely to produce them) should be carefully defined for the watershed. Although this community decision is made only infrequently, it is critical to ensuring that SCMs are designed to prevent or reduce the maximum load of the pollutants of greatest concern. This choice may be guided by regional water quality priorities (such as nutrient reduction in the Chesapeake Bay or Neuse River watersheds) or may be an outgrowth of the total maximum daily load process where there is known water quality impairment or a listed pollutant. The choice of a pollutant of concern is paramount, since individual SCMs have been shown to have highly variable capabilities to prevent or reduce specific pollutants (see WERF, 2006; ASCE, 2007; CWP, 2007b). In some cases, the capability of SCMs to reduce a specific pollutant may be uncertain or unknown.

BOX 5-11
Examples of Communities Using Consolidated versus Distributed SCMs

Stapleton Airport New Community

This is a mixed-use, mixed-density New Urbanist community that has been under development for the past 15 years on the 4,500-acre former Stapleton Airport site in central Denver. As shown in Figures 5-55 and 5-56, the stormwater system emphasizes surface conveyance and treatment on individual sites, as well as in consolidated regional facilities.

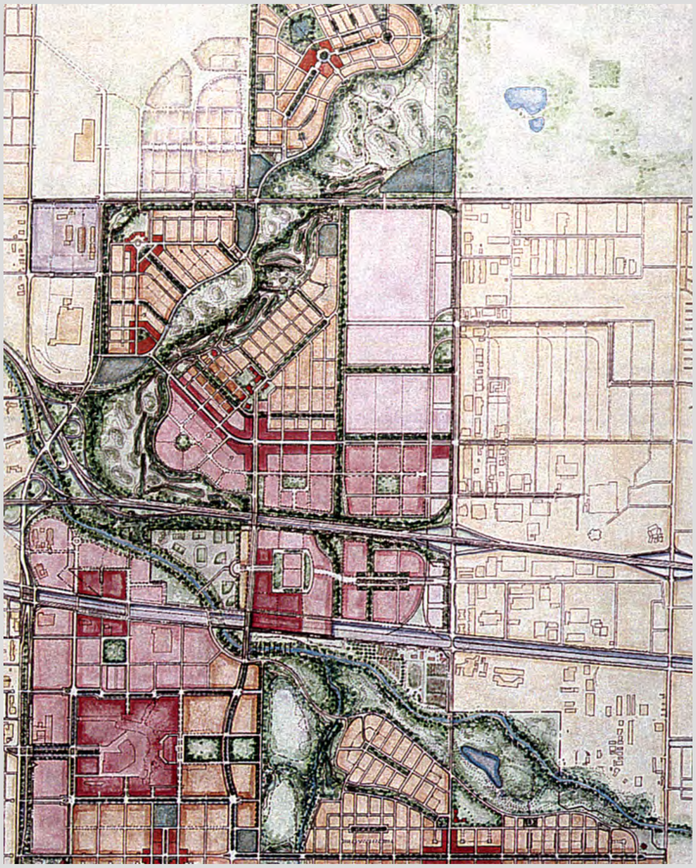


FIGURE 5-55 The community plan, shown on the left, is organized around two day lighted creeks, formerly buried under airport runways, and a series of secondary conveyances which provide recreational open space within neighborhoods. The image above illustrates one of the multi-functional creek corridors. Consolidated stormwater treatment areas and surface conveyances define more traditional park recreation and play areas. SOURCE: Courtesy of the Stapleton Redevelopment Foundation.

FIGURE 5-56 A consolidated treatment area adjacent to one of several neighborhoods that have been constructed as part of the project's build-out. SOURCE: Courtesy of Wenk Associates.

continues next page

BOX 5-11 Continued

Heritage Park Neighborhood Redevelopment

A failed public housing project adjacent to downtown Minneapolis, Minnesota, has been replaced by a mixed-density residential neighborhood. Over 1,200 rental, affordable, and market-rate single- and multi-family housing units have been provided in the 100-acre project area. The neighborhood is organized around two neighborhood parks and a parkway that serve dual functions as neighborhood recreation space and as surface stormwater conveyance and a consolidated treatment system (see Figure 5-57). Water quality treatment is being provided for a combined area of over 660 acres that includes the 100-acre project area and over 500 acres of adjacent neighborhoods. Existing stormwater pipes have been routed through treatment areas with treatment levels ranging from 50 to 85 percent TSS removal, depending on the available land area.

FIGURE 5-57 View of a sediment trap and porous landscape detention area in the central parkway spine of Heritage Park. The sediment trap in the center left of the photo was designed for ease of maintenance access by city crews with standard city maintenance equipment. SOURCE: Courtesy of the SRF Consulting Group, Inc.

The High Point Neighborhood

This Seattle project is the largest example of the city's Natural Drainage Systems Project and it illustrates the incorporation of individual SCMs into street rights-of-way as well as a consolidated facility. The on-site, distributed SCMs in this 600-acre neighborhood are swales, permeable pavement, and disconnected downspouts. A large detention pond services the entire region that is much smaller than it would have been had the other SCMs not been built. Both types of SCMs are shown in Figure 5-58.

FIGURE 5-58 Natural drainage system methods have been applied to a 34-block, 1,600-unit mixed-income housing redevelopment project called High Point. Shown on top, vegetated swales, porous concrete sidewalks, and frontyard rain gardens convey and treat stormwater on-site. Below is the detention pond for the development. SOURCE: top, William Wenk, Wenk Associates, and bottom, Laura Ehlers, National Research Council.

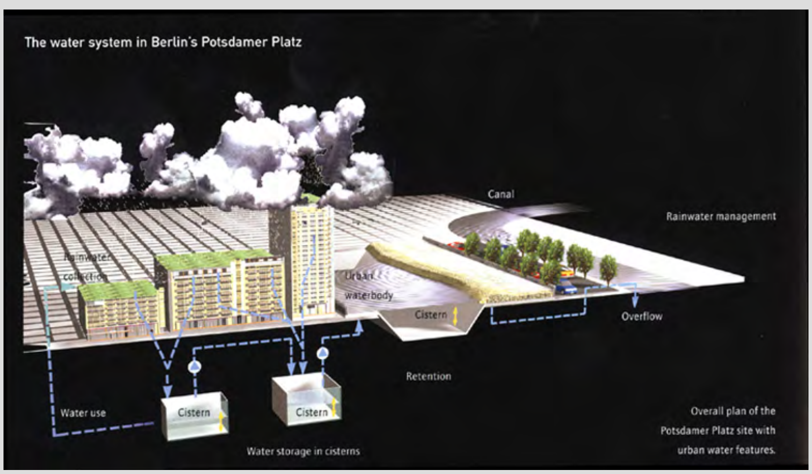
continues next page

BOX 5-11 Continued

Pottsdammer Platz

This project, in the heart of Berlin, Germany, illustrates the potential for stormwater treatment in the densest urban environments by incorporating treatment into building systems and architectural pools that are the centerpiece of a series of urban plazas. As shown in Figure 5-59, on-site, individual SCMs are used to collect stormwater and use it for sanitary purposes.

FIGURE 5-59 As shown to the left and below, stormwater is collected and stored on-site in a series of vaults. Water is circulated through a series of biofiltration areas and used for toilets and other mechanical systems in the building complex. Large storms overflow into an adjacent canal. SOURCE: Reprinted, with permission, from Herbert Dreiseitl, Dieter Grau (2001). Copyright 2001 by Birkhäuser Publishing Ltd.



Menomonee Valley Redevelopment, Wisconsin

The 140-acre redevelopment of abandoned railyards illustrates how a Brownfield site within an existing floodplain can be redeveloped using both on-site and consolidated treatment. As shown in Figure 5-60, consolidated treatment is incorporated into park areas which provide recreation for adjacent neighborhoods and serve as a centerpiece for a developing light industrial area that provides jobs to surrounding neighborhoods. Treatment on individual privately owned parcels is limited to the removal of larger sediments and debris only, making more land available for development. The volume of water that, by regulation, must be captured and treated on individual sites is conveyed through a conventional subsurface system for treatment in park areas.

FIGURE 5-60 Illustrations show consolidated treatment areas in proposed parks. The top image illustrates the fair weather condition, the center image the water quality capture volume, and the bottom image the 100-year storm event. Construction was completed in spring 2007. SOURCE: Courtesy of Wenk Associates.

Determining Goals for the Receiving Waters

It is important to set biological and public health goals for the receiving water that are achievable given the ultimate impervious cover intended for the local watershed (see the Impervious Cover Model in Box 3-10). If the receiving water is too sensitive to meet these goals, one should consider adjustments to zoning and development codes to reduce the amount of impervious cover. The biological goals may involve a keystone species, such as salmon or trout, a desired state of biological integrity in a stream, or a maximum level of eutrophication in a lake. In other communities, stormwater goals may be driven by the need to protect a sole-source drinking water supply (e.g., New York watersheds) or to maintain water contact recreation at a beach, lake, or river. Once again, the watershed goals that are selected have a strong influence on the assembly of SCMs needed to meet them, since individual SCMs vary greatly in their ability to achieve different biological or public health outcomes.

Noting the Physical Constraints

The specific physical constraints of the watershed terrain and the development pattern will influence the selection and assembly of SCMs. The application of SCMs must be customized in every watershed to reflect its unique terrain, such as karst, high water tables, low or high slopes, freeze–thaw depth, soil types, and underlying geology. Each SCM has different restrictions or constraints associated with these terrain factors. Consequently, the SCM prescription changes as one moves from one physiographic region to another (e.g., the flat coastal plain, the rolling Piedmont, the ridge and valley, and mountainous headwaters).

Developing SCM Guidance and Performance Criteria for the Local Watershed

Based on the foregoing factors, the community should establish specific sizing, selection, and design requirements for SCMs. These SCM performance criteria may be established in a local, regional, or state stormwater design manual, or by reference in a local watershed plan. The Minnesota Stormwater Steering Committee (MSSC, 2005) provides a good example of how SCM guidance can be customized to protect specific types of receiving waters (e.g., high-quality lakes, trout streams, drinking water reservoirs, and impaired waters). In general, the watershed- or receiving water-based criteria are more specific and detailed than would be found in a regional or statewide stormwater manual. For example, the local stormwater guidance criteria may be more prescriptive with respect to runoff reduction and SCM sizing requirements, outline a preferred sequence for SCMs, and indicate where SCMs should (or should not) be located in the watershed. Like the identification of stressors or pollutants of concerns, this step is rarely taken under current paradigms of stormwater management.

Establishing a Trading System

A stormwater trading or offset system is critical to situations when on-site SCMs are not feasible or desirable in the watershed. Communities may choose to establish some kind of stormwater trading or mitigation system in the event that full compliance is not possible due to physical constraints or because it is more cost effective or equitable to achieve pollutant reduction elsewhere in the local watershed. The most common example is providing an offset fee based on the cost to remove an equivalent amount of pollutants (such as phosphorus in the Maryland Critical Area—MD DNR, 2003). This kind of trading can provide for greater cost equity between low-cost Greenfield sites and higher-cost ultra-urban sites.

Ensuring the Safe and Effective Performance of the Drainage Network, Streams, and Floodplains

The urban water system is not solely designed to manage the quality of runoff. It also must be capable of safely handling flooding from extreme storms to protect life and property. Consequently, communities need to ensure that their stormwater infrastructure can prevent increased flooding caused by development (and possibly exacerbated future climate change). In addition, many SCMs must be designed to safely pass extreme storms when they do occur. This usually requires a watershed approach to stormwater management to ensure that quality and quantity control are integrated together, with an emphasis on the connection and effective use of conveyance channels, streams, riparian buffers, and floodplains.

Establishing Community Objectives for the Publicly Owned Elements of Stormwater Infrastructure

The stormwater infrastructure in a community normally occupies a considerable surface area of the landscape once all the SCMs, drainage easements, buffers, and floodplains are added together. Consequently, communities may require that individual SCM elements are designed to achieve multiple objectives, such as landscaping, parks, recreation, greenways, trails, habitat, sustainability, and other community amenities (as discussed extensively above). In other cases, communities may want to ensure that SCMs do not cause safety or vector problems and that they look attractive. The best way to maximize community benefits is to provide clear guidance in local SCM criteria at the site level and to ensure that local watershed plans provide an overall context for their implementation.

Establishing an Inspection and Maintenance Plan

The long-term performance of any SCM is fundamentally linked to the frequency of inspections and maintenance. As a result, NPDES stormwater permit conditions for industrial, construction, and municipal permittees specify that pollution prevention, construction, and post-construction SCMs be adequately maintained. MS4 communities are also required under NPDES stormwater permits to track, inspect, and ensure the maintenance of the collective system of SCMs and stormwater infrastructure within their jurisdiction. In larger communities, this can involve hundreds or even thousands of individual SCMs located on either public or private property. In these situations, communities need to devise a workable model that will be used to operate, inspect, and maintain the stormwater infrastructure across their local watershed. Communities have the lead responsibility in their MS4 permits to assure that SCMs are maintained properly to ensure their continued function and performance over time. They can elect to assign the responsibility to the public sector, the private sector (e.g., property owners and homeowners association), or a hybrid of the two, but under their MS4 permits they have ultimate responsibility to ensure that SCM maintenance actually occurs. This entails assigning legal and financial responsibilities to the owners of each SCM element in the watershed, as well as maintaining a tracking and enforcement system to ensure compliance.

Summary

Taking all of the elements above into consideration, the emerging goal of stormwater management is to mimic, as much as possible, the hydrological and water quality processes of natural systems as rain travels from the roof to the stream through combined application of a series of practices throughout the entire development site and extending to the stream corridor. The series of SCMs incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required.

There is no single SCM prescription that can be applied to each kind of development; rather, a combination of interacting practices must be used for full and effective treatment. For a low-density residential Greenfield setting, a combination of SCMs that might be implemented is illustrated in Table 5-8. There are many successful examples of SCMs in this context and at different scales. By contrast, Tables 5-9 and 5-10 outline how the general “roof-to-stream” stormwater approach is adapted for intense industrial operations and urban redevelopment sites, respectively. As can be seen, these development situations require a differ combination of SCMs and practices to address the unique design

TABLE 5-8 From the Roof to the Stream: SCMs in a Residential Greenfield

SCM	What it Is	What it Replaces	How it Works
Land-Use Planning	Early site assessment	Doing SWM design after site layout	Map and plan submitted at earliest stage of development review showing environmental, drainage, and soil features
Conservation of Natural Areas	Maximize forest canopy	Mass clearing	Preservation of priority forests and reforestation of turf areas to intercept rainfall
Earthwork Minimization	Conserve soils and contours	Mass grading and soil compaction	Construction practices to conserve soil structure and only disturb a small site footprint
Impervious Cover Minimization	Better site design	Large streets, lots and cul-de-sacs	Narrower streets, permeable driveways, clustering lots, and other actions to reduce site IC
Runoff Volume Reduction—Rainwater Harvesting	Utilize rooftop runoff	Direct connected roof leaders	A series of practices to capture, disconnect, store, infiltrate, or harvest rooftop runoff
Runoff Volume Reduction—Vegetated	Frontyard bioretention	Positive drainage from roof to road	Grading frontyard to treat roof, lawn, and driveway runoff using shallow bioretention
	Dry swales	Curb/gutter and storm drain pipes	Shallow, well-drained bioretention swales located in the street right-of-way
Peak Reduction and Runoff Treatment	Linear wetlands	Large detention ponds	Long, multi-cell, forested wetlands located in the stormwater conveyance system
Aquatic Buffers and Managed Floodplains	Stream buffer management	Unmanaged stream buffers	Active reforestation of buffers and restoration of degraded streams

Note: SCMs are applied in a series, although all of the above may not be needed at a given residential site. This "roof-to-stream" approach works best for low- to medium-density residential development.

TABLE 5-9 From the Roof to the Outfall: SCMs in an Industrial Context

SCM Category	What it Is	What it Replaces	How it Works
Pollution Prevention	Drainage mapping	No map	Analysis of the locations and connections of the stormwater and wastewater infrastructure from the site
	Hotspot site Investigation	Visual inspection	Systematic assessment of runoff problems and pollution prevention opportunities at the site
	Rooftop management	Uncontrolled rooftop runoff	Use of alternative roof surfaces or coatings to reduce metal runoff, and disconnection of roof runoff for stormwater treatment
	Exterior maintenance practices	Routine plant maintenance	Special practices to reduce discharges during painting, powerwashing, cleaning, sealcoating and sandplasting
	Extending roofs for no exposure	Exposed hotspot operations	Extending covers over susceptible loading/unloading, fueling, outdoor storage, and waste management operations
	Vehicular pollution prevention	Uncontrolled vehicle operations	Pollution prevention practices applied to vehicle repair, washing, fueling, and parking operations
	Outdoor pollution prevention practices	Outdoor materials storage	Prevent rainwater from contact with potential pollutants by covering, secondary containment, or diversion from storm-drain system
	Waste management practices	Exposed dumpster or waste streams	Improved dumpster location, management, and treatment to prevent contact with rainwater or runoff
	Spill control plan and response	No plan	Develop and test response to spills to the storm-drain system, train employees, and have spill control kits available on-site
	Greenscaping	Routine landscape and turf maintenance	Reduce use of pesticides, fertilization, and irrigation in pervious areas, and conversion of turf to forest
	Employee stewardship	Lack of storm-water awareness	Regular ongoing training of employees on stormwater problems and pollution prevention practices
	Site housekeeping and stormwater maintenance	Dirty site and unmaintained infrastructure	Regular sweeping, storm-drain cleanouts, litter pickup, and maintenance of stormwater infrastructure
Runoff Treatment	Stormwater retrofitting	No stormwater treatment	Filtering retrofits to remove pollutants from most severe hotspot areas
IDDE	Outfall analysis	No monitoring	Monitoring of outfall quality to measure effectiveness

Note: While many SCMs are used at each individual industrial site, the exact combination depends on the specific configuration, operations, and footprint of each site.

TABLE 5-10 From the Roof to the Street: SCMs in a Redevelopment Context

SCM Category	What it Is	What it Replaces	How it Works
Impervious Cover Minimization	Site design to prevent pollution	Conventional site design	Designing redevelopment footprint to restore natural area remnants, minimize needless impervious cover, and reduce hotspot potential
Runoff Volume Reduction—Rainwater Harvesting and Vegetated	Treatment on the roof	Traditional rooftops	Use of green rooftops to reduce runoff generated from roof surfaces
	Rooftop runoff treatment	Directly connected roof leaders	Use of rain tanks, cisterns, and rooftop disconnection to capture, store, and treat runoff
	Runoff treatment in landscaping	Traditional landscaping	Use of foundation planters and bioretention areas to treat runoff from parking lots and rooftops
Soil Conservation and Reforestation	Runoff reduction in pervious areas	Impervious or compacted soils	Reducing runoff from compacted soils through tilling and compost amendments, and in some cases, removal of unneeded impervious cover
	Increase urban tree canopy	Turf or landscaping	Providing adequate rooting volume to develop mature tree canopy to intercept rainfall
Runoff Reduction—Subsurface	Increase permeability of impervious cover	Hard asphalt or concrete	Use of permeable pavers, porous concrete, and similar products to decrease runoff generation from parking lots and other hard surfaces.
Runoff Reduction—Vegetated	Runoff treatment in the street	Sidewalks, curb and gutter, and storm drains	Use of expanded tree pits, dry swales and street bioretention cells to further treat runoff in the street or its right-of-way
Runoff Treatment	Underground treatment	Catch basins and storm-drain pipes	Use of underground sand filters and other practices to treat hotspot runoff quality at the site
Municipal Housekeeping	Street cleaning	Unswept streets	Targeted street cleaning on priority streets to remove trash and gross solids
Watershed Planning	Off-site stormwater treatment or mitigation	On-site waivers	Stormwater retrofits or restoration projects elsewhere in the watershed to compensate for stormwater requirements that cannot be met on-site

Note: SCMs are applied in a series, although all of the above may not be needed at a given redevelopment site.

challenges of dense urban environments. The tables are meant to be illustrative of certain situations; other scenarios, such as commercial development, would likely require additional tables.

In summary, a watershed approach for organizing site-based stormwater decisions is generally superior to making site-based decisions in isolation. Communities that adopt the preceding watershed elements not only can maximize the performance of the entire system of SCMs to meet local watershed objectives, but also can maximize other urban functions, reduce total costs, and reduce future maintenance burdens.

COST, FINANCE OPTIONS, AND INCENTIVES

Municipal Stormwater Financing

To be financially sustainable, stormwater programs must develop a stable long-term funding source. The activities common to most municipal stormwater programs (such as education, development design review, inspection, and enforcement) are funded through general tax revenues, most commonly property taxes and sales taxes (NAFSMA, 2006), which is problematic for several reasons. First, stormwater management financed through general tax receipts does not link or attempt to link financial obligation with services received. The absence of such links can reduce the ability of a municipality to adequately plan and meet basic stormwater management obligations. Second, when funded through general tax revenues, stormwater programs must compete with other municipal programs and funding obligations. Finally, in programs funded by general tax revenue, responsibilities for stormwater management tend to be distributed into the work responsibilities of existing and multiple departments (e.g., public works, planning, etc.). One recent survey conducted in the Charles River watershed in Massachusetts found that three-quarters of local stormwater management programs did not have staff dedicated exclusively for stormwater management (Charles River Watershed Association, 2007).

Increasingly, many municipalities are establishing stormwater utilities to manage stormwater (Kaspersen, 2000). Most stormwater utilities are created as a separate organizational entity with a dedicated, self-sustaining source of funding. The typical stormwater utility generates the large majority of revenue through user fees (Florida Stormwater Association, 2003; Black and Veatch, 2005; NAFSMA, 2006). User fees are established and set so as to have a close nexus to the cost of providing the service and, thus, are most commonly based on the amount of impervious surface, frequently measured in terms of equivalent residential unit. For example, an average single-family residence may create 3,000 square feet of impervious surface (roof and driveway area). A per-unit charge is then assigned to this "equivalent runoff unit." To simplify program administration, utilities typically assign a flat rate for residential properties (customer class average) (NAFSMA, 2006). Nonresidential properties are then charged individually based on the total amount of impervious surface (square feet or equivalent runoff units) of the parcel. Fees are sometimes also based on gross area (total area of a parcel) or some combination of gross area and a development intensity measure (Duncan, 2004; NAFSMA, 2006).

Municipalities have the legal authority to create stormwater utilities in most states (Lehner et al., 1999). In addition to creating the utility, a municipality will generally establish the utility rate structure in a separate ordinance. Separating the ordinances allows the municipality flexibility to change the rate structure without revising the ordinance governing the entire utility (Lehner et al., 1999). While municipalities generally have the authority to collect fees, some states have legal restrictions on the ability of local governments to levy taxes (Lehner et al., 1999; NAFSMA, 2006). The legal distinction between a tax and a fee is the most common legal challenge to a stormwater utility. For example, stormwater fees have been subject to litigation in at least 17 states (NAFSMA, 2006). To avoid legal challenges, care must be taken to meet a number of legal tests that distinguish a fee for a specific service and a general tax.

Stormwater utilities typically bill monthly, and fees range widely. A recent survey of U.S. stormwater utilities reported that fees for residential households range from $1 to $14 per month, but a typical residential household rate is in the range of $3 to $6 (Black and Veatch, 2005). Despite the dedicated funding source, the majority of stormwater utilities responding to a recent survey (55 percent) indicated that current funding levels were either inadequate or just adequate to meet their most urgent needs (Black and Veatch, 2005).

Both municipal and state programs can finance administrative programming costs through stormwater permitting fees. Municipal stormwater programs can use separate fees to finance inspection activities. For instance, inspection fees can be charged to cover the costs of ensuring that SCMs are adequately planned, installed, or maintained (Debo and Reese, 2003). Stormwater management programs can also ensure adequate funding for installation and maintenance of SCMs by requiring responsible parties to post financial assurances. Performance bonds, letters of credit, and cash escrow are all examples of financial assurances that require up-front financial payments to ensure that longer-term actions or activities are successfully carried out. North Carolina's model stormwater ordinance recommends that the amount of a maintenance performance security (bond, cash escrow, etc.) be based on the present value of an annuity based on both inspection costs and operation and maintenance costs (Whisnant, 2007).

In addition to fees or taxes, exactions such as impact fees can also be used as a way to finance municipal stormwater infrastructure investments (Debo and Reese, 2003). An impact fee is a one-time charge levied on new development. The fee is based on the costs to finance the infrastructure needed to service the new development. The ability to levy impact fees varies between states. Municipalities that use impact fees are also required to show a close nexus between the size of the fee and the level of benefits provided by the fee; a failure to do so exposes local government to law suits (Keller, 2003). Compared to other funding sources, impact fees also exhibit greater variability in revenue flows because the amount of funds collected is dependent on development growth.

Bonds and grants can supplement the funding sources identified above. Bonds and loans tend to smooth payments over time for large up-front stormwater investments. For example, state and federal loan programs (state revolving funds) provide long-term, low-interest loans to local governments or capital investments (Keller, 2003). In addition, grant opportunities are sometimes available from state and federal sources to help pay for specific elements of local stormwater management programs.

Municipalities require funds to meet federal and state stormwater requirements. Understanding of the municipal costs incurred by implementing stormwater regulations under the Phase I and II stormwater rules, however, is incomplete (GAO, 2007). Of the six minimum measures of a municipal stormwater program (public education, public involvement, illicit discharge detection and elimination, construction site runoff control, post-construction stormwater management, and pollution prevention/good housekeeping—see Chapter 2), a recent study of six California municipalities found that pollution prevention activities (primarily street sweeping) accounted for over 60 percent of all municipal stormwater management costs in these communities (Currier et al., 2005). Annual per-household costs ranged from $18 to $46.

Stormwater Cost Review

Conceptually, the costs of providing SCMs are all opportunity costs (EPA, 2000). Opportunity costs are the value of alternatives (next best) given up by society to achieve a particular outcome. In the case of stormwater control, opportunity costs include direct costs necessary to control and treat runoff such as capital and construction costs and the present value of annual operation and maintenance costs. Initial installation costs should also include the value of foregone opportunities on the land used for stormwater control, typically measured as land acquisition (land price).

Costs also include public and private resources incurred in the administration of the stormwater management program. Private-sector costs might include time and administrative costs associated with permitting programs. Public costs include agency monitoring and enforcement costs.

Opportunity costs also include other values that might be given up as a consequence of stormwater management. For example, the creation of a wet pond in a residential area might be opposed because of perceived safety, aesthetic, or nuisance concerns (undesirable insect or animal species). In this case, the diminished satisfaction of nearby property owners is an opportunity cost associated with the wet pond. On the other hand, if SCMs are considered a neighborhood amenity (e.g., a constructed wetland in a park setting), opportunity costs may decrease. In addition, costs of a given practice may be reduced by reducing costs elsewhere. For example, increasing on-site infiltration rates can reduce off-site storage costs by reducing the volume and slowing the release of runoff.

In general the cost of SCMs is incompletely understood and significant gaps exist in the literature. More systematic research has been conducted on the cost of conventional stormwater SCMs (wet ponds, detention basins, etc.), with less research applied to more recent, smaller-scale, on-site infiltration practices. Cost research is challenging given that stormwater treatment exhibits considerable site-specific variation resulting from different soil, topography, climatic conditions, local economic conditions, and regulatory requirements (Lambe et al., 2005).

The literature on stormwater costs tend to be oriented around construction costs of particular types of SCMs (Wiegand et al., 1986; SWRPC, 1991; Brown and Schueler, 1997; Heaney et al., 2002; Sample et al., 2003; Wossink and Hunt, 2003; Caltrans, 2004; Narayanan and Pitt, 2006; DeWoody, 2007). In many of these studies, construction cost functions are estimated statistically based on a sample of recently installed SCMs and the observed total construction costs. Observed costs are then related statistically to characteristics that influence cost such as practice size. Other studies estimate costs by identifying the individual components of a construction project (pipes, excavation, materials, labor, etc.), estimating unit costs of each component, and then summing all project components. These studies generally find that construction costs decrease on a per-unit basis as the overall size (expressed in volume or drainage area) of the SCM increases (Lambe et al., 2005). These within-practice economies of scale are found across certain SCMs including wet ponds, detention ponds, and constructed wetlands. Several empirical studies, however, failed to find evidence of economies of scale for bioretention practices (Brown and Schueler, 1997; Wossink and Hunt, 2003).

Increasing attention has been paid to small-scale practices, including efforts to increase infiltration and retain water through such means as green roofs, permeable pavements, rain barrels, and rain gardens (under the label of LID). The costs of these practices are less well studied compared to the other stormwater practices identified above. In general, per-unit construction and design costs exceed larger-scale SCMs (Low Impact Development Center, 2007). Higher construction costs, however, may be offset to various degrees by reducing the investments in stormwater conveyance and storage infrastructure (i.e., less storage volume is needed) (CWP, 1998a, 2000a; Low Impact Development Center, 2007). Others have suggested that per-unit costs to reduce runoff may be less for these small-scale distributed practices because of higher infiltration rates and retention rates (MacMullan and Reich, 2007).

Compared to construction costs, less is known about the operation and maintenance costs of SCMs (Wossink and Hunt, 2003; Lambe et al., 2005; MacMullan and Reich, 2007). Most stormwater practices are not maintenance free and can create financial and long-term management obligations for responsible parties (Hager, 2003). Cost-estimation programs and procedures have been developed to estimate operation and maintenance costs as well as construction costs (SWRPC, 1991; Lambe et al., 2005; Narayanan and Pitt, 2006), but examination of observed maintenance costs is less common. Based on estimates from Wossink and Hunt (2003), the total present value of maintenance costs over 20 years can range from 15 to 70 percent of total capital construction costs for wet ponds and constructed wetlands and appear generally consistent with percentages reported in EPA (1999). Operation and maintenance costs were also reported to be a substantial percentage of construction costs of infiltration pits and bioretention areas in Southern California (DeWoody, 2007). Others estimate that over the life of many SCMs, maintenance costs may equal construction costs (CWP, 2000a). In general, maintenance costs tend to decrease as a percentage of total SCM cost as the total size of the SCM increases (Wossink and Hunt, 2003).

Very few quantifiable estimates are available for public and private regulatory compliance costs. Compliance costs could include both initial permitting costs (labor and time delays) of gaining regulatory approval for a particular stormwater design to post-construction compliance costs (administration, inspection monitoring, and enforcement). Compliance monitoring is a particular concern if a stormwater management program relies on widespread use of small-scale distributed on-site practices (Hager, 2003). Unlike larger-scale or regional stormwater facilities that might be located on public lands or on private lands with an active stormwater management plan, a multitude of smaller SCMs would increase monitoring and inspection times by increasing the number of SCMs. Furthermore, municipal governments may be reluctant to undertake enforcement actions against citizens with SCMs located on private land.

Land costs tend to be site specific and exhibit a great deal of spatial variation. Some types of SCMs, such as constructed wetlands, are more land intensive than others. In highly urban areas, land costs may be the single biggest cost outlay of land-intensive SCMs (Wossink and Hunt, 2003).

In general, cost analyses generally find that the cost to treat a given acreage or volume of water is less for regional SCMs than for smaller-scale SCMs (Brown and Schueler, 1997; EPA, 1999; Wossink and Hunt, 2003). For example, considering maintenance, capital construction, and land costs, recent estimates for North Carolina indicate that annual costs for wet ponds and constructed wetlands range between $100 and $3,000 per treated acre (typically less than $1,000). Per-acre annual costs for bioretention and sand filters typically ranged between $300 and $3,500, and between $4,500 and 8,500, respectively. However, if SCMs face space constraints, bioretention areas can become more cost effective. Furthermore, other classes of small, on-site practices, such as grass swales and filter strips, can sometimes be implemented for relatively low cost.

There are exceptions to the general conclusion that larger-scale stormwater practices tend to be less costly on a per-unit basis than more numerous and distributed on-site practices. For instance, in Sun Valley, California, a recent study indicates that installing small distributed practices (infiltration practices, porous pavement, rain gardens) was more cost effective than centralized approaches for a retrofit program (Cutter et al., 2008). In this particular setting, the difference tended to revolve around the high land costs in the urbanized setting. Small-scale practices can be placed on low-valued land or integrated into existing landscaping, reducing land costs. Centralized stormwater facilities require substantial purchases of high-priced urban properties. Similarly, small distributed practices (porous pavement, green roofs, rain gardens, and constructed wetlands) can also provide a more cost-effective approach to reducing combined sewer overflow (CSO) discharges in a highly urban setting than large structural CSO controls (storage tanks) (Montalto et al., 2007).

SCMs are now a part of most development processes and consequently will increase the cost of the development. Randolph et al. (2006) report on the cost of complying with stormwater and sediment and erosion control regulations for six developments in the Washington, D.C., metropolitan area. These costs include primarily stormwater facility construction and land costs. The findings from these case studies indicate that stormwater and erosion and sediment control comprised about 60 percent of all environmental-related compliance costs for the residential developments studied and added about $5,000 to the average price of a home. Nationwide, stormwater and erosion and sediment controls are estimated to add $1,500 to $9,000 to the cost of a new residential dwelling unit (Randolph et al., 2006).

As a means to control targeted chemical constituents, SCMs may be an expensive control option relative to other control alternatives. For example, nutrients from anthropocentric sources are an increasing water quality concern for many fresh and marine waters. Some states (e.g., Virginia, Maryland, and North Carolina) require stormwater programs to achieve specific nutrient (nitrogen or phosphorus) stormwater standards. The construction, maintenance, and land costs of reducing nitrogen discharge from residential developments using bioretention areas, wet ponds, constructed wetlands, or sand filters range from $60 to $2,500 per pound (Aultman, 2007). These control costs can be an order of magnitude higher than nitrogen control costs from point sources or agricultural nonpoint sources. The high per-pound removal costs are due in part to the relatively low mass load of nutrients carried in stormwater runoff. These estimates, however, assume that all costs are allocated exclusively to nitrogen removal. The high per-pound removal costs from the control of single pollutants highlight the importance of achieving ancillary and offsetting benefits associated with stormwater control (e.g., removal of other pollutants of concern, stream-channel protection from volume reduction, and enhancement of neighborhood amenities).

It should also be noted that installing SCMs in an existing built environment tends to be significantly more expensive than new construction. Construction costs for retrofitted extended detention ponds, wet ponds, and constructed wetlands were estimated to be two to seven times more costly than new SCMs (Schueler et al., 2007). Retrofit costs can be higher for a variety of reasons, including the need to upgrade existing infrastructure (culverts, drainage channels, etc.) to meet contemporary engineering and regulatory requirements. Retrofitting a single existing residential city block in Seattle with a new stormwater drainage system that included reduced street widths, biofiltration practices, and enhanced vegetation cost an estimated $850,000 (see Box 5-5; Seattle Public Utilities, 2007). Estimates suggested that the costs might have been even higher using more conventional stormwater piping/drainage systems (Chris May, personal communication, August 2007; EPA, 2007).

As discussed earlier in the chapter, stormwater runoff can be reduced and managed through better site design to reduce impervious cover. Low- to medium-density developments can reduce impervious cover through cluster development patterns that preserve open space and reduce lot sizes. Impervious surfaces and infiltration rates could be altered by any number of site-design characteristics such as reduction in street widths, reduction in the number of cul-de-sacs, and different setback requirements (CWP, 2000a). Finally, impervious surface per capita could be substantially reduced by increasing the population per dwelling unit.

Quantifying the cost of many of these design features is more challenging, and the literature is much less developed or conclusive than the literature on conventional SCM costs. Many design features described above (clustering, reduced setbacks, narrower streets, less curb and gutter) can significantly lower construction and infrastructure costs (CWP, 2001; EPA, 2007). Such features may reduce the capital cost of subdivision development by 10 to 33 percent (CWP, 2000a).

On the other hand, the evidence is unclear whether consumers are willing to pay for these design features. If consumers prefer features typically associated with conventional developments (large suburban lot, for example), then some aspects of alternative development designs/patterns could impose an opportunity cost on builders and buyers alike in the form of reduced housing value. For example, most statistical studies in the U.S. housing market find that consumers prefer homes with larger lots and are willing to pay premiums for homes located on cul-de-sacs, presumably for privacy and safety reasons (Dubin, 1998; Fina and Shabman, 1999; Song and Knapp, 2003). These effects, however, might be partly or completely offset by the higher value consumers might place on the proximity of open space to their homes (Palmquist, 1980; Cheshire and Sheppard, 1995; Qiu et al., 2006). Anecdotal evidence indicates that residents feel that Seattle's Street Edge Alternative program (the natural drainage system retrofit program that combines swales, bioretention and reduced impervious surfaces) increased their property values (City of Seattle, undated). Studies that have attempted to assess the net change in costs are limited, but some evidence suggests that the amenity values of lower-impact designs may match or outweigh the disamentities (Song and Knapp, 2003).

Incentives for Stormwater Management

The dominant policy approach to controlling effluent discharge under the Clean Water Act is through the application of technology-based effluent standards or the requirements to install particular technologies or practices. Some note that this general policy approach may not provide the regulated community with (1) incentives to invest in pollution prevention activities beyond what is required in the standard or with (2) sufficient opportunities or flexibility to lower overall compliance costs (Parikh et al., 2005).

A loosely grouped set of policies, called here "incentive-based,"[1] aim to create financial incentives to manage effluent or volume discharge. Such policies tend to be classified into two groups: price- and quantity-based mechanisms (Stavins, 2000; Parikh et al., 2005). Price-based mechanisms are created when government creates a charge (tax, fee, etc.) or subsidy (payment) on an outcome that government wants to either discourage or encourage. Ideally, the price would be placed on a target outcome (effluents discharged, volume of water released, etc.) and not on the means to achieve that outcome end (such as a tax or subsidy to adopt specific technologies or practices).[2] Quantity-based policies require government to establish some binding limit or cap on an outcome (e.g., mass load of effluent, volume of runoff, etc.) for an identified group of dischargers, but then allow the regulated parties to "trade" responsibilities for meeting that limit or cap. The opportunity to trade creates the financial incentive. The trading concept is discussed in greater detail in Chapter 6, while this section focuses on price-based incentives.

Some stormwater utilities offer reductions in stormwater fees to landowners who voluntarily undertake activities to reduce runoff from their parcels (Doll and Lindsey, 1999; Keller, 2003). The reduction in tax obligations, called credits, can be interpreted as a financial subsidy or payment for implementing on-site runoff controls. Credit payments are typically made based on the volume of water detained. For example, as part of Portland, Oregon's Clean River Rewards program, residents and commercial property owners can reduce their stormwater utility fee by as much as 35 percent by reducing stormwater runoff from existing developed properties (Portland Bureau of Environmental Services, 2008a). Residential and commercial property owners are given a number of ways to reduce runoff to receive this financial benefit. In addition, Portland has a downspout disconnection program that aims to reduce discharge into CSOs in targeted areas in the city. Property owners may be reimbursed up to $53 per eligible downspout (Portland Bureau of Environmental Services, 2008b).

Alternatively, stormwater utilities could (where allowed) also use fee revenue to provide private incentives for stormwater control through a competitive

[1] These policies are sometimes called "market-based" policies, but that term will not be used here because many of the incentive-based policies discussed fail to contain features characteristic of a market system.

[2] The literature on what level to set the price (tax or subsidy) is vast, complex, and controversial. Parikh et al. (2005) seem to wander into this debate (perhaps unwittingly) by making a distinction between taxes based on some optimality rule (marginal damage costs equal to marginal control costs) and those based on some other sort of decision rule. Without getting into the specifics of this debate here, this discussion will simply assert more generally that price-based incentive policies structure taxes and subsidies to induce desirable behavioral change (rather than simply to raise revenue).

bidding process. Such a bidding process ("reverse auction") would request proposals for stormwater reduction projects and fund projects that reduce volume at the least cost. Proposed investments that can meet the program objectives at the lowest per unit cost would receive payments. Such a program creates private incentives to search for low-cost stormwater investments by creating a price for runoff volume reduction. The bidding program could also be used to identify cost-effective stormwater investments in areas targeted for enhanced levels of restoration. A bidding program has been proposed as a way to lower overall costs of a stormwater program in Southern California (Cutter et al., 2008). Revenue to fund such a competitive bid program could come from a variety of sources including stormwater utility fees or fees paid into an in lieu fee program.

Finally, impact fees on new developments can be structured in a way to create incentives to reduce stormwater runoff volumes. Charges based on runoff volume (or a surrogate measure like impervious surface) can provide an incentive for developers to reduce the volume of new runoff created.

CHALLENGES TO IMPLEMENTATION OF WATERSHED-BASED MANAGEMENT AND STORMWATER CONTROL MEASURES

The implementation of SCMs has seen variable success. Environmental awareness, threats to potable water sources or to habitat for threatened and endangered species, problems with combined sewer overflows, and other environmental factors have caused cities such as Portland, Oregon; Seattle, Washington; Chicago, Illinois; and Austin, Texas to aggressively pursue widespread implementation of a broad range of SCMs. In contrast, other cities have been slow to implement recommended practices, for many reasons. This is particularly true for nonstructural SCMs, despite their popularity among planners and regulators for the past two decades. A host of real and perceived concerns about individual nonstructural SCMs are often raised regarding development costs, market acceptance, fire safety, emergency access, traffic and parking congestion, basement seepage, pedestrian safety, backyard flooding, nuisance conditions, maintenance, and winter snow removal operations. While most of these concerns are unfounded, they contribute to a culture of inertia when it comes to code change (CWP, 1998a, 2000a). As a result, some nonstructural SCMs are discouraged or even prohibited by local development codes. Very few communities make the consideration of nonstructural practices a required element of stormwater plan review, nor do they require that they be considered early in the site layout and design process when their effectiveness would be maximized. Finally, many engineers and planners feel they can fully comply with existing stormwater criteria without resorting to nonstructural SCMs.

Cost Issues

There are numerous cost issues that have proven to be significant barriers to the use of innovative SCMs. Special construction techniques required for the proper design and function of SCMs, specially formulated manufactured soils, expensive subsurface vaults, and increased land area requirements as a result of increased stormwater storage requirements can significantly increase site development costs. For smaller projects in highly urbanized areas where land costs are high, there can be a disproportionately large expense to comply with stormwater regulations, causing developers to seek, and often receive, exemption from requirements.

Sediment removal and related maintenance activities required to ensure the proper ongoing functioning of SCMs are activities that are not a part of normal building maintenance. Data on maintenance costs of SCMs on privately owned facilities are limited, and management companies responsible for commercial and office building maintenance have yet to provide SCM maintenance as part of their services.

Additional costs are incurred when development review periods by public agencies get extended because of an increased level of design review required to evaluate the compliance of SCMs with city ordinances. Additional review increases development costs and extends the design process. Even with specialized training for city staff to evaluate SCM submittals, deviation from the most basic type of SCM design seems to require extended review and documentation.

Cost concerns are partly responsible for the markedly slow implementation of the stormwater program. The federal deadlines for permit coverage have long passed; in fact more than 14 years have lapsed for medium and large municipalities. A good part of the delay can be explained by the resistance of states and local governments to the unknown cost burden. Cities contend that the permit requirements are unreasonable, expensive, and unrealistic to achieve. Many local government officials view some permit provisions such as LID or better site design as intrusion into the land-use authority of local governments.

As discussed in Chapter 2, the U.S. Congress provided no start-up or upgrade financial assistance, unlike what it did for municipally owned and operated wastewater treatment plants after the promulgation of the NPDES permit program under the Clean Water Act in 1972. Local governments have been reluctant to tax residents or create stormwater utilities. States like California and Michigan even have laws that require voter approval in order for local governments to assess new fees. Thus, to implement the NPDES stormwater program, states have had to largely rely on stormwater permit fees collected to support a skeletal to modest staff for program oversight. In Denver, and presumably in other cities, there is no reduction in stormwater fees when impervious area is reduced because of construction of on-site SCMs. This amounts to a disincentive to do the "right thing." Meanwhile, the overall federal budget for the NPDES program, including stormwater, has been declining.

Long-Term Maintenance of Stormwater Control Measures

One of the weakest parts of most stormwater management programs is the lack of information about, and funding to support, the long-term maintenance of SCMs. If SCMs are not inspected and maintained on a regular basis, the stormwater management program is likely to fail. This also negatively impacts the design process—if there is no inspection program oand no accountability for maintenance, the designer has no incentive to build better, more maintenance-friendly SCMs. Finally, without an accurate assessment of the maintenance needs of an SCM, land owners and other responsible parties cannot anticipate their total costs over the lifetime of the device.

Almost all SCMs require active long-term maintenance in order to continue to provide volume and water quality benefits (Hoyt and Brown, 2005; Hunt and Lord, 2006b). Furthermore, a typical municipality may contain hundreds or thousands of individual SCMs within its jurisdiction. Thus, the long-term obligations for maintenance are considerable. For example, the annual maintenance cost of 100 medium-sized wet ponds (one-half acre to 2 acres) is estimated to be a quarter of a million dollars (Hunt and Lord, 2006c). Currently, the majority of municipal stormwater programs do not have adequate plans or resources in place for the long-term maintenance of SCMs (GAO, 2007).

A number of issues confront the long-term maintenance of SCMs. First, legal and financial responsibility for maintenance must be assigned. Historically stormwater ownership and responsibility have been poorly defined and implemented (Reese and Presler, 2005). If a party is an industrial facility that is required to obtain a permit, then responsibility for maintaining SCMs rests with the permittee. Other instances are more ambiguous. For residential developments, the responsibility for long-term maintenance could be assigned to the developer (e.g., establishing long-term financial accounts for maintenance), individual landowners, homeowners associations, or the municipality itself. Some cities, like Austin and Seattle, assume responsibility for long-term maintenance of SCMs in residential areas. Concerns over assigning responsibility to individual residential landowners or homeowners associations include insufficient technical and financial resources to conduct consistent maintenance and a lack of inspection to require maintenance. A recent survey of municipal stormwater programs found that less than one-third perform regular maintenance on stormwater detention ponds or water quality SCMs in general residential areas (Reese and Presler, 2005). To ensure that adequate maintenance will occur, municipalities can require performance securities (performance bonds, escrow accounts, letter of credit, etc.) that ensure adequate funds are available for maintenance and repair in the event of failure to maintain the SCM by the responsible party.

An effective maintenance program also requires a system to inventory and track SCMs, inspection/monitoring, and enforcement against noncompliance. The large number of SCMs to track and manage creates management challenges. Municipal stormwater programs must administer their regulatory programs, perform inspection and enforcement activities, and maintain SCMs in public lands/rights-of-way and sometimes in residential areas. Municipal programs often do not have adequate staff to ensure that these maintenance responsibilities are adequately carried out. The lack of adequate staff for inspection and an inadequate system for prioritizing inspections have been repeatedly pointed out (Duke and Beswick, 1997; Duke, 2007; GAO, 2007).

Tracking and monitoring costs may also create disincentives for municipalities to adopt smaller-scale SCMs. Residential-scale rain gardens, porous driveways, rain barrels, and grass swales all have the potential to increase the cost and complexity of compliance monitoring because of the multitude of small infiltration devices that are located on private property as opposed to having fewer SCMs located in public rights-of-way or public lands. Small-scale distributed SCMs located on private property raise concerns of municipal willingness to inspect and enforce against noncompliance. Indeed, some municipalities have banned innovative SCMs like pervious pavement because the municipalities have no means to ensure their maintenance and continued operation.

Finally, there is concern that there is inadequate funding to maintain the growing number of SCMs on the landscape. The long-term funding obligation for maintenance has been difficult to assess (GAO, 2007), partly because many stormwater programs frequently do not have adequate accounting practices to define capital value and depreciation, maintenance, operation, or management programs (Reese and Presler, 2005). The problem is compounded because the long-term maintenance cost associated with various types of SCMs is not well understood. Additional research and information are needed on the costs of maintaining the performance of SCMs as experienced in the field (rather than ex ante estimates based on design plans). Research into long-term maintenance costs should include not only routine operation and maintenance costs but also costs for inspection and enforcement and remediation costs associated with SCM performance failures. Such research is critical to understanding the long-term cost obligation that is being assumed by municipal stormwater programs that are responsible for managing a growing number of SCMs.

At the present time, the maintenance schedule for many of the proprietary and non-proprietary SCMs is poorly defined. It will vary with the type of drainage area and the activities that are occurring within it and with the efficiency of the SCM. (For example, the city of Austin, Texas, has determined that the average lifespan of their sand filters ranges from 5 to 15 years, but can be as little as one year if there is construction in the drainage area.) In order to establish a maintenance schedule, an assessment protocol needs to be adopted by municipalities. The protocol, which is specific to the type of SCM, could consist of the following: each year municipalities would be required to collect data from a subset of their SCMs on public and private property, and then over a period of years these data could be used to determine maintenance schedules, predict performance based on age and sediment loading, and identify failed systems. A measurement of the depth of deposited sediment might be the only test needed for settling devices, such as hydrodynamic devices and wet detention ponds. Two levels of analysis could be performed for infiltration devices—one based on simple visual observations and the other using an instrument to check infiltration rates. These assessment methods for infiltration devices have been tested at the University of Minnesota (Gulliver and Anderson, 2007). Without an assessment protocol for SCMs, the chances for poor maintenance and outright failure are greatly increased, it is difficult if not impossible to determine the actual performance of an SCM, and there will be insufficient data to reduce the uncertainty in future SCM design.

Lack of Design Guidance on Important SCMs and Lack of Training

Progress in implementing SCMs is often handicapped by the lack of local or national design guidance on important SCMs, and by the lack of training among the many players in the land development community (planners, designers, plan reviewers, public works staff, regulators, and contractors) on how to properly implement them on the ground. For example, design guidance is lacking or just emerging for many of the non-traditional SCMs, such as conservation of natural areas, earthwork minimization, product substitution, reforestation, soil restoration, impervious cover reduction, municipal housekeeping, stormwater education, and residential stewardship. Some LID techniques are better covered, such as the standards for pervious concrete from the American Concrete Institute and the National Ready Mixed Concrete Association. Design guidance for traditional SCMs such as erosion and sediment control may exist but is often incomplete, outdated, or lacking key implementation details to ensure proper on-the-ground implementation. In other cases, design guidance is available, but has not been disseminated to the full population of Phase II MS4 communities. For example, in an unpublished survey of state manuals used to develop national post-construction stormwater guidance, Hirschman and Kosco (2008) found that less than 25 percent provided sizing criteria, detailed engineering design specifications, or maintenance criteria. Nationwide guidance on SCM design and implementation may not be advisable or applicable to all physiographic, climatic, and ecoregions of the country. Rather, EPA and the states should encourage the development of regional design guidance that can be readily adapted and adopted by municipal and industrial permittees. Improvement of SCM design guidance should incorporate more direct consideration of the parameters of concern, how they move across the landscape, and the issues in receiving waters—a strategy both espoused in this report (page 351) and in recent publications on this topic (Strecker et al., 2005, 2007).

The second key issue relates to how to train and possibly certify the hundreds of thousands of individuals that are responsible for land development and stormwater infrastructure at the local and state level. New stormwater methods and practices cannot be effectively implemented until local planners, engineers, and landscape architects fully understand them and are confident on how to apply them to real-world sites. Currently, stormwater design is not a major component of the already crowded curriculum of undergraduate or graduate planning engineering or landscape architecture programs. Most stormwater professionals acquire their skills on the job. Given the rapid development of new stormwater technologies, there is a critical need for implementation of regional or statewide training programs to ensure that stormwater professionals are equipped with the latest knowledge and skills. The training programs should ultimately lead to formal certification for stormwater designers, inspectors, and plan reviewers.

Different Standards in Different Jurisdictions That Are Within the Same Watershed

Governmental and watershed boundaries rarely coincide, with the result that most watersheds are made up of many municipal bodies regulating stormwater management. Unfortunately in most cases there is no overarching stormwater regulatory structure that is based upon a watershed analysis. This can result in many unfortunate conflicts, where approval of a stormwater facility does not affect the community issuing the permit. It is often said that the most effective stormwater management for an area high in the watershed is to speed the water downstream, thus saving the upstream community but severely damaging the downstream rivers. While this may be an exaggeration, the problems downstream are less of a concern to the upper watershed communities, and downstream communities may not be able to solve their water issues without help from the upstream communities.

Often neighboring communities' plans or the methods or data used do not coincide. For example, often out-of-date rainfall distributions, methods, or standards are required in the code that do not apply to the newer focus on smaller storms and volume reduction. If methods that include Modified Rational or TR-55 are used, it is difficult if not impossible to show the benefits in peak flow reduction gained through volume reduction devices. Also, some municipalities may require curb and piping and not allow swales, impending the implementation of a cost-effective design. Finally, it is difficult to observe a measureable impact of SCMs when they are guided by a patchwork of regulations. One community may require removal of the first inch of runoff, and another may require the reduction of the 25-year, post-construction peak to the 10-year preconstruction level.

Water Rights that Conflict with Stormwater Management

In the West, water is considered real property, governed by state law and regional water compacts. Landowners in urban areas rarely own surface water rights and are typically prohibited from "beneficial use" of that water, which affects how SCMs are chosen. For example, current practices in Colorado typically allow stormwater to be infiltrated within a short period of time on-site without violation of water laws. However, storage of and/or pumping this water for broader distribution is considered to be a beneficial use and is therefore prohibited. Moreover, as discussed in Chapter 2, SCMs that manage stormwater by driving the water underground with a bored, drilled, or driven shaft or a hole dug deeper than its widest surface dimension are typically considered to be "injection wells," requiring a federal permit and regular monitoring under the Safe Drinking Water Act.

Some states prohibit infiltration because of concerns over long-term groundwater pollution. In California, which does not have a uniform policy for groundwater management and groundwater rights, authority over groundwater quality management falls to several regional and local agencies. For example, the Upper Los Angeles River Area (ULARA) has a court-appointed Watermaster to manage the complex appropriation of its groundwater to user cities and agencies. The ULARA has clashed with the City of Los Angeles regarding rights to all of the water that normally recharges the Los Angeles River via runoff from precipitation. In 2000, the ULARA Watermaster expressed a concern with certain permit provisions of the Los Angeles County MS4 Permit for New Development/ Redevelopment that promoted infiltration, stating that the MS4 permit interfered with the adjudicated right of the City of Los Angeles to manage groundwater.

Urban Development and Sprawl

The continued expansion of urban areas is inevitable given population increases worldwide and the transition from agricultural to industrial economies. Given that urbanization of almost any magnitude—even less than 10 percent impervious area—has been demonstrated to have an impact on in-stream water quality, a central question to be addressed is how water quality can be maintained as cities grow, without having negative impacts on social and economic systems. Ideally, SCMs would perform their water quality function, contribute to the livability of cities, and enhance their economic and social potentials.

Low-density, auto-oriented urban development, commonly known as sprawl, has been the predominant pattern of development in the United States, and increasingly worldwide, since World War II. It has been widely criticized for its inefficient use of land, its high use of natural resources, and its high energy costs—all of which are associated with the required auto-oriented travel. Additionally, ongoing economic costs related to the provision of widely dispersed services and social impacts of a breakdown in community life have been identified (Bruegmann, 2005). Sprawl and the impacts on in-stream water quality that result from urbanization have been an inevitable consequence of improved economic conditions. In the United States, sprawl constitutes the vast majority of development occurring today because a majority of the population is attracted to the benefits of a suburban lifestyle, government has subsidized roads and highways at the expense of public transit, and local zoning often limits development density.

There has been a great deal of innovation in city planning and design in the past decade that encourages greater density and a return to urban living. New types of zoning, New Urbanism, Smart Growth, and related innovations in urban planning and design have been developed in parallel with environmental regulations at local to national levels (see Chapter 2). They acknowledge the importance of protecting natural resources to maintain quality of life and have established water quality as an important consideration in city building.

It is not clear that current stormwater regulations can be effectively implemented over the broad range of development patterns that characterize contemporary cities or if they inadvertently favor one type of development over another. For example, on-site SMCs are often recommended as the preferred means of stormwater management, although they tend to encourage lower-density development patterns. And while they are easily implemented and regulated given the incremental, site-by-site development that is typical of most urban growth, monitoring and maintenance can be expensive and difficult for both the individual property owner and the regulating authority. In highly urbanized areas, they are often relegated to subsurface systems that are expensive and that, to be effective, require high levels of maintenance.

In newly developing areas, cluster development should be encouraged whenever possible, according to the Smart Growth principles of narrower streets, reduced setbacks, and related approaches to reduce the amount of impervious area required and land consumed. Furthermore, an interconnected series of on-site and consolidated SCMs can reduce subsurface stormwater piping requirements. Most planned communities have dedicated park and open-space areas that can constitute 25 percent or more of a development's total land area, making it feasible to easily accommodate consolidated SCMs (typically 8 to 10 percent of impervious area) within multi-functional open space and park lands. Cost efficiencies such as a 30 percent reduction in infrastructure costs (Duaney Plater-Zyberk & Company, 2006) can be realized through Smart Growth development techniques. Clustered housing surrounded by open space, laced with trails, has appreciated in value at a higher rate than conventionally designed subdivisions (Crompton, 2007).

In order to encourage infill or redevelopment over sprawl patterns of development, innovative zoning and other practices will be needed to prevent stormwater management from becoming onerous. For example, incentive zoning or performance zoning could be used to allow for greater densities on a site, freeing other portions of the site for SCMs. Innovations in governance and finance can also be used to incorporate consolidated SCMs into urban environments. For example, the City of Denver, in updating its Comprehensive Plan, designated certain underdeveloped corridors and districts in the city as "areas of change" where it hoped to encourage large-scale infill redevelopment. Given the scale of redevelopment, it would be feasible to establish special maintenance districts, allowing the development of consolidated SCMs that have multiple functions. To fund land purchase and facility design and construction, cash in lieu of payments could be made.

Safety and Aesthetic Concerns

Vector-borne diseases, especially West Nile virus, are a concern when SCMs such as extended detention basins, constructed wetlands, and rain barrels are proposed. Furthermore, other SCMs that are poorly designed, improperly constructed, or inadequately maintained may retain water and provide an ideal breeding ground for mosquitoes, increasing the potential for disease transmission to humans and wildlife. Kwan et al. (2005) found that water-retaining SCMs increase the availability of breeding habitats for disease vectors and provide opportunistic species an extended breeding season. State Health Departments generally recommend that SCMs be designed to drain fully in 72 hours, which is the minimum time required for a mosquito to complete its life cycle under optimum conditions. In SCMs where there is permanent standing water, such as stormwater wetlands, there is the possibility of introducing biota that might prey on mosquitoes. Municipalities may have to consider the added cost of vector control and public health when implementing stormwater quality management programs.

With larger consolidated and regional extended detention facilities, concerns about the safety of children who may be attracted to such SCMs and ensuing liability must be considered. These SCMs need to be fenced off or otherwise designed appropriately to reduce the risk of drowning.

One aspect of stormwater management that is infrequently considered is the aesthetic appeal, or lack thereof, of SCMs. The visual qualities of SCMs are important because they are a growing part of the urban landscape setting. Although it can be assumed that landscapes that are carefully tended are often preferred over other types of landscapes, it depends substantially on one's point of view. For example, an engineer may consider a particular SCM that is functioning as expected to be beautiful in the sense that its engineering function has been realized, even though there is sediment buildup, algae, or other products of a properly functioning SCM visible. Similarly, a biologist or ecologist evaluating an ecologically healthy SCM in an urban context might find it to be beautiful because of its biological or ecological diversity, whereas another individual who evaluates the same SCM finds it to be "weedy." SCMs can be viewed as a means of restoring a degraded landscape to a state that might have existed before urban development. The desire to "return to nature" is a seductive idea that suggests naturalistic SCMs that may have very little to do with an original landscape, given the dramatic changes in hydrology that are inevitable with urban streams. Each of these widely varied views of SCMs may be appropriate depending on the context and the viewer.

A goal of stormwater management should be to make SCMs desirable and attractive to a broader audience, thereby increasing their potential for long-term effectiveness. For example, the Portland convention center rain gardens demonstrate how native and non-native wetland plantings can be carefully composed as a landscape composition and also provide for stormwater treatment. If context and aesthetics of a chosen SCM are poorly matched, there is a high probability that the SCM will be eliminated or its function compromised because of modifications that make its landscape qualities more appropriate for its context.

CONCLUSIONS AND RECOMMENDATIONS

SCMs, when designed, constructed, and maintained correctly, have demonstrated the ability to reduce runoff volume and peak flows and to remove pollutants. However, in very few cases has the performance of SCMs been mechanistically linked to the guaranteed sustainment at the watershed level of receiving water quality, in-stream habitat, or stream geomorphology. Many studies demonstrate that degradation in rivers is directly related to impervious surfaces in the contributing watershed, and it is clear that SCMs, particularly combinations of SMCs, can reduce the runoff volume, erosive flows, and pollutant loadings coming from such surfaces. However, none of these measures perfectly mimic natural conditions, such that the accumulation of these SCMs in a watershed may not protect the most sensitive beneficial aquatic life uses in a state. Furthermore, the implementation of SCMs at the watershed scale has been too inconsistent and too recent to observe an actual cause-and-effect relationship between SCMs and receiving waters. The following specific conclusions and recommendations about stormwater control measures are made.

Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds. SCM implementation needs to be designed as a system, integrating structural and nonstructural SCMs and incorporating watershed goals, site characteristics, development land use, construction erosion and sedimentation controls, aesthetics, monitoring, and maintenance. Stormwater cannot be adequately managed on a piecemeal basis due to the complexity of both the hydrologic and pollutant processes and their effect on habitat and stream quality. Past practices of designing detention basins on a site-by-site basis have been ineffective at protecting water quality in receiving waters and only partially effective in meeting flood control requirements.

Nonstructural SCMs such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from a new development. Such SCMs should be considered first before structural practices. For example, lead concentrations in stormwater have been reduced by at least a factor of 4 after the removal of lead from gasoline. Not creating impervious surfaces or removing a contaminant from the runoff stream simplifies and reduces the reliance on structural SCMs.

SCMs that harvest, infiltrate, and evapotranspirate stormwater are critical to reducing the volume and pollutant loading of small storms. Urban municipal separate stormwater conveyance systems have been designed for flood control to protect life and property from extreme rainfall events, but they have generally failed to address the more frequent rain events (<2.5 cm) that are key to recharge and baseflow in most areas. These small storms may only generate runoff from paved areas and transport the "first flush" of contaminants. SCMs designed to remove this class of storms from surface runoff (runoff-volume-reduction SCMs—rainwater harvesting, vegetated, and subsurface) can also address larger watershed flooding issues.

Performance characteristics are starting to be established for most structural and some nonstructural SCMs, but additional research is needed on the relevant hydrologic and water quality processes within SCMs across different climates and soil conditions. Typical data such as long-term load reduction efficiencies and pollutant effluent concentrations can be found in the International Stormwater BMP Database. However, understanding the processes involved in each SCM is in its infancy, making modeling of these SCMs difficult. Seasonal differences, the time between storms, and other factors all affect pollutant loadings emanating from SCMs. Research is needed that moves away from the use of percent removal and toward better simulation of SCM performance. Hydrologic models of SCMs that incorporate soil physics (moisture, wetting fronts) and groundwater processes are only now becoming available. Research is particularly important for nonstructural SCMs, which in many cases are more effective, have longer life spans, and require less maintenance than structural SCMs. EPA should be a leader in SCM research, both directly by improving its internal modeling efforts and by funding state efforts to monitor and report back on the success of SCMs in the field.

Research is needed to determine the effectiveness of suites of SCMs at the watershed scale. In parallel with learning more about how to quantify the unit processes of both structural and nonstructural practices, research is needed to develop surrogates or guidelines for modeling SCMs in lumped watershed models. Design formulas and criteria for the most commonly used SCMs, such as wet ponds and grass swales, are based on extensive laboratory and/or field testing. There are limited data for other SCMs, such as bioretention and proprietary filters. Whereas it is important to continue to do rigorous evaluations of individual SCMs, there is also a role for more simple methods to gain an approximate idea about how SCMs are performing. The scale factor is a problem for watershed managers and modelers, and there is a need to provide guidance on how to simulate a watershed of SCMs, without modeling thousands of individual sites.

Improved guidance for the design and selection of SMCs is needed to improve their implementation. Progress in implementing SCMs is often handicapped by the lack of design guidance, particularly for many of the non-traditional SCMs. Existing design guidance is often incomplete, outdated, or lacking key details to ensure proper on-the-ground implementation. In other cases, SCM design guidance has not been disseminated to the full population of MS4 communities. Nationwide guidance on SCM design and implementation may not be advisable or applicable to all physiographic, climatic, and ecoregions of the country. Rather, EPA and the states should encourage the development of regional design guidance that can be readily adapted and adopted by municipal and industrial permittees. As our understanding of the relevant hydrologic, environmental, and biological processes increases, SCM design guidance should be improved to incorporate more direct consideration of the parameters of concern, how they move across the landscape, and the issues in receiving waters.

The retrofitting of urban areas presents both unique opportunities and challenges. Promoting growth in these areas is desirable because it takes pressure off the suburban fringes, thereby preventing sprawl, and it minimizes the creation of new impervious surfaces. However, it is more complex than Greenfields development because of the need to upgrade existing infrastructure, the limited availability and affordability of land, and the complications caused by rezoning. These sites may be contaminated, requiring cleanup before redevelopment can occur. Both innovative zoning and development incentives, along with the selection of SCMs that work well in the urban setting, are needed to achieve fair and effective stormwater management in these areas. For example, incentive or performance zoning could be used to allow for greater densities on a site, freeing other portions of the site for SCMs. Publicly owned, consolidated SCMs should be strongly considered as there may be insufficient land to have small, on-site systems. The performance and maintenance of the former can be overseen more effectively by a local government entity. The types of SCMs that are used in consolidated facilities—particularly detention basins, wet/dry ponds, and stormwater wetlands—perform multiple functions, such as prevention of streambank erosion, flood control, and large-scale habitat provision.

REFERENCES

Alexander, D., and J. Heaney. 2002. Comparison of Conventional and Low Impact Development Drainage Designs. Final Report to the Sustainable Futures Society. University of Colorado, Boulder.

Andrews, E. D. 1984. Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. Geological Society of America Bulletin 95:371-378.

Angus, R., K. Marion, and M. Lalor. 2002. Continuation of Studies to Evaluate the Effectiveness of Current BMPs in Controlling Stormwater Discharges from Small Construction Sites: Pilot Studies of Methods to Improve their

Effectiveness, and Assessment of the Effects of Discharge on Stream Communities. Alabama Water Resources Research Institute.

Arendt, R. 1996. Conservation Design for Subdivisions. Covelo, CA: Island Press.

ASCE (American Society of Civil Engineers). 2007. 2007 Data Analysis Report. International Stormwater BMP Database. U.S. Environmental Protection Agency and the Water Environment Research Foundation. Available at www.bmpdatabase.orgr.

Athayde, D. N., P. E. Shelly, E. D. Driscoll, D. Gaboury, and G. Boyd. 1983. Results of the Nationwide Urban Runoff Program—Vol. 1, Final Report. EPA WH-554. Washington, DC: EPA.

Aultman, S. 2007. Analyzing Cost Implications of Water Quality Trading Provisions: Lessons from the Virginia Nutrient Credit Exchange Act. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg.

Balusek, J. 2003. Quantifying Decreases in Stormwater Runoff from Deep-Tilling, Chisel-Planting and Compost Amendments. Dane County Land Conservation Department. Madison, WI.

Bannerman, R., J. Konrad, D. Becker, G. V. Simsiman, G. Chesters, J. Goodrich-Mahoney, and B. Abrams. 1979. The IJC Menomonee River Watershed Study—Surface Water Monitoring Data, EPA-905/4-79-029. Chicago: U.S. Environmental Protection Agency.

Bannerman, R., K. Baun, M. Bohn, P. E. Hughes, and D. A. Graczyk. 1983. Evaluation of Urban Nonpoint Sources Pollution Management in Milwaukee County, Wisconsin—Vol. I, Urban Stormwater Characteristics, Constituent Sources, and Management by Street Sweeping: Chicago, U.S. PB 84–114164. Springfield, VA: NTIS.

Barr Engineering Co. 2001. Minnesota Small Urban Sites BMP Manual. St. Paul, MN: Metropolitan Council Environmental Services.

Barrett, M. E., J. F. Malina, Jr., and R. J. Charbeneau. 1998. An evaluation of the performance of geotextiles for temporary sediment control. Water Environment Research 70(3):283-290.

Barten, J., and J. Johnson. 2007. Nutrient management with the Minnesota phosphorus fertilizer law. Lakeline (Summer):23-28.

Bean, E. Z., W. F. Hunt, and D. A. Bidelspach. 2007. Evaluation of Four Permeable Pavement Sites in Eastern North Carolina for Runoff Reduction and Water Quality Impacts. ASCE Journal of Irrigation and Drainage Engineering 133(6):583-592.

Bender, G. M., and M. L. Terstriep. 1984. Effectiveness of street sweeping in urban runoff pollution control. The Science of the Total Environment 33:185-192.

Bernhardt, E., and M. Palmer. 2007. Restoring streams in an urbanizing landscape. Freshwater Biology 52:731-751.

Bernhardt, E., M. Palmer, J. Allen, G. Alexander, K. Barnas, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G. M. Kondolf, P. S. Lake, R. Lave,

J. L. Meyer, T. K. O'Donnell, L. Pagano, B. Powell, E. Sudduth. 2005. Ecology: Synthesizing U.S. river restoration efforts. Science: 308:636-637.

Bernot, M., and W. Dodds. 200 5. Nitrogen retention, removal and saturation in lotic ecosystems. Ecosystems 8:442-453.

Black and Veatch. 2005. Stormwater Utility Survey. Overland, KS: Black and Veatch.

Braga, A., M. Horst, and R. Traver. 2007. Temperature effects on the infiltration rate through an infiltration basin BMP. Journal of Irrigation and Drainage Engineering 133(6):593-601.

Braskerud, B. C. 2001. The Influence of vegetation on sedimentation and resuspension of soil particles in small constructed wetlands. Journal of Environmental Quality 30:1447-1457.

Brinkman, R., and G. A. Tobin. 2001. Urban Sediment Removal: The Science, Policy, and Management of Street Sweeping. Boston, MA: Kluwer Academic.

Brown, E., D. Carac, and R. Pitt. 2004. Illicit discharge detection and elimination: a guidance manual for program development and technical assessments. Ellicott City, MD: Center for Watershed Protection.

Brown, W., and D. Caraco. 1997. Muddy water in, muddy water out. Watershed Protection Techniques 2(3):393-404.

Brown, W., and T. Schueler. 1997. The Economics of Stormwater BMPs in the Mid-Atlantic Region. Ellicott City, MD: Center for Watershed Protection.

Bruegmann, R. 2005. Sprawl: A Compact History. The University of Chicago Press.

Bukaveckas, P. 2007. Effects of channel restoration on water velocity, transient storage and nutrient uptake in a channelized stream. Environmental Science and Technology 41:1570-1576.

Burton, G., and R. Pitt. 2002. Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists and Engineers. Boca Raton, FL: CRC/Lewis.

Caltrans. 2004. BMP Retrofit Pilot Program Final Report CTSW-RT-01-050. Sacramento, CA: California Department of Transportation.

Cappiella, K., and K. Brown. 2000. Derivation of impervious cover for suburban land uses in the Chesapeake Bay. Final Report. Chesapeake Research Consortium. Ellicott City, MD: Center for Watershed Protection.

Cappiella, K., T. Schueler, and T. Wright. 2006. Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites. Newtown Square, PA: USDA Forest Service.

Carling, P. 1988. The concept of dominant discharge applied to two gravel-bed streams in relation to channel stability thresholds. Earth Surface Processes and Landforms 13:355-367.

CASQA (California Stormwater Quality Association). 2007. Municipal Stormwater Program Effectiveness Assessment Guidance. Sacramento, CA: California Association of Stormwater Quality Agencies.

Chang, M. 2006. Forest Hydrology: An Introduction to Water and Forests, 2nd

Ed. New York: CRC Press.

Chang, Y., Chou, C., Su, K., and C. Tseng. 2005. Effectiveness of street sweeping and washing for controlling ambient TSP. Atmospheric Environment 39:1891-1902.

Charles River Watershed Association. 2007. CRWA municipal stormwater financing: Survey results. Charles River Watershed Association. Weston, MA.

Cheng, M., L. Coffman, Y. Zhang, and J. Licsko. 2005. Hydrologic responses from low impact development compared to conventional development. Pp 337-357 *In:* Stormwater Management for Smart Growth. New York: Springer.

Cheshire, P., and S. Sheppard. 1995. On the price of land and the value of amenities. Economica 62:247-267.

Chollak, T., and P. Rosenfeld. 1998. Guidelines for Landscaping with Compost-Amended Soils. Prepared for City of Redmond Public Works, Redmond, WA. Available at http://www.ci.redmond.wa.us/insidecityhall/ publicworks/environment/pdfs/compostamendedsoils.pdf. Last accessed August 26, 2008.

City of Seattle. No date. Seattle's Natural Drainage Systems: A low-impact development approach to stormwater management. Brochure, Seattle, WA.

Clark, S., M. Lalor, R. Pitt, and R. Field. 2005. Wet-weather pollution from commonly used building materials. Paper presented at the 10th International Conference on Urban Drainage, August 21-26, Copenhagen.

Clausen, J. C. 2007. Jordan Cover Watershed Project Final Report. Storrs, CT: University of Connecticut.

Coombes, P. 2004. Water sensitive design in the Sydney Region—Practice Note 4. Rainwater Tanks. Published by the Water Sensitive Design in the Sydney Region Project.

Coombes, P., J. Argue, and G. Kuczera. 2000. Figtree Place: a case study in water sensitive urban development (WSUD). Urban Water Journal 4(1):335-343.

Crompton, J. 2007. The impact of parks and open spaces on property taxes. Chapter 1 *In:* The Economic Benefits of Land Conservation. T. F. de Brun (ed.). Trust for Public Lands.

Cross, L., and L. Duke. 2008. Regulating industrial stormwater: state permits, municipal implementation, and a protocol for prioritization. Journal of the American Water Resources Association 44(1):86-106.

Currier, B., J. Jones, and G. Moeller. 2005. NPDES Stormwater Cost Survey. Report prepared for the California State Water Resources Control Board. Sacramento, CA: California State Water Resources Control Board.

Cutter, W. B., K. A. Baerenklau, A. DeWoody, R. Sharma, and J. G. Lee. 2008. Costs and benefits of capturing urban runoff with competitive bidding for decentralized best management practices. Water Resources Research, doi:10.1029/2007WR006343.

CWP (Center for Watershed Protection). 1998a. Better Site Design: A Handbook for Changing Development Rules in Your Community. Ellicott City, MD: Center for Watershed Protection.

CWP. 1998b. The benefits of better site design in residential subdivisions. Watershed Protection Techniques 3(2):633-646.

CWP. 1998c. The benefits of better site design in commercial developments. Watershed Protection Techniques 3(2):647-656.

CWP. 2000a. Introduction to better site design. Watershed Protection Techniques 3(2):623-632.

CWP. 2000b. National Pollutant Removal Performance Database, 2nd Ed. Ellicott City, MD: Center for Watershed Protection.

CWP. 2001. The Economic Benefits of Better Site Design in Virginia. Document prepared for Virginia Department of Conservation and Recreation.

CWP. 2004. Stormwater pond and wetland maintenance guidebook. Ellicott City, MD: Center for Watershed Protection.

CWP. 2005. Pollution Source Control Practices. Manual 8, Urban Subwatershed Restoration Manual Series. Ellicott City, MD: Center for Watershed Protection.

CWP. 2007a. National Pollutant Removal Performance Database, 3rd Ed. Ellicott City, MD: Center for Watershed Protection.

CWP. 2007b. Urban stormwater retrofit practices. Manual 3, Urban Small Watershed Restoration Manual Series. Ellicott City, MD: Center for Watershed Protection.

CWP. 2008. Municipal good housekeeping practices. Manual 9, Urban Small Watershed Restoration Manual Series. Ellicott City, MD: Center for Watershed Protection.

Davis, A. P., W. F. Hunt, R. G. Traver, and M. E. Clar. 2008. Bioretention technology: an overview of current practice and future needs. ASCE Journal of Environmental Engineering (in press).

Debo, T. N., and A. J. Reese. 2002. Municipal Stormwater Management, Second Edition. Location: Lewis Publishers, CRC Press.

Deschesne, M., S. Barraud, and J. P. Bardin. 2005. Experimental Assessment of Stormwater Infiltration Basin Evolution. J. Env. Engineering 131(7):1090–1098.

DeWoody, A. E. 2007. Determining Net Social Benefits from Optimal Parcel-Level Infiltration of Urban Runoff: A Los Angles Analysis. Master's Thesis, University of California, Riverside.

Dietz, M. E., and Clausen, J. C. 2008. Stormwater Runoff and Export Changes with Development in a Traditional and Low Impact Subdivision. Journal of Environmental Management 87(4):560-566.

Dietz, M., and J. Clausen. 2006. Saturation to improve pollutant retention in a rain garden. Environmental Science and Technology 40(4):1335-1340.

Doll, A., and G. Lindsey. 1999. Credits bring economic incentives for onsite stormwater management. Watershed and Wet Weather Technical Bulletin 4(1):12-15.

Doll, R., and G. Jennings. 2003. Stream restoration: a natural channel design handbook. North Carolina State University Extension, Raleigh.

Duaney Plater-Zyberk & Company. 2006. Light Imprint New Urbanism: A Case Study Comparison. Chicago: Congress for the New Urbanism. Available at http://www.cnu.org/sites/files/Light%20 Imprint%20NU%20Report-web.pdf. Last accessed August 26, 2008.

Dubin, R. A. 1998. Predicting house prices using multiple listings data. Journal of Real Estate Finance and Economics 17:35-59.

Duke, L. D. 2007. Industrial stormwater runoff pollution prevention regulations and implementation. Presentation to NRC Stormwater Committee, August 22, Seattle, WA.

Duke, L. D., and P. G. Beswick. 1997. Industry compliance with storm water pollution prevention regulations: the case of transportation industry facilities in California and the Los Angles Region. Journal of the American Water Resources Association 33(4):825-838.

Duke, L., and C. Augustenberg. 2006. Effectiveness of self regulation and self-reported environmental regulations for industry: the case of stormwater runoff in the U.S. Journal of Environmental Planning and Management 49(3):385-411

Duncan, R. 2004. Selecting the "right" stormwater utility rate model — an adventure in political and contextual sensitivity. *In:* World Water Congress 2001 Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges. ASCE Conference Proceedings, May 20–24, 2001, Orlando, FL.

Emerson, C. H., C. Welty, and R. Traver. 2005. Watershed-scale evaluation of a system of storm water detention basins. Journal of Hydrologic Engineering 10(3):237-242.

Emerson, C., and R. Traver. 2008. Multiyear and Seasonal Variation of Infiltration from Storm-Water Best Management Practices. J. Irrig. Drain. Engrg. 134(5):598-605.

EPA (U.S. Environmental Protection Agency). 1983. Results of the Nationwide Urban Runoff Program. PB 84-185552. Washington, DC: Water Planning Division.

EPA. 1999. Preliminary Data Summary of Urban Stormwater Best Management Practices. EPA-821-R-99-012. Washington, DC: EPA Office of Water.

EPA. 2000. Social Costs in Guidelines for Preparing Economic Analysis. Publ. 240 R-00-003. Washington DC: EPA.

EPA. 2005a. Environmental Technology Verification Report, Stormwater Source Area Treatment Device—BaySaver Technologies, Inc., BaySaver Separation System, Model 10K. September 2005. EPA/600/R-05/113. Washington DC: EPA.

EPA. 2005b. Environmental Technology Verification Report; Stormwater Source Area Treatment Device--The Stormwater Management StormFilter® using Perlite Filter Media. August 2005. EPA/600/R-05/137. Washington DC: EPA.

EPA. 2005c. Environmental Technology Verification Report: Stormwater Source Area Treatment Device: Vortechnics, Inc. Vortechs System, Model 1000 September 2005 EPA/600/R-05/140. Washington DC: EPA.

EPA. 2005d. National Management Measures to Control Nonpoint Source Pollution from Urban Areas. Washington, DC: U.S. Government Printing Office.

EPA. 2007. Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices. EPA 841-F-07-006. Washington DC: EPA.

Ermilio, J., and R. Traver. 2006. Hydrologic and pollutant removal performance of a bio-infiltration BMP. EWRI 2006, National Symposium.

Ferguson, B. K. 1991. The Failure of Detention and the Future of Stormwater Design. Landscape Architecture 81(12):76-79.

Ferguson, B. K. 2002. Stormwater Management and Stormwater Restoration. Chapter I.1 of Handbook of Water Sensitive Planning and Design. R. L. France (ed.). Lewis Publishers.

Ferguson, B. K. 1994. Stormwater Infiltration. Boca Raton, FL: CRC Press.

Ferguson, B. K. 1998. Introduction to Stormwater. New York: John Wiley & Sons.

Fina, M., and L. Shabman. 1999. Some unconventional thoughts on sprawl. William and Mary Environmental Law Review 23(3):739-775.

FISRWG (Federal Interagency Stream Restoration Working Group). 2000. Stream Corridor Restoration: Principles, Processes and Practices. Washington, DC: USDA Natural Resource Conservation Service.

Florida Stormwater Association. 2003. Stormwater Utilities Survey. Available online at http://www.florida-stormwater.org/surveys/2003/menu.asp. Last accessed July 2006.

GAO. 2007. Further Implementation and Better Cost Data Needed to Determine Impact of EPA's Storm Water Program on Communities. GAO-07-479. Washington, DC: GAO.

Goetz, S., R. Wright, A. Smith, E. Zinecker, and E. Schaub. 2003. IKONOS imagery for resource management: tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. Remote Sensing in the Environment 88:195-208.

Gomi, T., R. Sidle, and J. Richardson. 2002. Understanding processes and downstream linkages of headwater systems. BioScience 53(10):905-915.

Greenway, M., P. Dale, and H. Chapman. 2003. An assessment of mosquito breeding and control in 4 surface flow wetlands in tropical–subtropical Australia. Water Science and Technology 48(5):249–256.

Gregory, J., M. Duke, D. Jones, and G. Miller. 2006. Effect of urban soil compaction on infiltration rates. Journal of Soil and Water Conservation 61(3):117-133.

Groffman, P., A. Dorset, and P. Mayer. 2005. N processing within geomorphic structures in urban streams. Journal North American Benthological Society 24(3):613-625.

Gulliver, J. S., and J. L. Anderson. 2007. Assessment of Stormwater Best Management Practices. Regents of the University of Minnesota. Available at http://wrc.umn.edu/outreach/stormwater/ Last accessed December 4, 2007.

Hager, M. C. 2003. Low impact development: lot-level approaches to stormwater management are gaining ground. Stormwater. Available at http://www.lowimpactdevelopment.org/lid%20articles /stormwater_feb2003.pdf. Last accessed August 26, 2008.

Hardy, M, P. Coombes, and G. Kuczera. 2004. An investigation of estate level impacts of spatially distributed rainwater tanks. Proceedings of the 2004 International Conference on Water Sensitive Urban Design—Cities as Catchments, November 21–25, 2004, Adelaide.

Hathaway, J., and W. Hunt. 2006. Level spreaders: Overview, design and maintenance. Urban Waterways. North Carolina State University and Cooperative Extension. Raleigh.

Heaney, J. P., D. Sample, and L. Wright. 2002. Costs of Urban Stormwater Control. EPA-600-02/021. Washington, DC: EPA.

Heasom, W., R. G. Traver, and A. Welker. 2006. Hydrologic modeling of a bioinfiltration best management practice. Journal of the American Water Resources Association 42(5):1329-1347.

Hillel, D. 1998. Environmental Soil Physics. San Diego, CA: Academic Press.

Hirschman, D., and J. Kosco. 2008. Managing stormwater in your community: a guide for building an effective post-construction problem. EPA 833-R-08-001. Tetra-tech, Inc. and Center for Watershed Protection. Ellicott City, MD.

Holman-Dodds, J., A. Bradley, and K. Potter. 2003. Evaluation of hydrologic benefits of infiltration based urban stormwater management. Journal of the American Water Resources Association 39(l):205-215.

Horner, R. R., and C. Chapman. 2007. NW 110th Street Natural Drainage System Performance Monitoring, with Summary of Viewlands and 2nd Avenue NW SEA Streets Monitoring. Report to Seattle Public Utilities by Department of Civil and Environmental Engineering, University of Washington, Seattle.

Horner, R., H. Lim, and S. Burges. 2003. Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Project. Water Resources Series. Technical Report 170. Seattle, WA: University of Washington Department of Civil and Environmental Engineering.

Hoyt, S., and T. Brown. 2005. Stormwater pond and wetland maintenance concerns and solutions. Paper presented at the EWRI 2005: Impacts of Global Climate Change Conference, American Society of Civil Engineers, Anchorage, Alaska, May 15-19.

Huber, W. L. Cannon and M. Stouder. 2006. BMP Modeling Concepts and Simulation. EPA/600/R-06/033. Corvallis, OR: U.S. Environmental Protection Agency.

Hunt, W., and W. Lord. 2006a. Bioretention Performance, Design, Construction, and Maintenance. AG-588-05. North Carolina Cooperative Extension Service. Urban Waterways.

Hunt, W. F., and W. G. Lord. 2006b. Determining Inspection and Maintenance Costs for Structural BMPs in North Carolina. Submitted to University of North Carolina, Water Resources Research Institute. (November).

Hunt, W. F., and B. Lord. 2006c. Stormwater wetlands and wet pond maintenance. AGW-588-07. North Carolina Cooperative Extension Service.

Hunt, W. F., J. T. Smith, S. J. Jadlocki, J. M. Hathaway, and P. R. Eubanks. 2008. Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. ASCE Journal of Environmental Engineering 134(5):403-408.

Jefferies, C. 2004. Sustainable Drainage Systems in Scotland: The Monitoring Programme. Scottish Universities SUDS Monitoring Project. Dundee, Scotland.

Johnson, C., T. Driscoll, T. Siccama and G. Likens. 2000. Elemental fluxes and landscape position in a northern hardwood forest ecosystem. Ecosystems 3:159-184.

Johnston, D. M., J. B. Braden, and T. H. Price. 2006. Downstream economic benefits of conservation development. Journal of Water Resources Planning and Management 132(1):35-43.

Kaspersen, J. 2000. The stormwater utility: will it work in your community? Stormwater 1(1). Available at http://www.forester.net/sw_0011_utility.html. Last accessed August 26, 2008.

Kaushal, S., P. Groffman, P. Meyer, E. Striz, and A. Gold. 2008. Effects of stream restoration on denitrification in an urbanizing watershed. Ecological Applications 18(3):789-804.

Keller, B. 2003. Buddy can you spare a dime? What is stormwater funding? Stormwater 4:7.

Kitchell, A. 2002. Managing for a pure water supply. Watershed Protection Techniques 3(4):800-812.

Konrad, C. 2003. Opportunities and constraints for urban stream rehabilitation. *In:* Restoration of Puget Sound Rivers. D. Montgomery, S. Bolton, D. Booth, and L. Wall (eds.). Seattle, WA: University of Washington Press.

Kwan, J., M. Metzger, M. Shindelbower, and C. Fritz. 2005. Mosquito production in stormwater treatment devices in South Lake Tahoe, California. Proceedings and Papers of the Seventy-Third Annual Conference of the Mosquito and Vector Control Association of California 73:113-119.

Kwiatkowski, M., A. L. Welker, R. G. Traver, M. Vanacore, and T. Ladd. 2007. Evaluation of an infiltration best management practice (BMP) utilizing pervious concrete. Journal of the American Water Resources Association 43(5):1208-1222.

Lager, J. A., W. G. Smith, and G. Tchobanoglous. 1977. Catchbasin Technology Overview and Assessment. EPA-600/2-77-051. Cincinatti, OH: EPA.

Lambe, L., M. Barrett, B. Woods-Ballard, R. Kellagher, P. Martin, C. Jefferies, and M. Hollon. 2005. Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems. Publ. 01-

CTS-21T. Alexandria VA: Water Environment Research Foundation.

Larson, M. L., D. B. Booth, and S. M. Morley. 2001. Effectiveness of large woody debris in stream rehabilitation projects in urban basins. Ecological Engineering 18(2):211-226.

Law, N. 2006. Research in support of an interim pollutant removal rate for street sweeping and storm drain cleanout. Technical Memo No. 2. Prepared for the EPA Chesapeake Bay Program and Urban Stormwater Working Group. Ellicott City, MD: Center for Watershed Protection.

Law, N., K. Diblasi, and U. Ghosh. 2008. Deriving Reliable Pollutant Removal Rates for Municipal Street Sweeping and Storm Drain Cleanout Programs in the Chesapeake Bay Basin. Ellicott City, MD: Center for Watershed Protection.

Legg, A., R. Bannerman, and J. Panuska. 1996. Variation in the relation of runoff from residential lawns in Madison, Wisconsin. USGS Water Resources Investigations Report 96-4194. U.S. Geological Survey.

Lehner, P., G. P. Aponte Clark, D. M. Cameron, and A. G. Frank. 1999. Stormwater Strategies: Community Strategies to Runoff Pollution. Natural Resources Defense Council. Available at http://www.nrdc.org/water/pollution/storm/stoinx.asp. Last accessed October 19, 2008.

Leopold, L. B. 1968. Hydrology for Urban Planning—A Guidebook on the Hydrologic Effects of Urban Land Use. USGS Circular 554. Washington, DC: U.S. Geological Survey.

Lichter, J., and P. Lindsey. 1994. Soil compaction and site construction: assessment and case studies. The Landscape Below Ground. G. W. Watson, and D. Neely (eds.). Savoy, IL: International Society of Arboriculture.

Line, D., and N. White. 2007. Effect of development on runoff and pollutant export. Water Environment Research 75(2):184-194.

Lloyd, S., T. Wong and C. Chesterfield. 2002. Water sensitive urban design: a stormwater management perspective. Cooperative Research Centre for Catchment. Monash University, Victoria 3800 Australia. Industry Report 02/10

Loucks, D. P., E. van Beek, J. R. Stedinger, J. P. M. Dijkman, and M. T. Villars. 2005. Water Resources Systems Planning and Management: An Introduction to Methods, Models, and Applications. Paris: UNESCO.

Low Impact Development Center. 2007. Introduction to low impact development. Available at http://www.lid-stormwater.net/intro/background.htm. Last accessed December 4, 2007.

Lowrance, R., and J. Sheridan. 2005. Surface runoff quality in a managed three zone riparian buffer. Journal of Environmental Quality 34:1851-1859.

MacMullan, E., and S. Reich. 2007. The Economics of Low-Impact Development: A Literature Review. Eugene, OR: ECONorthwest. Available at http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf. Last accessed August 26, 2007.

MacCrae, C. R. 1997. Experience from morphological research on Canadian streams: Is control of the two-year frequency runoff event the best basis for stream channel protection? Proceedings of the Effects of Watershed Developments and Management on Aquatic Ecosystems Conference, Snowbird, UT, August 4–9, 1996. L. A. Roesner (ed.). New York: American Society of Civil Engineers.

Manor, A. W. 1966. Public works in ancient Mesopotamia. Civil Engineering 36(7):50-51.

MD DNR. 2005. A Users Guide to Watershed Planning in Maryland. Annapolis, MD: DNR Watershed Services.

McBride, M., and D. Booth. 2005. Urban impacts on physical stream condition: effects on spatial scale, connectivity, and longitudinal trends. Journal of the American Water Resources Association 6:565-580.

McCuen, R. H. 1979. Downstream effects of stormwater management basins. Journal of the Hydraulics Division 105(11):1343-1356.

McHarg, I. L., and F. R. Steiner. 1998. To Heal the Earth, Selected Writings of Ian McHarg. Washington, DC: Island Press.

McHarg, I. L., and J. Sutton. 1975. Ecological Plumbing for the Texas Coastal Plain. Landscape Architecture 65:78-89.

MD DNR (Maryland Department of Natural Resources). 2003. Critical Area 10% Rule Guidance Manual: Maryland Chesapeake and Atlantic Coastal Bays. Annapolis, MD: Critical Area Commission.

Meyers, J. 2003. Where Rivers Are Born: The Scientific Imperative for Defending Small Streams and Wetlands. Washington, D.C.: American Rivers.

Mineart, P., and S. Singh. 1994. Storm Inlet Pilot Study. Performed by Woodward Clyde Consultants for Alameda County Urban Runoff Clean Water Program.

Montalto, F., C. Behr, K. Alfredo, M. Wolf, M. Arye, and M. Walsh. 2007. Rapid assessment of the cost-effectiveness of low impact development for CSO control. Landscape and Urban Planning 82(3):117-131.

Moore, A. and M. Palmer. 2005. Invertebrate diversity in agricultural and urban headwater streams: Implications for conservation and management. Ecological Applications 15(4):1169-1177.

Morgan, R. A., F. G. Edwards, K. R. Brye, and S. J. Burian. 2005. An evaluation of the urban stormwater pollutant removal efficiency of catch basin inserts. Water Environment Research 77(5):500-510.

MSSC (Minnesota Stormwater Steering Committee). 2005. Minnesota Stormwater Manual. St. Paul MN: Emmons & Oliver Resources, Inc., and the Minnesota Pollution Control Agency.

NAFSMA (National Association of Flood and Stormwater Management Agencies). 2006. Guidance for Municipal Stormwater Funding. Washington, DC: NAFSMA. Available at http://www.nafsma.org/Guidance%20 Manual%20Version%202X.pdf. Last accessed October 19, 2008.

Narayanan, A., and R. Pitt. 2006. Costs of urban stormwater control practices. Tuscaloosa, AL: Department of Civil, Construction and Environmental Engineering, University of Alabama.

Nichols, D., Akers, M.A., Ferguson, B., Weinberg, S., Cathey, S., Spooner, D., and Mikalsen, T. 1997. Land development provisions to protect Georgia water quality. The School of Environmental Design, University of Georgia. Athens, GA. 35pp.

NRC (National Research Council). 2000. Watershed Management for a Potable Water Supply. Washington, DC: National Academy Press.

PaDEP (Pennsylvania Department of Environmental Protection). 2006. Pennsylvania Stormwater Best Management Practices Manual. Harrisburg, PA: Bureau of Stormwater Management, Division of Waterways, Wetlands and Erosion Control.

Palmquist, R. 1980. Alternative techniques for developing real estate price indexes. Review of Economics and Statistics 62(3):442-448.

Parikh, P., M. A. Taylor, T. Hoagland, H. Thurston, and W. Shuster. 2005. Application of market mechanism and incentives to reduce stormwater runoff: an integrated hydrologic, economic, and legal approach. Environmental Science and Policy 8:133-144.

Perez-Pedini, C., J. Limbruneer, and R. Vogel. 2004. Optimal location of infiltration-based Best management practices for stormwater management. ASCE Journal of Water Resources Planning and Management 131(6):441-448.

Philips, R., C. Clausen, J. Alexpoulus, B. Morton, S. Zaremba, and M. Cote. 2003. BMP research in a low-impact development environment: The Jordan Cove Project. Stormwater 6(1):1-11.

Pickup, G., and R. F. Warner. 1976. Effects of hydrologic regime on magnitude and frequency of dominant discharge. Journal of Hydrology 29:51-75.

Pitt, R. 1979. Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices. EPA-600/2-79-161. Cincinnati, OH: EPA.

Pitt, R., with contributions from S. Clark, R. Field, and K. Parmer. 1996. Groundwater Contamination from Stormwater. ISBN 1-57504-015-8. Chelsea, MI: Ann Arbor Press, Inc.

Pitt, R., T. Brown, and R. Morchque. 2004a. National Stormwater Quality Database. Version 2.0. University of Alabama and Center for Watershed Protection Final Report to U.S. Environmental Protection Agency.

Pitt, R., Maestre, A., and Morquecho, R. 2004b. National Stormwater Quality Database. Version 1.1. Available at http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html.

Pitt, R., S. Chen, S. Clark, and J. Lantrip. 2005. Soil structure effects associated with urbanization and the benefits of soil amendments. *In:* World Water and Environmental Resources Congress. Conference Proceedings. American Society of Civil Engineers. Anchorage, AK.

Pouyat, R., I. Yesilonis, J. Russell-Anelli, and N. Neerchal. 2007. Soil chemical and physical properties that differentiate urban land use and cover types. Soil Science Society of America Journal 71(3):1010-1019.

Pouyat, R., M. McDonnel, and S. Pickett. 1995. Soil characteristics of oak stands along an urban-rural land use gradient. Journal of Environmental Quality 24:516-526.

Prince George's County, Maryland. 2000. Low-Impact Development Design Strategies. EPA 841-B-00-003. Washington, DC: EPA.

Qiu, Z., T. Prato, and G. Boehm. 2006. Economic valuation of riparian buffer and open space in a suburban watershed. Journal of the American Water Resources Association 42(6):1583-1596.

Randolph, J., A. C. Nelson, J. M. Schilling, and M. Nowak. 2006. Impact of environmental regulations on the cost of housing. Paper presented at the Association of Collegiate School of Planning, Fort Worth, TX. November 9.

Rea, M., and R. Traver. 2005. Performance monitoring of a stormwater wetland best management practice. National Conference, World Water & Environmental Resources Congress 2005 (EWRI/ASCE).

Reed, S. C., R. W. Crites, and E. J. Middlebrooks. 1998. Natural systems for waste management and treatment. McGraw-Hill Professional. ISBN 0071346627, 9780071346627.

Reese, A. J., and H. H. Presler. 2005. Municipal stormwater system maintenance. Stormwater. Available at http://www.stormh2o.com/sw_0509_municipal.html. Last accessed December 4, 2007.

Richman, T. 1997. Start at the Source: Design Guidance for Storm Water Quality Protection. Oakland, CA: Bay Area Stormwater Management Agencies Association.

Roy, A., C. Faust, M. Freeman, and J. Meyer. 2005. Reach-scale effects of riparian forest cover on urban stream ecosystems. Canadian Journal of Fisheries and Aquatic Science 62:2312-2329.

Roy, A., M. Freeman, B. Freeman, S. Wenger, J. Meyer, and W. Ensign. 2006. Importance of riparian forests in urban subwatersheds contingent on sediment and hydrologic regimes. Environmental Management 37(4):523-539.

Rushton, B. 2002. Low impact parking lot design infiltrates stormwater. *In:* Sixth Biennial Stormwater Research & Watershed Management Conference, September 14-17, 1999, Tampa FL. Brooksville, FL: Southwest Florida Water Management District.

Sample, D. J., J. P. Heaney, L. T. Wright, C.-Y. Fan, F.-H. Lai, and R. Field. 2003. Costs of best management practices and associated land for urban stormwater controls. Journal of Water Resources Planning and Management 129(1):59-68.

Schollen, M., T. Schmidt, and D. Maunder. 2006. Markham Small Streams Study—Policy Update and Implementing Guidelines for the Protection and Management of Small Drainage Courses. Town of Markham, Ontario.

Schueler, T. 1998. Irreducible pollutant concentration discharged from stormwater practices. Watershed Protection Techniques 2(2):369-372. Ellicott City, MD: Center for Watershed Protection.

Schueler, T. 2001a. The compaction of urban soils. Watershed Protection

Techniques 3(2):661-665. Ellicott City, MD: Center for Watershed Protection.

Schueler, T. 2001b. Can urban soil compaction be reversed? Watershed Protection Techniques 3(2):666-669. Ellicott City, MD: Center for Watershed Protection.

Schueler, T. 2001c. On watershed education. Watershed Protection Techniques 3(3):680-689. Ellicott City, MD: Center for Watershed Protection.

Schueler, T. 2002. On watershed behavior and resident education. Watershed Protection Techniques 3(3):671-686. Ellicott City, MD: Center for Watershed Protection.

Schueler, T., and K. Brown. 2004. Urban Stream Repair Practices: Manual 4. Urban Subwatershed Restoration Manual Series. Ellicott City, MD: Center for Watershed Protection.

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban Stormwater Retrofit Practices: Urban Stormwater Restoration Manual 3. Ellicott City, MD: Center for Watershed Protection.

Seattle Public Utilities. 2007. Street Edge Alternatives: Community Cost and Benefits. Available at http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Street_Edge_Alternatives/COMMUNITY_200406180902084.asp. Last accessed August 2007.

Selbig, W., and R. Bannerman. 2008. A Comparison of Runoff Quality and Quantity from Two Small Basins Undergoing Implementation of Conventional and Low Impact Development Strategies : Cross Plains, WI, Water Years 1999-2005. USGS Scientific Investigations Report 2008-5008. U.S. Geological Survey.

Sharkey, L. J. 2006. The Performance of Bioretention Areas in North Carolina: A Study of Water Quality, Water Quantity, and Soil Media. Thesis: North Carolina State University, Raleigh.

Shaver, E., R. Horner, J. Skupien, C. May, and G. Ridley. 2007. Fundamentals of Urban Runoff Management—Technical and Institutional Issues. Madison, WI: North American Lake Management Society.

Sidle, R. C. 1988. Bed load transport regime of a small forest stream. Water Resources Research 24: 207-218.

Singer, M., and R. Rust. 1975. Phosphorus in surface runoff from a deciduous forest. Journal of Environmental Quality 4:302-311.

Smith, R. A., and W. F. Hunt. 2007. Pollutant removal in bioretention cells with grass cover. Pp. 1-11 *In:* Proceedings of the World Environmental and Water Resources Congress 2007.

Song, Y., and G. Knaap. 2003. New urbanism and housing values: a disaggregate assessment. Journal of Urban Economics 54(2):218-238

Stagge, J. 2006. Field Evaluation of Hydrologic and Water Quality Benefits of Grass Swales for Managing Highway Runoff. Master's Thesis, University of Maryland.

Stavins, R. N. 2000. Market-based environmental policies. Public Policies for

Environmental Protection. P. R. Portney and R. N. Stavins (eds.). Washington, DC: Resources for the Future.

Stephens, K., P. Graham, and D. Reid. 2002. Stormwater Planning: A Guidebook for British Columbia. Vancouver, BC: Environment Canada.

Strecker, E. W., W. C Huber, J. P. Heaney, D. Bodine, J. J. Sansalone, M. M. Quigley, D. Pankani, M. Leisenring, and P. Thayumanavan. 2005. Critical assessment of Stormwater Treatment and Control Selection Issues. Water Environment Research Federation, Report No. 02-SW-1. ISBN 1-84339-741-2. 290pp. and NCHRP Report 565.

Strecker, E., M. Quigley, and M. Leisenring. 2007. Critical Assessment of Stormwater Treatment and Control Selection Issues- Implications and Recommendations for Design Standards. 6th International Conference on Sustainable Techniques and Strategies in Urban Watershed Management. June 24-28, 2007, Lyon, France. Novatech 2007.

Strecker, E., M. Quigley, B. Urbonas, and J. Jones. 2004. Stormwater management: state-of-the-art in comprehensive approaches to stormwater. The Water Report 6:1-10.

Sudduth, E., J. Meyer, and E. Bernhardt. 2007. Stream restoration practices in the southeastern U.S. Restoration Ecology 15:516-523.

Swamikannu, X. 1994. Auto Recycler and Dismantler Facilities: Environmental Analysis of the Industry with a Focus on Stormwater Pollution. Ph.D. Dissertation, University of California, Los Angeles.

SWRPC (Southeastern Wisconsin Regional Planning Commission). 1991. Costs of Urban Nonpoint Source Water Pollution Control Measures. Technical Report No. 31. Waukesha, WI: Southeastern Regional Planning Commission.

Traver, R. G., and R. A. Chadderton. 1992. Accumulation Effects of Stormwater Management Detention Basins. Hydraulic Engineering: Saving a Threatened Resource—In Search of Solutions. Baltimore, MD: American Society of Civil Engineers.

Turner, M. 2005. Leachate, Soil and Turf Concentrations from Fertilizer-Results from the Stillhouse Neighborhood Fertilzer Leachate Study. Austin: City of Austin Watershed Protection and Development Review Department.

USGS (United States Geological Survey). 2005. Evaluation of Street Sweeping as a Water-Quality Management Tool in Residential Basins in Madison. Scientific Investigations Report. September. Reston, VA: USGS.

Van Metre, P. C., B. J. Mahler, M. Scoggins, and P. A. Hamilton. 2006. Parking Lot Sealcoat: A Major Source of Polycyclic Aromatic Hydrocarbons (PAHs) in Urban and Suburban Environmental. USGS Fact Sheet 2005-3147.

Van Seters, T., D. Smith and G. MacMillan. 2006. Performance evaluation of permeable pavement and a bioretentions swale. Proceedings 8th International Conference on Concrete Block Paving. November 6-8, 2006, San Francisco, CA.

Walsh, C, K. Waller, J. Gehling, and R. MacNally. 2007. Riverine invertebrate assemblages are degraded more by catchment urbanisation than riparian deforestation. Freshwater Biology 52(3):574-587.

Wang, L., J. Lyons, P, Rasmussen, P. Simons, T. Wiley, and P. Stewart. 2003a. Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest Ecoregion. Canadian Journal of Fisheries and Aquatic Science 60:491-505.

Wang, L., J. Lyons, and P. Kanehl. 2003b. Impacts of urban land cover on trout streams in Wisconsin and Minnesota. Transactions of the American Fisheries Society 132:825-839.

WERF (Water Environment Research Foundation). 2006. Performance and Whole-Life Costs of BMPs and SUDs. Alexandria, VA: IWA.

WERF. 2008. Analysis of Treatment System Performance: International Stormwater Best Management Practices (BMP) Database [1999-2008]. Alexandria, VA: WERF.

Whisnant, R. 2007. Universal Stormwater Model Ordinance for North Carolina. Chapel Hill, NC: University of North Carolina Environmental Finance Center.

Wiegand, C., T. Schueler, W. Chittenden, and D. Jellick. 1986. Cost of Urban Stormwater Runoff Controls. Pp. 366-380 *In:* Proceedings of an Engineering Foundation Conference. Urban Water Resource. Henniker, NH: American Society of Civil Engineers.

Winter, T. 2007. The role of groundwater in generating streamflow in headwater areas in maintaining baseflow. Journal of American Water Resources Association 43(1):15-25.

Wisconsin DNR (Department of Natural Resources). 2002. Wisconsin Administrative Code: Environmental Protection General: chaps. TRANS 401.03. Madison, WI: Wisconsin DNR.

Wossink, A., and B. Hunt. 2003. The Economics of Structural Stormwater BMPs in North Carolina. Research Report Number 344. Raleigh, NC: Water Resources Research Institute.

Zarriello, P., R. Breault, and P. Weiskel. 2002. Potential effects of structural controls and street sweeping on stormwater loads to the Lower Charles River, Massachusetts. USGS Water Resources Investigations Report 02-4220. U.S. Geological Survey.

6
Innovative Stormwater Management and Regulatory Permitting

There are numerous innovative regulatory strategies that could be used to improve EPA's stormwater program. This chapter first outlines a substantial departure from the status quo, namely, basing all stormwater and other wastewater discharge permits on watershed boundaries instead of political boundaries. Watershed-based permitting is not a new concept, but it has been attempted in only a few communities. Development of the new permitting paradigm is followed by more modest and easily implemented recommendations for improving the stormwater program, from a new plan for monitoring industrial sites to encouraging greater use of quantitative measures of the maximum extent practicable requirement. The recommendations in the latter half of the chapter do not preclude adoption of watershed-based permitting at some future date, and indeed they lay the groundwork in the near term for an eventual shift to watershed-based permitting.

WATERSHED PERMITTING FRAMEWORK FOR MANAGING STORMWATER

At its initial meeting in January 2007, the committee heard opinions that collectively pointed in a new direction for managing and regulating stormwater that would differ from the end-of-pipe approach traditionally applied by regulatory agencies under the National Pollutant Discharge Elimination System (NPDES) permits and be based instead on a watershed framework. Indeed, the U.S. Environmental Protection Agency (EPA) has already given substantial thought to watershed permitting and issued a Watershed-Based NPDES Permitting Policy Statement (EPA, 2003a) that defined watershed-based permitting as an approach that produces NPDES permits that are issued to point sources on a geographic or watershed basis. It went on to declare that, "The utility of this tool relies heavily on a detailed, integrated, and inclusive watershed planning process. Watershed planning includes monitoring and assessment activities that generate the data necessary for clear watershed goals to be established and permits to be designed to specifically address the goals."

In the statement, EPA listed a number of important benefits of watershed permitting:

- More environmentally effective results;
- Ability to emphasize measuring the effectiveness of targeted actions on improvements in water quality;

- Greater opportunities for trading and other market-based approaches;
- Reduced cost of improving the quality of the nation's waters;
- More effective implementation of watershed plans, including total maximum daily loads (TMDLs); and
- Other ancillary benefits beyond those that have been achieved under the Clean Water Act (e.g., integrating CWA and Safe Drinking Water Act [SDWA] programs).

Subsequent to the policy statement, EPA published two guidance documents that lay out a general process for a designated state that wishes to set up any type of permit or permits under CWA auspices on a watershed basis (EPA, 2003b, 2007a). It also outlined a number of case studies illustrating various kinds of permits that contain some watershed-based elements. Box 6-1 describes in greater detail the more recent report (EPA, 2007a) and its 11 "options" for watershed-based permitting. Unfortunately, the EPA guidance is lacking in its description of what constitutes watershed-based permitting, who would be covered under such a permit, and how it would replace the current program for municipalities and industries discharging stormwater under an individual or general NPDES permit. Few examples are given, some of which are not even watershed-based, with most of the examples involving grouping municipal wastewater treatment works under a single permit with no reference to stormwater. Most of the 11 options are removed from the fundamental concept of watershed-based permitting. Finally, the guidance fails to elaborate on the policy statement goal to make water quality standards watershed-based. The committee concluded that, although the EPA documents lay some groundwork for watershed-based permitting—especially the ideas of integrated municipal permits, water quality trading, and monitoring consortia—the sum total of EPA's analysis does not define a framework for moving toward true watershed-based permitting. The guidance attends to few of the details associated with such a program and it has made no attempt to envision how such a system could be extended to the states and the municipal and industrial stormwater permittees. This chapter attempts to overcome these shortcomings by presenting a more comprehensive description of watershed-based permitting for stormwater dischargers.

The approach proposed in this chapter fits within the general framework outlined by EPA but goes much further. First, it is intended to replace the present structure, instead of being an adjunct to it, and to be uniformly applied nationwide. The proposal adopts the goal orientation of the policy statement and then extends it to root watershed management and permitting in comprehensive objectives representing the ability of waters to actually support designated beneficial uses. The proposal builds primarily around the integrated municipal permit concept in the policy statement and technical guidance. Like EPA's outline, the committee emphasizes measuring the effectiveness of actions in bringing improvements, but goes on from there to recommend a set of monitoring activi-

BOX 6-1
EPA's Current Guidance on Watershed-Based Permitting

Rather than explicitly define watershed based permitting, the EPA's recent guidance (EPA, 2007a) groups a large number of activities as having elements of watershed-based permitting, and defines how each might be utilized by a community. They are

- NPDES permitting development on a watershed basis,
- Water quality trading,
- Wet weather integration,
- Indicator development for watershed-based stormwater management,
- TMDL development and implementation,
- Monitoring consortium,
- Permit synchronization,
- Statewide rotating basin planning,
- State-approved watershed management plan development,
- Section 319 planning, and
- Source water protection planning.

Taking these topics in order, the first option is generally similar to that in EPA (2003a,b), but with some more detail on possible permitting forms. "Coordinated individual permits" implies that individual permits would be made similar and set with respect to one another and to a holistic watershed goal. The nature of such permits is not fully described, and there are no examples given. An "integrated municipal permit," also presented in the earlier policy statement, would place the disparate individual NPDES permits in a municipality (e.g., wastewater plants, combined sewer overflows, municipal separate storm sewer systems [MS4s]) under one permit. However, such a permit is not necessarily watershed-based. Finally, the "multi-source permit" could go in numerous directions, none of which are described in detail. In one concept, all current individual permittees who discharge a common pollutant into a watershed would come under one new individual permit that regulates that pollutant, while keeping the existing individual permits intact for other purposes. The Neuse River Consortium is given as an example. Alternatively, a multi-source permit could cover all dischargers of a particular type now falling under one individual permit that regulates all of their pollutants (no examples are given). In yet another application, this permit could be a general permit, and it would be identical to the existing general permits, except that it would be organized along watershed boundaries. As above, it could be refined on the basis of pollutant or discharger type.

The other ten options are more distant from the fundamental concept of watershed-based permitting. The water quality trading description is minimal, though it does mention a new EPA document that gives guidance to permittees for trading. Wet weather integration, the third topic, can mean any number of things, from creating a single permit to cover all discharges of pollutants during wet weather in a municipality, as described above for "coordinated individual permits," to just having all the managers of the systems get together and strategize. Although a stated goal is to reduce the amount of water in the sewer system after a storm, this integration is not particularly well defined in the document, nor is it well differentiated from other activities that would normally occur under an MS4 permit.

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BOX 6-1 Continued

Indicator development for watershed-based stormwater management refers to identifying indicators that are better than one or a few pollutants at characterizing the degree of impairment wrought by stormwater. Stormwater runoff volume is one indicator being developed by Vermont, and percent impervious surface is another. As discussed in Chapter 2, some states have long used biological indicators that integrate the effects of many pollutants as well as physical stresses such as elevated flow velocities. Indicators can be used as TMDL targets or as goals in NPDES permits. Identifying and adopting indicators is, essentially, a prerequisite to implementing some of the other options listed above.

Regarding the next topic on the list, the option of TMDL development is obvious, since the TMDL program is by definition watershed based. If it can be made the highest priority, and if stormwater is a contributor, then the implementation plan can be an excellent way to combat stormwater pollution on a watershed basis. Reducing the contribution of the pollutant from a stormwater source can involve water quality trading, better enforcement of existing permits, or creating new watershed-based permits. Hence, again, there is considerable overlap with the previously discussed options.

Developing a monitoring consortium is an option that works when sufficient data are not available to do much else. The concept mainly refers to monitoring of ambient waters. The activity is shared among partners (e.g., all wastewater plants in a region), with the goal of collecting and analyzing enough data to improve management decisions on a watershed basis, instead of for a single plant.

The following topic, permit synchronization, refers to having all permits within a watershed expire and be renewed simultaneously. This approach could be helpful for streamlining administrative, monitoring, and management tasks associated with maintaining the permits. Some states have operated in this way, whereas others have decided not to. It is one way to coordinate permits in cases where other types of watershed-based permitting would not work. Similarly, the statewide rotating basin approach, used by many states, relies on a five-year cycle. The state is divided into major watersheds, and each watershed is in a different stage of the cycle every year. It is a way to distribute the workload such that there is never a year when, for example, every watershed would require monitoring. Since it is a statewide program, how it relates to a watershed-based permitting situation is not at all clear.

ties designed to support active adaptive management to achieve objectives, aswell as to assess compliance. Credit trading, indicator development, the rotating basin approach, and monitoring should be part of management and permitting programs within watersheds, and ideas are advanced to develop these and other elements.

In addition to building on the work of EPA, the proposed approach tackles many of the impediments to effective watershed management identified in the National Research Council (NRC) treatise on watershed management (NRC, 1999). That report noted that watershed approaches are easiest to implement at the local level; thus, the approach developed in this chapter is a bottom-up process in which programmatic responsibility lies mainly with municipalities. Because the natural boundaries of watersheds rarely coincide with political jurisdictions, watersheds as geographic areas are less useful for political, institutional, and funding purposes, such that initiatives and organizations directed at watershed management should be flexible. The proposed approach recognizes this reality and makes numerous suggestions for pilot testing, funding, and institutional arrangements that will facilitate success. Finally, NRC (1999) notes the

With regard to the next topic, there has been a great deal of watershed planning around the nation and tremendous variety in form and comprehensiveness. Plans generally contain some information on the state of the watershed, goals for the watershed, and activities to meet those goals. Development of such plans in areas that do not have them could facilitate watershed-based permitting by providing much needed information about conditions, sources of pollutants, and methods to reduce pollution. According to EPA, a watershed plan may or may not indicate the need for watershed-based permitting.

The Section 319 Program refers to voluntary efforts to reduce pollution from nonpoint sources. The program in and of itself is not relevant to NPDES permits, since it deals strictly with activities that are not regulated. However, these activities could be traded with more traditional stormwater practices as part of a watershed-based effort to reduce overall pollution reaching waterbodies. Many watershed plans must consider guidance for the 319 program in order to get funding for their management activities.

If the watershed in question contains a drinking water source (either surface water or groundwater), then a good source water protection plan can have a significant impact on NPDES permitting in a watershed. Information collected during the assessment phase of source water protection could be used to help inform watershed-based permitting. Also, NPDES permits could be rewritten taking into account the proximity of discharges to source water intakes.

Following its coverage of the 11 options, EPA (2007a) gives a hypothetical example of picking six of the options to develop permitting for a watershed. It discusses how the options might be prioritized, but in a very qualitative manner, according to considerations such as availability of funding and personnel, stakeholder desires, environmental impacts, and sequencing of events. Chapter 1 of the report ends with a list of performance goals that might apply to the 11 options.

Chapter 2 further explains the multi-source watershed-based permit, discussing, for example, who would be covered by it, who would administer it, and how credit trading fits in. The chapter has a lot of practical, although quite intuitive, information about how to write such a permit. Much of the decision making is left to the permit writer. There are discussions of effluent limitations, monitoring requirements, reporting and record keeping, special conditions, and public notice. Chapter 3 follows by presenting case studies, although fewer than appeared in 2003 and not all truly watershed based.

need to "develop practical procedures for considering risk and uncertainty in real world decision-making in order to advance watershed management." The proposed revised monitoring system presented later in this chapter is designed to provide information in the face of ongoing uncertainty, i.e., adaptive management in a permitting context.

Watershed Management and Permitting Issues

There are many implications of redirecting the stormwater management and regulatory system from a site-by-site, SCM-by-SCM approach to an emphasis on attainment of beneficial uses throughout a watershed. Most fundamentally, the program's focus would shift to a primary concentration on broad goals in terms of, for example, achieving a targeted condition in a biological indicator associated with aquatic ecosystem beneficial uses or no net increase in elevated flow duration. Application of site-specific stormwater control measures (SCMs) would no longer constitute presumptive evidence of permit compliance, as is often the case in permits now, although it would still be an essential means to meeting goals. Achieving those goals, however, would form the compliance criteria.

In recognition of the demonstrated negative effects of watershed hydrologic modification on the attainment of beneficial uses, the proposal steps beyond the generally prevailing practice by embracing water quantity as a concern along with water quality. The inclusion of hydrology is consistent with the CWA on several grounds. First, elevated runoff peak flow rates and volumes increase erosive shear stress on stream beds and banks and directly contribute particulate pollutants to the flow (such as suspended and settleable solids, as well as nutrients and other contaminants bound to the soil material). Conversely, reduced dry-weather flows often occur in urban streams as a result of lost groundwater recharge and tend to concentrate pollutants and, hence, worsen their biological effects. Moreover, pollutant mass loading is the product of concentration and flow volume, and thus increased wet-weather surface runoff directly augments the cumulative burden on receiving waters. Finally, regulatory precedent for incorporating hydrology exists, as demonstrated by Vermont's stormwater program (LaFlamme, 2007).

At this time, stormwater management and regulation are divorced from the management and regulation of municipal and industrial wastewater. A true watershed-based approach would incorporate the full range of municipal and industrial sources, including (1) public streets and highways; (2) municipal stormwater drainage systems; (3) municipal separate and combined wastewater collection, conveyance, and treatment systems; (4) industrial stormwater and process wastewater discharges; (5) private residential and commercial property; and (6) construction sites. These many sources represent an array of uncoordinated permits under the current system and a strong challenge to developing a watershed-based approach. As pointed out in Chapter 2, multi-source considerations are an implicit facet of TMDL assessments, wherein states must consider both point and nonpoint sources. EPA (2003b) identified, among other possible permit types, an Integrated Municipal NPDES Permit, which would bundle all requirements for a municipality (e.g., stormwater, combined sewer overflows, biosolids, pretreatment) into a single permit. The Tualatin River watershed in Oregon has faced this challenge, at least in part, through an innovative watershed permit that combines both wastewater treatment and stormwater, brings in management of agricultural contributions to thermal pollution, and allows for pollutant trading among sources (see Box 6-2). It appears that the various participating parties did not use their energies in trying to allocate blame but instead determined the most effective and efficient ways of improving conditions. For example, the municipal permittees willingly offered incentives to agricultural landowners to plant riparian shade trees as an alternative to more expensive means of reducing stream temperatures under their direct control. Indeed, with agriculture not being regulated by the Clean Water Act, watershed permitting

BOX 6-2
Watershed-Based Permitting in Oregon

Clean Water Services is a wastewater and stormwater utility that covers a special service district of 12 cities and unincorporated areas in urban Washington County, Oregon. It was originally chartered in the 1970s as the Unified Sewerage Agency to consolidate the management of 26 "package" wastewater treatment facilities. Its responsibilities expanded to stormwater management in the early 1990s and it now serves nearly 500,000 customers. There are four wastewater treatment plants (WWTPs) in the district, with a dry weather capacity of 71 million gallons per day (MGD). During low-flow months, the discharge from these plants can account for 50 percent of the water in the Tualatin River. The district also own rights to one-quarter of the stored water in Hagg Lake. The land use in the watershed is about one-third urban, one-third agriculture, and one-third forest.

In 2001, the region was faced with TMDLs on the Tualatin River or its tributaries for total phosphorus, ammonia, temperature, bacteria, and dissolved oxygen. By 2002, the area was also dealing with four expired NPDES permits and one expired MS4 permit (all of which had been administratively extended), approval of a second TMDL, and an Endangered Species Act (ESA) listing. The region decided that it wanted to try to integrate all of these programs using a watershed-based regulatory framework. This would include a TMDL implementation mechanism, an ESA response plan, and integrated water resources management (meaning that water quantity, water quality, and habitat considerations would be made at the same time). Prior to integration, water quality was covered by the TMDL and NPDES programs, but these programs did not cover water quantity and habitat issues. The ESA listing addressed the habitat issues, but it was done totally independently of the TMDLs and NPDES permits.

Thus, the region applied for an integrated municipal NPDES permit that bundles all NPDES permit requirements for a municipality into a single permit, including publicly owned treatment works (POTWs), pretreatment, stormwater, sanitary sewer overflows, and biosolids. Initially, it encompassed the four WWTP permits, the one MS4 permit, and the industrial and construction stormwater permits. The hope was that this would streamline multiple permits and capture administrative and programmatic efficiencies; provide a mechanism for implementing more cost-effective technologies and management practices including water quality credit trading; integrate watershed management across federal statutes such as the CWA, SDWA, and ESA; and encourage early and meaningful collaboration and cooperation among key stakeholders.

This case study was successful because a single entity—Clean Water Services—was already in charge of what would have otherwise been a group of individual permittees. Furthermore, all the NPDES permits had expired and the TMDL had just been issued, providing a window of opportunity. The state regulatory agency was very willing, and EPA provided a $75,000 grant. Finally, there was a robust water quality database and modeling performed for the area because of the previous TMDL work. The watershed-based permit, the first in the nation, was issued February 26, 2004. Among its unique elements are an intergovernmental agreement companion document signed by the Oregon Department of Environmental Quality (DEQ), water quality credit trading, and consolidation of reporting requirements. The water quality trading is one of the most interesting elements, and several variations have been attempted. Biological oxygen demand (BOD) and NH_3 have been traded both intra-facility and inter-facility.

The temperature TMDL on the Tualatin River is a particularly interesting example of trading because it helped to bring agriculture into the process, where it would otherwise not have been involved. Along the length of the river, there are portions that exceed the temperature standard. A TMDL allocation was calculated that would lower temperatures by the

continued next page

BOX 6-2 Continued

same amount everywhere, such that there would be no point along the river that would be in exceedance. Options for reducing temperature include reducing the influent wastewater temperature (which is hard to do), reducing the total WWTP discharge to the Tualatin River (which is not practical), mechanically cooling or refrigerating WWTP discharge (which would require more energy), or trading the heat load via flow augmentation and increased shading (which is what was attempted).

Clean Water Services choose to utilize a market-based, watershed approach to meet the Tualatin temperature TMDL. It was market-based because it had financial incentives for certain groups to participate, it was cost-effective, and it provided ancillary ecosystem services. It was a watershed-based approach because it capitalized on the total assimilative capacity of the basin. What was done was to (1) provide cooling and in-stream flow augmentation by releasing water from Hagg Lake Reservoir, and (2) trade riparian stream surface shading improvement credits. They also reused WWTP effluent in lieu of irrigation withdrawals. For the riparian shading, they developed an “enhanced” CREP program to increase the financial incentives to rural landowners (with Clean Water Services paying the difference over existing federal and state programs). Clean Water Services also made incentive payments to the Soil and Water Conservation District to hire people to act as agents of Clean Water Services. Oregon DEQ’s Shadalator model was used to quantify thermal credits for riparian planting projects, which required that information be collected at 100-foot increments along the stream on elevation, aspect, wetted width, Nordfjord-Sogn Detachment Zone, channel incision, and plant type and planting corridor width. To summarize, over the five-year term of the permit, Clean Water Services will release 30 cfs/d of stored water from Hagg Lake each July and August and shade roughly 35 miles of tributary riparian area (they have already planted 34 miles of riparian buffer). This plan involved an element of risk taking, since the actions of unregulated parties (such as farmers) have suddenly become the responsibility of Clean Water Services.

and initiatives of this type represent the best, and perhaps only, mechanism for ameliorating negative effects of agricultural runoff that, left unattended, would undo gains in managing urban runoff. The Neuse River case study, discussed later in this chapter, is another example of bringing agricultural contributions to aquatic degradation under control, along with urban sources, through a watershed-based approach.

Significant disadvantages of the current system of separate permits for municipal, construction, and industrial activities are (1) the permits attack the problem on a piecemeal basis, (2) they are hard to coordinate because they expire at different times, (3) they are not designed to allow for long-term operation of SCMs, and (4) they do not cover all discharges. A solution to these problems would be to integrate all discharge permitting under municipal authority, as is proposed here. The lead permittee and co-permittees would bear ultimate responsibility for meeting watershed goals and would regulate all public and private discharges within their jurisdictions to attain them. Municipalities are the natural focus for this role because they are the center of land-use decisions throughout the nation.

Municipalities must be provided with substantially greater resources than they have now to take on this increased responsibility. Beyond funding, regulatory responsibilities must be realigned to some degree. The norm now is for states to administer industrial permits directly and generally attend to all aspects of permit management. However, states, more often than not, are unable because of resource limitations to give permittees much attention in the form of inspection and feedback to ensure compliance. At the same time, some states, explicitly or implicitly, expect municipal permittees to set up programs to meet water quality standards in the waters to which all land uses under their jurisdictions discharge.[1] It only makes sense in this situation to have designated states (or EPA for the others) specify criteria for industrial and construction permits but revise regulations to empower and support municipal co-permittees in compliance-related activities. This paradigm is not unprecedented in environmental permitting, as under the Clean Air Act, states develop state implementation plans for implementation by local entities. For this new arrangement to work, states would have to be comfortable that municipalities could handle the responsibility and be able to exercise the added authority granted. The committee's opinion is that municipalities generally do have the capability, working together as co-permittees with a large-jurisdiction lead permittee and with guidance and support from states.

It bears noting at the outset that the proposed new program would not reduce the present system's reliance on general permits. Whereas a general permit now can be issued to a group of municipalities having differing circumstances, under the new system a permit could just as well be formulated in the same way for a group of varying watersheds. General industrial and construction permits would be just as prevalent too.

Toward Watershed-Based Permitting

Watershed-based permitting is taken in this report to mean regulated allowance of discharges of water and wastes borne by those discharges to waters of the United States, with due consideration of (1) the implications of those discharges for preservation or improvement of prevailing ecological conditions in the watershed's aquatic systems, (2) cooperation among political jurisdictions sharing a watershed, and (3) coordinated regulation and management of all discharges having the potential to modify the hydrology and water quality of the watershed's receiving waters.

[1] For example, the second Draft Ventura County [California] Municipal Separate Storm Sewer System Permit states (under Findings D. Permit Coverage), "Provisions of this Order apply to the urbanized areas of the municipalities, areas undergoing urbanization and areas which the Regional Water Board Executive Officer determines are discharging storm water that causes or contributes to a violation of a water quality standard … ." The permit further states (under Part 2—Receiving Water Limitations), "1. Discharges from the MS4 that cause or contribute to a violation of water quality standards are prohibited. … 3. … This Order shall be implemented to achieve compliance with receiving water limitations. If exceedence(s) of water quality objectives or water quality standards persist … the Permittee shall assure compliance with discharge prohibitions and receiving water limitations … ."

Determining Watershed Scale for Permitting

A fundamental question that must be answered at the outset of any move to watershed permitting is, What is a watershed? Hydrologically, a watershed is the rain catchment area draining to a point of interest. Hence, the question comes down to, Where should the point of interest be located to define watersheds for permitting purposes? If placed close to the initial sources of surface runoff (e.g., on each first-order stream just above its confluence with another first-order stream), attention would be very specifically directed. However, there would be little flexibility to devise solutions for the greatest good. For example, trading of the commodities runoff quantity and quality would be very restricted. If on the other hand the point of interest is placed far downstream, thus defining a very large watershed, a welter of issues, and probably also of involved jurisdictions, would overly confuse the management and regulatory task.

The U.S. Geological Survey (USGS) delineates watersheds in the United States using a nationwide system based on surface hydrologic features. This system divides the country into 21 regions, 222 subregions, 352 accounting units, and 2,262 cataloging units. These hydrologic units are arranged within each other, from the smallest (cataloging units) to the largest (regions). USGS identifies each hydrologic unit by a unique hydrologic unit code (HUC) consisting of 2 to 16 digits based on the four levels of classification in the hydrologic unit system. Watersheds thus delineated are typically of the order a few square kilometers in area. This system is now being linked to the National Hydrography Dataset (NHD) and the National Land Cover Dataset to produce NHDPlus, an integrated suite of application-ready geospatial datasets.

The USGS system provides a starting point. Ultimately, though, what constitutes a watershed will best be answered with reference to specific biogeophysical conditions and problems and by personnel at relatively close hand (i.e., state or regional oversight agency staff). A general guideline might be the catchment area of a waterbody influenced by a set of similar subwatersheds. Similar subbasins would presumably be amenable to similar solutions and trading off reduced efforts in some places for compensating additional efforts elsewhere, as well as to analysis and monitoring on a representative basis, instead of exhaustively throughout. Often, a watershed defined in this way would flow into another watershed and influence it. Thus, there would have to be coordination among managers and regulators of interacting watersheds. It would be common for several watersheds ranging from relatively small to large in scale to be nested. Each would have its management team, and a committee drawn from those teams should be formed to coordinate goals and actions.

A prerequisite to moving toward watershed permitting, then, is for states or regions within states to delineate watersheds. California took this step early in the NPDES stormwater permitting process and offers a model in this respect, as well as in encompassing all jurisdictions coordinated by a lead permittee. First, the state organized its California EPA regional water boards on a watershed basis. Furthermore, since 1992 it has been common in California to establish one jurisdiction as the lead permittee (e.g., Los Angeles County in the Los Angeles region, Orange County in the Santa Ana Region, and San Diego County in the San Diego Region) and all of the politically separate cities as co-permittees. The lead permittee has typically been the jurisdiction most widely distributed geographically in the region and large enough to develop compliance mechanisms and coordinate their implementation among all participants. Box 6-3 describes the approach taken to delineating management units within the Chesapeake Bay watershed, which comprises parts of Pennsylvania, Maryland, Virginia, and the District of Columbia. The case study illustrates well the approach advocated here of focusing on the outcome in the receiving water and considering all aspects of land and water resources management that determine that outcome.

Steps Toward Watershed-Based Permitting

Once a watershed is defined, a further question arises regarding how much and what part of its territory to cover formally under permit conditions. Under the present system substantial development occurring outside Phase I or Phase II municipal jurisdictions is escaping coverage. Failing to control relatively high levels of development both outside a permitted jurisdiction and upstream of more lightly developed areas within a permitted area is particularly contrary to the watershed approach. Areas having a more urban than rural character are already essentially treated as urban in water supply and sewer planning, and the same should occur in the area of stormwater management. Accordingly, the permit should extend to any area in the watershed, even if outside Phase I or II jurisdictions, zoned or otherwise projected for development at an urban scale (e.g., more than one dwelling per acre). States do have authority under the CWA to designate any area for Phase II coverage based on projected growth or the presence of impact sources. They should be required to do so for nationwide uniformity and best protection of water resources.

It is essential to clarify that watershed-based permitting as formulated in this chapter differs sharply from what has been termed watershed (or basin) planning. According to EPA, watershed planning "identifies broad goals and objectives, describes environmental problems, outlines specific alternatives for restoration and protection, and documents where, how, and by whom these action alternatives will be evaluated, selected, and implemented" (*http://www.epa.gov/watertrain/planning/planning7.htm*). Drawing up such a plan is a time-consuming process, which has often become an end in itself, instead of a means to an end. Completing a full watershed plan, as usually construed, should not be a prerequisite to watershed-based permitting. Rather, the anticipated process would spring much more from comprehensive, advanced scientific and technical analysis of the water resources to be managed and their contributing catchment areas than from a planning framework.

BOX 6-3
Watershed Delineation for the Chesapeake Bay

The "Tributary Strategy Team" approach of the Chesapeake Bay Watershed provides a specific example of a watershed-scale approach to implementation of water quality control measures. Some background on this longstanding program is first provided, before turning to how watersheds were delineated. In 1983, the states of Virginia, Maryland, and Pennsylvania; the District of Columbia; and EPA signed an agreement to form the Chesapeake Bay Program with a goal to restore and protect the bay, which was suffering from nutrient overenrichment, severely reduced submerged aquatic vegetation, and contamination by toxics. In 1987 the program established a target of a 40 percent reduction in the amount of nutrients entering the Bay by 2000. In 1992 the bay program partners agreed to continue the 40 percent reduction goal beyond 2000 by allocating nutrient reduction targets to the bay's tributaries. In Chesapeake 2000, the most recent version of the Chesapeake Bay agreement, the nutrient reduction goals were reaffirmed, and an additional goal of sediment reduction was established. New York, Delaware, and West Virginia, locations of the bay's headwaters, also became involved in nutrient and sediment reduction. Cap load allocations for nutrients (nitrogen and phosphorus) and sediment to be reached by 2010 were agreed upon by the states. The states began developing 36 voluntary watershed-based tributary strategies to meet the state cap load allocations covering the entire 64,000-square-mile Chesapeake Bay watershed.

Watershed-based tributary strategies are developed in cooperation with local watershed stakeholders. For rural areas, where stakeholders include farmers, nutrient strategies include promotion of management practices such as maintaining cover crops on recently harvested cropland to reduce soil erosion, reduction in nitrogen applications, conservation tillage, and establishment of riparian buffers. For urban-area stakeholders such as homeowners and municipalities, tributary strategies include practices such as enhanced nutrient removal at WWTPs, low-impact development (LID) practices, erosion and sediment control practices, and septic system upgrades.

The first cut at delineating the watershed, which was based on hydrography and topography, defined the eight major areas draining to the Chesapeake Bay: six major basins (Susquehanna, Potomac, York, James, Rappahannock, and Patuxent) plus smaller areas not draining to a major river on the Eastern and Western Shores of the bay in Maryland. These subdivisions are disparate with respect to size (the Susquehanna can engulf almost the entire other seven), but direct drainage to the bay was the criterion at this level.

The next cut was made at state borders. For example, the Susquehanna traverses three states and was subdivided at the New York–Pennsylvania and Pennsylvania–Maryland political boundaries. Further cuts were subsequently made within some states. The criteria for these cuts varied from state to state, but generally involved a combination of smaller political jurisdictions (e.g., county, township), subwatershed basin borders, and other local considerations, such as local interest and investment (e.g., watershed associations).

The resulting delineations are highly variable in size but apparently satisfactory to the local parties who decided on the areas. They represent individual "tributary strategy areas" but are also nested within the larger eight designations and involve interjurisdictional and interstate coordination where a subbasin is divided by a political boundary. Although the example of the Chesapeake Bay is at a very large scale, the principles of watershed delineation it illuminates apply at all scales.

Effective watershed-based permitting as outlined in this report is composed of:

- Centralizing responsibility and authority for implementation with a municipal lead permittee working in partnership with other municipalities in the watershed as co-permittees;
- Adopting a minimum goal in every watershed to avoid any further loss or degradation of designated beneficial uses within the watershed's component waterbodies;
- Assessing waterbodies that are not providing designated beneficial uses in order to set goals aimed at recovering these uses;
- Defining careful, complete, and clear specific objectives to be achieved through management and permitting;
- Comprehensive impact source analysis as a foundation for targeting solutions;
- Determining the most effective ways to isolate, to the extent possible, receiving waterbodies from exposure to those impact sources;
- Developing and appropriately allocating funding sources to enable the lead permittee and partners to implement effectively;
- Developing a monitoring program composed of direct measures to assess compliance and progress toward achieving objectives and diagnosing reasons for the ability or failure to meet objectives, in support of active adaptive management; and
- Developing a market system of trading credits as a tool available to municipal co-permittees to achieve watershed objectives, even if solutions cannot be uniformly applied.

The system proposed herein is a significant departure from the road traveled in the 20 years since CWA amendments began to bring stormwater under direct regulation. This reorganization is necessary because of the failure of the present system to achieve widespread and relatively uniform compliance (see Chapter 2) and, ultimately, to protect the nation's water resources from degradation by municipal, industrial, and construction runoff. The workload associated with adopting this approach will be considerable and will take some time to complete. The structure of the new program should be fully in place within five years, which is considered to be a reasonable period to complete the work. It could be fully implemented throughout the nation within ten years. However, interim measures toward its fulfillment should occur sooner, within one to two years. Such measures should be applied to each land-use and impact-source category (i.e., existing residential and commercial development, existing industry, new development, redevelopment, construction sites). For example, measures such as an effective impervious area limit or a requirement to maintain predevelopment recharge to the subsurface zone could make early progress in managing new development, and lead toward the ultimate, objective-based management and permitting strategy for that category. Advanced source control performance standards would be appropriate interim measures for existing development.

One innovative approach to watershed-based management that can ease the burden of the proposed new system is the rotating basin approach. As described by EPA (2007a), this option entails delineating state watershed boundaries and grouping the watersheds into basin management units, usually by the state water pollution control agency. Next, states implement a watershed management process on a rotating schedule, which is usually composed of five activities: (1) data collection and monitoring, (2) assessment, (3) strategy development, (4) basin plan review, and (5) implementation. Over time, different waterbodies are intensively studied as part of the rotation. Data collected can be used to support a number of different reporting and planning requirements, including a finding of attainment of water quality standards, a determination of impairment, or possible delisting if the waterbody is found not to be impaired. Florida offers a good example of the rotating basin approach. The Florida Department of Environmental Protection has defined five levels of intensity, or phases, each taking about one year to complete, and it has divided the state into 30 areas based on HUCs. At any one time six areas are in each phase before rotating to a subsequent phase. This division of effort would help alleviate the burden of moving to a new system of watershed-based permitting by programming the work over a period of years. It could certainly be organized on a priority basis, in which the watersheds of greatest interest for whatever reason (e.g., having the highest resource values, being most subject to new impacts) would get attention first.

An Objective-Based Framework

The proposed framework for watershed-based management and regulation of stormwater relies on broad goals to retain and recover aquatic resource beneficial uses, backed by specific objectives (e.g., water quality criteria) that must be achieved if the goals are to be fulfilled. Meeting the objectives and overarching goals is intended to become the basis for determining permit compliance, instead of the current reliance on implementation of SCMs as presumptive evidence of compliance.

The broad goals of retaining and recovering beneficial uses are entirely consistent with the antidegradation clause of the CWA. Antidegradation means that the current level of water quality shall be maintained and protected, unless waters exceed levels necessary for maintaining their beneficial uses *and* the state finds that allowing lower water quality is necessary to accommodate important economic or social development. In accordance with the antidegradation clause, a major pillar of the proposed concept is the goal of preventing degradation from the existing state of biological health, whatever it may be, to a lower state. Thus, fully and nearly pristine watersheds are to remain so and, at a minimum, partially or highly impaired ones are to suffer no further impairment. Beyond this minimum, impaired waters should be assessed to determine if feasible actions can be taken to recover lost designated beneficial uses or at least improve degraded uses.

As discussed in Chapter 2, beneficial uses relate to the social and ecological services offered, or intended to be offered, by waterbodies. For example, California has 20 categories of beneficial uses embracing water supply for various domestic, agricultural, and industrial purposes; provision of public recreation; and support of aquatic life and terrestrial wildlife (CalEPA, Central Coast Regional Water Board Basin Plan). That beneficial uses are usually assigned at the state level by waterbody classes or specific waterbodies would not change under the proposed permitting program revision. Most waters have several beneficial uses encompassing some water supply and ecological functions and, perhaps, some form of recreation. Unlike most current stormwater programs where attainment of beneficial uses is only implicit, these goals would become explicit in the altered system and officially promulgated by the authority operating the permit program (a designated state, in most cases, or EPA). The permitting authority would then partner with municipal permittees to determine the conditions that must be brought to bear to attain beneficial uses, set objectives or criteria to establish those conditions, and follow through with the tasks to accomplish objectives.

The proposed framework's reliance on achieving objectives that reflect the cumulative aquatic resource effects of contributing watershed conditions suggests the following related concepts:

- In whatever manner watershed boundaries are set, the full extent of the watershed from headwaters onward should be considered in defining objectives. This is important even where watershed scale and boundaries are based on local and/or regional hydrogeomorphic circumstances and their associated management and regulatory needs. Watersheds can and often will be defined and nested at different scales (e.g., streams tributary to a lake, a river flowing into an estuary or marine bay).

- The scale of objectives must be consistent with the scale and recognized beneficial uses of the watershed(s) in question; for example, sustaining salmonid fish spawning could be the basis for a stream objective, while retaining an oligotrophic state could be the essential objective for a lake to which the stream is tributary.

- Whenever beneficial uses pertain to living organisms (aquatic life or humans), representing the vast majority of all cases, objectives should be largely in biological terms. That is not to say that supplementary objectives cannot be stated otherwise (e.g., in terms of flow characteristics, chemical water quality constituents, or habitat attributes), but the ultimate direct thrust of the program should be toward the biota.

- Objectives must be carefully chosen to represent attributes of importance from a resource standpoint, limited in number for feasibility of tracking achievement, and defined in a way that achievement can be measured. For example, nitrogen is generally the nutrient limiting algal growth in saline systems and in excess it stimulates growth that can reduce dissolve oxygen, killing fish and other aerobic organisms. In this case the most productive objectives would probably target reduction of nitrogen concentration and mass flux and maintenance of dissolved oxygen. For waterbodies designated for contact recreation, fecal coliform indicators (although not directly pathogenic when waterborne) have proven to be an effective means of assessing condition and should continue to form the basis for objectives to protect contact recreation until research produces superior measures. If drinking water supply is a designated beneficial use of a lake, it will better serve that function in a lower than a higher state of eutrophication, which can be managed, according to a long limnological research record, by restricting water column chlorophyll *a* as an objective. Where the beneficial use is fish protection and propagation, biological criteria might include (1) maintenance of a specific population size of a resident fish species when that species' population can be assayed conveniently; (2) maintenance of a numerical index (e.g., benthic index of biotic integrity) when a fish species of ultimate interest cannot be assessed so conveniently but is known or reasonably hypothesized to be associated with the index; or (3) a related parameter, such as eelgrass beds, which are important fish nursery areas in estuarine waters, such that areal coverage by these beds would be an appropriate objective to track over time. An intermittent waterbody could have biological criteria related to, for example, fish migration or amphibian reproduction.

- The achievement of objectives, or lack thereof, is the basis for follow-up and prescription of remedies in an active adaptive management mode; that is, falling short of objectives would trigger a search for reasons throughout the watershed, followed by identification of actions necessary and sufficient to remedy the shortfall, assessment of their ability to reach objectives, and the cost of doing so. In the course of this assessment it may be concluded that the objective itself is faulty and should be restated, replaced, or discarded.

Basing the watershed framework principally on biological objectives grows out of the CWA's fundamental charge to protect the biological (as well as physical and chemical) integrity of the nation's waters. The tie between specific physical and chemical conditions and the sustenance of aquatic biological communities is not well established through an extensive, well-verified body of research. Moreover, living organisms consuming or living in water are subject to a vast multitude of simultaneous physical and chemical agents having the potential to harm them individually and interactively. There are no realistic prospects for research to determine the levels of these numerous agents that must be maintained to support beneficial uses. Therefore, their integrative effects must be determined using measures of biological populations or communities of interest.

By and large, state water quality standards as now promulgated would not serve the proposed objective-based system well. They are usually not phrased in biological terms or with respect to hydrologic variables now known to have instrumental negative effects on aquatic organisms, but instead mostly as concentrations of selected chemical elements or compounds. However, there is no prohibition of biological or hydrologic standards in the law. The recommended emphasis is consistent with and informed by the tiered aquatic life uses system applied by some states and illustrated for Ohio in Box 2-1. The use of such systems must expand greatly to support the recommended framework. An opportunity to do so exists through the triennial review already required for each state's water quality standards.

Certain special considerations affect the development and use of objectives as the device to carry forward watershed-based stormwater management and regulation. First, other elements of the CWA beyond the stormwater program and other laws may very well be involved in a watershed (see Chapter 2). Municipal and industrial wastewater discharges will often be contributors along with stormwater. Aquatic organisms may be listed as threatened or endangered under the federal ESA or state authority. Both objectives and the management and regulatory program designed to achieve objectives should reflect any such circumstances.

Instituting the proposed permitting program will require converting the TMDL program to one more suitable for its purposes and structure. The TMDL program is watershed based and hence offers some precedent and experience applicable to the new system. However, for the most part, it has operated only on waters declared to be impaired for specific pollutants, and it relies on management of specific physical and chemical water quality variables. Furthermore, in its current mode it takes no account of potential future impact sources. The TMDL program should be replaced with one adapted to the objective-based framework proposed here. This new program should apply to all waters assigned objectives, "impaired" or not, and formulate limits in whatever terms are best to achieve objectives. Hence, although the program would expand in coverage area, the efficient tailoring of objectives directly to beneficial uses could compensate for the expansion by targeting fewer variables. Finally, the new program should look to the future as well as the present by encompassing the anticipated impacts of prospective landscape changes.

The nature of a program to replace TMDLs can be glimpsed from a few attempts to move in the anticipated direction even under the existing structure. For example, Connecticut collected data directly linking impervious cover to poor stream health in Eagleville Brook (Connecticut Department of Environmental Protection, 2007). The stream's TMDL was developed using watershed impervious cover as a surrogate parameter for a mix of pollutants conveyed by stormwater. The intention is to reduce effective imperviousness by disconnecting impervious areas, installing unspecified SCMs, minimizing additional disturbance, and enhancing in-stream and riparian habitat. Flow was used as a surrogate for stormwater pollution in the Potash Brook, Vermont TMDL (Vermont DEC, 2006). In this waterbody, the impairment was based on biological indices that were then related to a hydrologic condition believed to be necessary to achieve the Vermont criteria for aquatic life. The TMDL will be implemented via the use of runoff-volume-reduction SCMs throughout the watershed.

Impact Sources

The CWA provides for regulating, as specific land-use types, only designated industrial categories, with construction sites disturbing one acre or more considered to be one of those categories. Otherwise, it gives authority to regulate municipal jurisdictions operating separate storm sewer systems. Generally speaking, these jurisdictions encompass, in addition to the industrial categories, the full range of urban land-use types, such as single- and multiple-family residential, various kinds and scales of commercial activity, institutional, and parks and other open space. All of these land uses and the activities conducted on them are, to one degree or another, sources of the agents that physically and chemically modify aquatic systems to the detriment of their biological health. Hence, most of the impact sources to which these aquatic systems are subject are not directly regulated under CWA authority as are industrial sources, but instead are indirectly regulated through the municipal program. Also, as already discussed, the situation is further complicated by the presence of municipal and industrial wastewater sources along with landscape sources contributing flow and pollutants to receiving waters via stormwater discharges.

The watershed-based framework envisioned here relies on municipalities led by a principal permittee. Thus, a fundamental task that municipal permittees charged with operating under a watershed-based permit must do is to find industries and construction sites in the watershed that have not filed for permit coverage and bring them under regulation. Furthermore, municipal co-permittees, with leadership by a watershed lead permittee, must classify industries and construction sites within their borders according to risk and accordingly prioritize them for inspection and monitoring (methods for doing this are discussed later in the chapter). Municipal permittees must have better tools than they have had in the past to assess the various impact sources and formulate strategies to manage them that have a reasonably high probability of fulfilling objectives. The present state of practice and research findings offers some directions for choosing or more completely developing these tools. However, by no means are all the necessary elements available, and substantial new basic and applied research must be performed.

From the literature come several possibilities to improve source analysis in the complex urban environment. Some examples of apparent promise, drawn from Clark et al. (2006) include the following:

- Nirel and Revaclier (1999) used the ratio of dissolved rubidium (Rb) to strontium (Sr) to identify and quantify the impact of sewage effluents on river quality in Switzerland. Rubidium was present in larger quantities than strontium in feces and urine, making the ratio of these two elements an effective tracer that does not vary with river flow for a given water quality condition. Using the ratio alone produced the same conclusions regarding impact as measuring a host of physicochemical water quality variables. The researchers estimated that the Rb:Sr ratio must be lower than 0.007 if biological diversity is to be maintained, which could be the basis of an objective to manage river water quality. Although this case pertains to municipal wastewater and the technique works best in waters with a naturally low Rb:Sr ratio (e.g., calcareous regions), it success points out a potential avenue of research to simplify stormwater management on the basis of quantitative objectives related to biological integrity.

- Cosgrove (2002) described the approach used in New Jersey to characterize the relative contribution of point and nonpoint sources of pollutants in the Raritan River Basin. Twenty-one surface water sampling locations within the watershed were monitored four to five times per year from 1991 to 1997. These data were evaluated by comparing the median concentration at each sampling location with land-use statistics. Cumulative probability curves were also developed for each pollutant to demonstrate the probability that the concentration at a given location would be below a certain level (e.g., a stream standard). These probability curves were useful in determining the risk that a given location would violate a particular standard. The concentration data, coupled with continuous flow monitoring records, were utilized to determine the total load for each constituent. Regression analysis was used to develop a relationship between the total in-stream loads and flow. Such an analysis provided an indication of municipal or industrial discharge versus diffuse-source-dominated locations. Pollutant loads could then be converted to yield (load per unit area) to normalize the results for comparison from one station to another. The "screening level" methodology uses only existing data and, not requiring advanced modeling techniques, can be used to understand where to focus more rigorous modeling techniques.

- Maimone (2002) presented the overall approach that was used to screen and evaluate potential pollutant sources within the Schuylkill River watershed as part of the Schuylkill River Source Water Assessment Partnership. The partnership performed source water assessments of 42 public water supply intakes for the Pennsylvania Department of Environmental Protection. The watershed encompasses over 1,900 square miles with more than 3,000 potential point sources of contamination. In addition, runoff from diverse land uses such as urban and agriculture had to be characterized using the Stormwater Management Model. For all 42 surface water intakes, potential point sources were identified using existing databases. The list was first passed through a series of Geographic Information System-based "screening" sieves to limit the sources to only those considered to be high priority (including proximity and travel time from source to intake). Ten categories were identified that cover the range of the most important contaminants that might be found within the watershed, and a representative or surrogate chemical was identified whose properties were used to stand in for the category. Beyond the geographic screening, a more sophisticated screening was needed to limit the number of sites, using a decision support computer software program called EVAMIX. The greatest benefit of EVAMIX, compared to other software, is that it allows mixed criteria evaluation, qualitative and quantitative, to be considered concurrently. EVAMIX produced source rankings representing an organized and consistent use of both the objective data and the subjective priorities of decision makers.

- Hetling et al. (2003) investigated the effect of water quality management efforts on wastewater discharges to the Hudson River (from Troy, New York to the New York City Harbor) from 1900 to 2000. The paper demonstrated a methodology for estimating historic loadings where data are not available. Under these circumstances, estimated historic sewered and treated populations and per capita values were used to calculate wastewater flow and loadings for 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), total nitrogen, and total phosphorus. The analysis showed that dispersed landscape sources have become the most significant contributors of the first two contaminants to the river, while municipal wastewater plants remain the largest sources of nutrients. The methodology presented in this paper could be used by co-permittees to estimate present-day sources of various types and contribute to moving toward a comprehensive permit incorporating multiple sources.

- Zeng and Rasmussen (2005) used multivariate statistics to characterize water quality in a lake and its tributaries. Tributary water was composed of three components. Factor analysis demonstrated that stormwater runoff was the predominant cause of elevation of a group of water quality variables in a factor including TSS, the measurement of which is a convenient surrogate for all variables in the factor. Similarly, municipal and industrial discharges could be characterized by total dissolved solids, and groundwater by alkalinity plus soluble reactive phosphorus. These sources can thus be distinguished through measurement of just four common water quality variables. Reducing the number of analytes reduces laboratory costs and allows resources to be freed up for other purposes. Cluster analyses performed on the data indicated that further savings could be realized by sampling just one among several stations in a cluster and sampling at just one point in time over a period of relatively stable water quality (e.g., a relatively dry period).

A key research need associated with applying the proposed framework is assessment of these and other mechanisms for sorting out the contributions of the variety of impact sources in the urban environment. Leading this effort would be a natural role for EPA.

Impact Reduction Strategies

The philosophical basis for impact reduction under a modified permitting system centered on a lead municipal permittee and associated co-permittees is to avoid, as far as possible, exposing receiving waters to impact sources or to otherwise minimize that exposure. The concept embraces both water quantity and quality impact sources and specifically raises the former category to the same level of scrutiny as traditionally applied to water quality sources. Furthermore, the endpoints upon which success and compliance would be judged are directly related to achievement of beneficial uses. This approach to impact reduction, where the direct focus is on reducing the loss of aquatic ecosystem functioning supportive of beneficial uses, fundamentally contrasts with the currently prevailing system. What are primary concerns in the existing system (e.g., discharge concentrations of certain chemical and physical substances, technological strategies from a menu of practices) are still prospectively important, but only as a means toward realizing functional objectives, not as endpoints themselves. To be sure, attaining beneficial uses will require wise choices among tools to decrease discharges and contaminant emissions. However, the ultimate proof will always be in biological outcomes.

As made clear in Chapters 3 and 4, linkages among myriad stressing agents, impact receptors, and specific mitigating abilities of technological fixes are poorly understood and not easily understandable. The proposed new paradigm acknowledges that the linkages are not established among the voluminous elements in an exceptionally complex system ranging from impact sources, through environmental transport and fate mechanisms, to ecosystem health. However, it is intuitively and theoretically clear that minimizing the generation of impacts in the first place and slowing their progression into aquatic environments can break the chain of landscape alteration that leads to increased runoff and pollutant production, modifies aquatic habitat, and ultimately causes deterioration of the biological community. Landscapes can be managed in a preventive, integrated fashion that deals with the many undifferentiated agents of impact and avoids, or at least reduces, the damage. Although the application of these theories may not automatically and quickly stem biological losses, the powerful mechanism of adaptive management, if correctly applied, can be used to make course corrections toward meeting the defined objectives.

An earlier National Research Council (NRC) committee examined the scientific basis of EPA's TMDL program and recommended "adaptive implementation" (AI) to water quality standards (NRC, 2001a). That committee drew AI directly from the concept of adaptive management for decision making under uncertainty, introduced by Holling and Chambers (1973) and Holling (1978) and described it as an iterative process in which TMDL objectives and the implementation plans to meet those objectives are regularly reassessed during the ongoing implementation of controls. Shabman et al. (2007) and Freedman et al. (2008) subsequently extended and refined the applicability of AI for promoting water quality improvement both within and outside of the TMDL program. In that broader context, AI fits well with the framework put forward here. Indeed, the proposed revised monitoring system presented later in this chapter is designed to provide information to support adaptive management in a permitting context.

The Stages of Urbanization and Their Effects on Strategy

In waterbodies that are not in attainment of designated uses, it is likely that the physical stresses and pollutants responsible for the loss of beneficial uses will have to be decreased, especially as human occupancy of watersheds increases. Reducing stresses, in turn, entails mitigative management actions at every life stage of urban development: (1) during construction when disturbing soils and introducing other contaminants associated with building; (2) after new developments on Greenfields are established and through all the years of their existence; (3) when any already developed property is redeveloped; and (4) through retrofitting static existing development. Most management heretofore has concentrated on the first two of those life stages.

The proposed approach recognizes three broad stages of urban development requiring different strategies: new development, redevelopment, and existing development. *New development* means building on land either never before covered with human structures or in prior agricultural or silvicultural use relatively lightly developed with structures and pavements (i.e., Greenfields development). *Redevelopment* refers to fully or partially rebuilding on a site already in urban land use; there are significant opportunities for bringing protective measures to these areas where none previously existed. The term *existing development* means built urban land not changing through redevelopment; retrofitting these areas will require that permittees operate creatively.

What is meant by redevelopment requires some elaboration. Regulations already in force typically provide some threshold above which stormwater management requirements are specified for the redeveloped site. For example, the third Draft Ventura County Municipal Separate Storm Sewer System Permit defines “significant redevelopment” as land-disturbing activity that results in the creation or addition or replacement of 5,000 square feet or more of impervious surface area on an already developed site. The permit goes on to state that where redevelopment results in an alteration to more than 50 percent of the impervious surfaces of a previously existing development, and the existing development was not subject to postdevelopment stormwater quality control requirements, the entire site becomes subject to application of the same controls required for new development. Where the alteration affects 50 percent or less of the impervious surfaces, only the modified portion is subject to these controls.

All urban areas are redeveloped at some rate, generally slowly (e.g., roughly one or at most a few percent *per annum*) but still providing an opportunity to ameliorate aquatic resource problems over time. Extending stormwater requirements to redeveloping property also gradually "levels the playing field" with new developments subject to the requirements. As pointed out in Chapter 2, some jurisdictions offer exemptions from stormwater management requirements to stimulate desired economic activities or realize social benefits. Such exemptions should be considered very carefully with respect to firm criteria designed to weigh the relative socioeconomic and environmental benefits, to prevent abuses, to gauge just how instrumental the exemption is to gaining the socioeconomic benefits, and to compensate through a trading mechanism as necessary to achieve set aquatic resource objectives.

It is important to mention that not only residential and commercial properties are redeveloped, but also streets and highways are periodically rebuilt. Highways have been documented to have stormwater runoff higher than other urban land uses in the concentrations and mass loadings of solids, metals, and some forms of nutrients (Burton and Pitt, 2002; Pitt et al., 2004; Shaver et al., 2007). Redevelopment of transportation corridors must be taken as an opportunity to install SCMs effective in reducing these pollutants.

Opportunities to apply SCMs are obviously greatest at the new development stage, somewhat less but still present in redevelopment, but most limited when land use is not changing (i.e., existing development). Still, it is extremely important to utilize all readily available opportunities and develop others in static urban areas, because compromised beneficial uses are a function of the development in place, not what has yet to occur. Often, possibly even most of the time, to meet watershed objectives it will be necessary to retrofit a substantial amount of the existing development with SCMs. To further progress in this overlooked but crucial area, the Center for Watershed Protection issued a practical Urban Stormwater Retrofit Practices manual (Schueler et al., 2007).

Practices for Impact Reduction

As described in Chapter 5, in the past 15 to 20 years stormwater management has passed through several stages. First, it was thought that the key to success was to match postdevelopment with predevelopment peak flow rates, while also reducing a few common pollutants (usually TSS) by a set percentage. Finding this to require large ponds but still not forestalling impacts, stormwater managers next deduced that runoff volumes and high discharge durations would also have to decrease. Almost simultaneously, although not necessarily in concert, the idea of LID arose to offer a way to achieve actual avoidance or at least minimization of discharge quantity and pollutant increases reaching far above predevelopment levels. For purposes of this discussion, the SCMs associated with LID along with others are named Aquatic Resources Conservation Design (ARCD). First, this term signifies that the principles and many of the methods apply not only to building on previously undeveloped sites, but also to redeveloping and retrofitting existing development. Second, incorporating aquatic resources conservation in the title is a direct reminder of the central reason for improving stormwater regulation and management. ARCD goes beyond LID to encompass many of the SCMs discussed in Chapter 5, in particular those that decrease surface runoff peak flow rates, volumes, and elevated flow durations caused by urbanization, and those that avoid or at least minimize the introduction of pollutants to any surface runoff produced. This concentration reduction, together with runoff volume decrease, cuts the cumulative mass loadings (mass per unit time) of pollutants entering receiving waters over time. The SCM categories from Table 5-1 that qualify as ARCD include:

- Product Substitution,
- Watershed and Land-Use Planning,
- Conservation of Natural Areas,
- Impervious Cover Minimization,
- Earthwork Minimization,
- Reforestation and Soil Conservation,
- Runoff Volume Reduction—Rainwater Harvesting, Vegetated, and Subsurface,
- Aquatic Buffers and Managed Floodplains, and
- Illicit Discharge Detection and Elimination.

The menu of ARCD practices begins with conserving, as much as possible, existing trees, other vegetation, and soils, as well as natural drainage features (e.g., depressions, dispersed sheet flows, swales). Clustering development to affect less land is a fundamental practice advancing this goal. Conserving natural features would further entail performing construction in such a way that vegetation and soils are not needlessly disturbed and soils are not compacted by heavy equipment. Using less of polluting materials, isolating contaminating materials and activities from contacting rainfall or runoff, and reducing the introduction of irrigation and other non-stormwater flows into storm drain systems are essential. Many ARCD practices fall into the category of minimizing impervious areas through decreasing building footprints and restricting the widths of streets and other pavements to the minimums necessary. Water can be harvested from impervious surfaces, especially roofs, and put to use for irrigation and gray water system supply. Harvesting is feasible at the small scale using rain barrels and at larger scales using larger collection cisterns and piping systems. Relatively low traffic areas can be constructed with permeable surfaces such as porous asphalt, open-graded Portland cement concrete, coarse granular materials, concrete or plastic unit pavers, or plastic grid systems. Another important category of ARCD practices involves draining runoff from roofs and pavements onto pervious areas, where all or much can infiltrate or evaporate in many situations.

If these practices are used, but excess runoff still discharges from a site, ARCD offers an array of techniques to reduce the quantity through infiltration and evapotranspiration and improve the quality of any remaining runoff. These practices include (1) bioretention cells, which provide short-term ponded and soil storage until all or much of the water goes into the deeper soil or the atmosphere; (2) swales, in which water flows at some depth and velocity; (3) filter strips, broad surfaces receiving sheet flows; (4) infiltration trenches, where temporary storage is in below-ground gravel or rock media; and (5) vegetated ("green") roofs, which offer energy as well stormwater management benefits. Natural soils sometimes do not provide sufficient short-term storage and hydraulic conductivity for effective surface runoff reduction because of their composition but, unless they are very coarse sands or fine clays, can usually be amended with organic compost to serve well.

ARCD practices should be selected and applied as close to sources as possible to stem runoff and pollutant production near the point of potential generation. However, these practices must also work well together and, in many cases, must be supplemented with strategies operating farther downstream. For example, the City of Seattle, in its "natural drainage system" retrofit initiative, built serial bioretention cells flanking relatively flat streets that subsequently drain to "cascades" of vegetated stepped pools created by weirs, along more sloping streets. The upstream components are highly effective in attenuating most or even all runoff. Flowing at higher velocities, the cascades do not perform at such a high level, although under favorable conditions they can still infiltrate or evapotranspire the majority of the incoming runoff (Horner et al., 2001, 2002, 2004; Chapman, 2006; Horner and Chapman, 2007). Their role is to reduce runoff from sources not served by bioretention systems as well as capture pollutants through mechanisms mediated by the vegetation and soils. The success of Seattle's natural drainage systems demonstrates that well-designed SCMs can mimic natural landscapes hydrologically, and thereby avoid raising discharge quantities above predevelopment levels.

In some situations ARCD practices will not be feasible, at least not entirely, and the SCMs conventionally used now and in the recent past (e.g., retention/detention basins, biofiltration without soil enhancement, and sand filters) should be integrated into the overall system to realize the highest management potential.

The proposed watershed-based program emphasizing ARCD practices would convey significant benefits beyond greatly improved stormwater management. ARCD techniques overall would advance water conservation, and infiltrative practices would increase recharge of the groundwater resource. ARCD practices can be made attractive and thereby improve neighborhood aesthetics and property values. Retention of more natural vegetation would both save wildlife habitat and provide recreational opportunities. Municipalities could use the program in their general urban improvement initiatives, giving incentives to property owners to contribute to goals in that area while also complying with their stormwater permit.

Municipal Permittee Roles in Implementing Strategies

Municipal permittees sharing a watershed will have key roles in promoting ARCD under the proposed new system. First, the lead permittee and its partners would be called upon to perform detailed scientifically and technically based watershed analysis as the program's foundation. The City of San Diego (2007) offers a model by which permittees could operate with its Strategic Plan for Watershed Activity Implementation. The plan consists of:

- Activity location prioritization—locations prioritized for action based on pollutant loading potential;
- Implementation strategy and activity prioritization—tiered approach identifying activities directed at meeting watershed goals over a five-year period;
- Potential watershed activities—general list of activities required and potentially required to meet goals as guidance for planning and budgeting;
- Watershed activity maps—specified locations for activities; and
- Framework for assessment monitoring—a plan for development of the monitoring and reporting program.

Municipal permittees would be required under general state regulations to make ARCD techniques top priorities for implementation in approving new developments and redevelopments, to be used unless they are formally and convincingly demonstrated to be infeasible. In that situation permit approval would still require full water quantity and quality management using conventional practices. Beyond regulation, municipalities would be called upon to give private property owners attractive incentives to select ARCD methods and support to implement them. Furthermore, they should supplement on-site ARCD installations with municipally created, more centralized facilities in subwatersheds.

Other municipal roles in the proposed program revolve around the prominence of soil infiltration as a mechanism in ARCD. Successful use of infiltration requires achieving soil hydraulic conductivity sufficient to drain the runoff collector quickly enough to provide capacity for subsequent storms and avoid nuisance conditions, while not so rapid that contaminants would reach groundwater. One important task for municipal co-permittees will be defining watershed soils and hydrogeological conditions to permit proper siting and design of infiltrative facilities. A great deal of soils information already exists in any community but must be assembled and interpreted to assist stormwater managers. U.S. Department of Agriculture soil surveys, while a start, are often insufficiently site-specific to characterize the subsurface accurately at a point on the landscape. More localized data available to municipalities come from years of recorded well logs, soil borings, and percolation test results. Municipalities should tap these records to define, to their best ability, soil types, hydraulic conductivities, and seasonal groundwater positions. Although abundant and valuable, these data are unlikely to be sufficient to define subsurface attributes across a watershed. Thus, municipalities should collect additional data (soil borings, soils analyses, and percolation tests) to obtain a good level of assurance of the prospects for infiltrative ARCD.

Part of the task for municipalities will be overcoming opposition to infiltration if it is unjustified. Some opponents discourage infiltration based on coarse soil survey data that may not apply at all at a locality, or they fail to take into account that the well-established ARCD practice of soil amendment, generally with organic compost, can improve the characteristics of somewhat marginal soils sufficiently to function well during infiltration. While such amendment cannot increase hydraulic conductivity sufficiently in restrictive clay soils, the technique has proven to effectuate substantial infiltration and attendant reduction in runoff volumes and peak flow rates in Seattle's natural drainage systems, discussed above. These systems lie on variable soils, including formations categorized by the Natural Resources Conservation Service (2007) as being in hydrologic group C. This group generally has somewhat restricted saturated hydraulic conductivity in the least transmissive layer between the surface and 50 centimeters (20 inches) of between 1.0 micrometers per second (0.14 inches per hour) and 10.0 micrometers per second (1.42 inches per hour). Furthermore, additional runoff reduction often occurs through evapotranspiration, which is enhanced by the vegetation in ARCD systems.

Another objection sometimes raised to infiltrating stormwater is its perceived potential to compromise groundwater quality. Whether or not that potential is very great depends upon a number of variables: rate of infiltration, ability of the soil type to extract and retain contaminants, distance of travel to groundwater, and any contaminated layers through which the water passes. It is unlikely that urban stormwater, with its prevailing pollutant concentrations, will threaten groundwater if it travels at a moderate rate, through soils of medium or fine textures without contaminant deposits, to groundwater at least several meters below the surface. To ensure that groundwater is not compromised when surface water is routed through infiltrative practices, municipalities must establish where appropriate conditions do and do not exist and spot infiltration opportunities accordingly. Records of past waste disposal, leaks, and spills must be consulted to clean up or stay away from contaminated zones. There are alternatives even if documented soils or groundwater limitations rule out infiltrative practices. Much can be accomplished to reduce the quantities of contaminated urban runoff discharged to receiving waters through impervious surface reduction, water harvesting, and green roofs.

One additional problem to infiltrating stormwater runoff exists in some relatively dry areas and must be countered by municipalities. Overirrigation of lawns and landscape plantings has already increased infiltration well over the predevelopment amount and raised groundwater tables, sometimes to problematic levels. This unnecessary use of irrigation not only wastes potable water, often scarce in such areas, but reduces capacity to infiltrate stormwater without further water table rise. Municipalities should set up effective programs to conserve water and simultaneously increase stormwater infiltration capacity.

A final element of an integrated management and permitting program under municipal control is use of capacity in the sanitary sewer and municipal wastewater treatment systems to treat some stormwater. This initiative must be pursued very carefully. One reason for care is that municipal treatment works have historically been overburdened with stormwater flows in combined sewers and have not yet broken free of that burden through sewer separation programs. A second reason is that municipal sewage treatment plants are generally designed to remove particulates and decompose organic wastes and not to capture the array of pollutants in stormwater, many dissolved or associated with the finest and most difficult to capture particles. Toxic contaminants can damage microbes and upset biological treatment plants. Nonetheless, capacity exists in many WWTPs to treat stormwater. The delivery of pollutants the plant was not designed to handle can be managed by pretreatment requirements, applied to industrial stormwater dischargers particularly. Dry weather flows, consisting mostly of excess irrigation runoff, can be diverted to treatment plants to prevent at least some of the nutrient and pesticide contamination that otherwise would flow to receiving waters. Additional capacity to treat stormwater can be gained by repairing defective municipal wastewater pipes that allow groundwater entry.

Special Considerations for Construction and Industrial Land Uses

All of the principles discussed above apply to industrial and construction sites as well: minimize the quantity of surface runoff and pollutants generated in the first place, or act to minimize what is exported off the site. Unfortunately, construction site stormwater now is managed all too often using sediment barriers (e.g., silt fences and gravel bags) and sedimentation ponds, none of which are very effective in preventing sediment transport. Much better procedures would involve improved construction site planning and management, backed up by effective erosion controls, preventing soil loss in the first place, which might be thought of as ARCD for the construction phase of development. Just as ARCD for the finished site would seek to avoid discharge volume and pollutant mass loading increase above predevelopment levels, the goal of improved construction would be to avoid or severely limit the release of eroded sediments and other pollutants from the construction site. Chapter 5 discusses construction-phase stormwater management in more detail.

Other industrial sites are faced with some additional challenges. First, industrial sites usually have less landscaping potentially available for land-based treatments. Their discharges are often more contaminated and carry greater risk to groundwater. On the other hand, industrial operations are amenable to a variety of source control options that can completely break the contact between pollutants and rainfall and runoff. Moving operations indoors or roofing outdoor material handling and processing areas can transform a high-risk situation to a no-risk one. It is recommended that industrial permits strongly emphasize source control (e.g., pollution prevention) as the first priority and the remaining ARCD measures as secondary options (as outlined in Table 5-9). Together these measures would attempt to avoid, or minimize to the extent possible, any discharge of stormwater that has contacted industrial sources.

It is likely that the remaining discharges that emanate from an industrial site will often require treatment and, if relatively highly contaminated, very efficient treatment to meet watershed objectives. Some industrial stormwater runoff carries pollutant concentrations that are orders of magnitude higher than now prevailing water quality standards. In these cases meeting watershed objectives may require providing active treatment, which refers to applying specifically engineered physicochemical mechanisms to reduce pollutant concentrations to reliably low levels (as opposed to the passive forms of treatment usually given stormwater, such as ponds, biofiltration, and sand filters). Examples now in the early stages of application to stormwater include chemical coagulation and precipitation, ion exchange, electrocoagulation, and filtration enhanced in various ways. These practices are undeniably more expensive than source controls and other ARCD options and traditional passive treatments. If they must be used at all, it is to the advantage of all parties that costs be lowered by decreasing contaminated waste stream throughput rates to the absolute minimum.

Administrative and Funding Arrangements

A number of practical, logistical considerations pertain to converting to the permitting and regulatory system discussed above. These considerations include:

- What design and performance standards should be placed on the management systems?
- What administrative vehicles offer the best prospects for success?
- What funding arrangements are necessary to support the revised permitting and management system?

Design and Performance Standards

It has already been asserted under the discussion of objectives above that ultimate performance standards should be based on results in the aquatic systems under protection. The report further advocates promulgating these standards primarily in terms of biological health (for protection of human health, aquatic life, or both), supplemented by measures of conditions well known to influence biological health quite directly, such as hydrologic variables. It was further proposed that active adaptive management be applied in relation to the degree of achievement of water resource objectives. However, it would not be wise to standardize entirely on this level and leave all questions of the means to the end to individual permittees. Certain design-level standards would also be appropriate. An example is provided by the recently issued draft municipal permit for Ventura County, California. In that permit, application of low-impact methods to new development and redevelopment is specified to hold the effective impervious area to 5 percent of the total contributing catchment. While technical experts may disagree on the precise number, the point is that adopting such a standard gives a straightforward design requirement on an evidentiary basis. Results in the receiving waters would still be tracked and used in active adaptive management if necessary, but effective application of the design standard would provide some level of initial assurance that the aquatic health standards can be met.

Forging Institutional Partnerships

At the heart of the proposal for a new system of regulating discharges to the nation's waters is issuing permits to groups of municipalities in a watershed operating as co-permittees under a lead permittee. Furthermore, the proposal envisions these municipal permittees assuming responsibility for and implementing the permits for all public and private dischargers in their jurisdictions. These admittedly sweeping changes in the way waters have been managed almost everywhere in the nation raise serious issues of acquiescence to the new arrangements, compatibility, and devising a sufficient and stable funding base. This section draws from the small number of examples where arrangements like those proposed here have been attempted.

The Los Angeles County Municipal Storm Water Permit offers a case study in how to aggregate municipalities in a co-permittee system while still allowing prospective members latitude should they perceive their own interests to deviate, even considering the advantages of group action. The permit, first issued in 1990, presently covers five watersheds and 86 municipal permittees. During the process of reissuing the 1996 permit, the City of Long Beach challenged the provisions of the Los Angeles County MS4 permit. The city was given the option of applying for its own individual permit, which it did. Long Beach was issued its own individual MS4 permit in 1999 with provisions similar to the Los Angeles County MS4 permit. As another example, a small coastal municipality (Hermosa Beach) covered by the Los Angeles County Municipal Storm Water Permit investigated the possibility of withdrawing from the county permit in 2000 to be reclassified as a Phase II municipality. Just as with Long Beach, Hermosa Beach was given the option of applying for an individual permit as a Phase I MS4, but in the end Hermosa Beach elected to remain within the areawide permit. Although this report strongly encourages cooperative participation of municipalities as co-permittees, it does not mandate it. Rather, the flexibility illustrated above should be retained in the proposed new permitting program. What matters for compliance with the CWA is that a municipality manage discharges in a manner at least equivalent to other permittees in the watershed.

Stephenson and Shabman (2005) gave thought to the dilemma of entities who may not naturally work well together being asked to cooperatively solve a problem that all have had a share in creating. They argued that new organizational forms that consolidate multiple regulated entities under a single organizational umbrella could be used to coordinate and manage jointly the collective obligations of a group of regulated parties at lower costs to members. Private and public regulated entities alike could benefit from participation in these new organizations. Such cooperative organizations could offer participating parties financial incentives and decision-making flexibility through credit trading programs.

Two larger-scale compliance associations exist in the Neuse and Tar-Pamlico river basins in North Carolina (Stephenson and Shabman, 2005). In both programs the state was concerned about nutrient enrichment of estuary waters and imposed an aggregate cap on industrial and municipal wastewater dischargers equivalent to a 30 percent reduction in nitrogen loads. In both programs, the state granted individual point source dischargers a choice: (1) accept new requirements to control nitrogen through individual NPDES permits or (2) form and join a discharger association. The rigidities associated with individual NPDES permits provided enough incentive for most point source dischargers to opt for the second choice. Compliance associations were then created and issued permits.

The Neuse River rules cover nonpoint agricultural sources as well as point discharges. Counties are responsible for reducing nutrient loads, and farmers must either join county associations that apply different strategies or individually contribute to meeting objectives by setting aside 50- to 100-foot buffers along all streams.

North Carolina requires compliance associations to meet a single mass load cap. In the Tar-Pamlico case, the legal requirement to meet the cap was established by an enforceable contractual agreement signed by the association and the state. In the Neuse program, a single "group compliance permit" was issued to the association. Both legal mechanisms established financial penalties for the two associations if aggregate discharges of the group exceed the association cap. A key advantage of the association is similar to that of a formal effluent trading program—granting dischargers flexibility to decide how best to meet the aggregate load cap. To date, the associations have managed to keep nitrogen loads considerably below their respective caps. Compliance costs have also fallen below original projections. Further, there is some evidence that the association concept is producing incentives for strong cooperative behavior that did not exist prior to implementation.

The case studies presented here illustrate ways in which both public and private entities subject to regulation can exercise options for operating autonomously should they not wish to incorporate with a group, while still contributing to the achievement of watershed objectives. The case studies suggest that most dischargers conclude in the end that group membership offers considerable advantages.

Funding Considerations

The existing stormwater permit program is characterized, in most of the nation, by municipal Phase I and now Phase II permittees operating mostly alone. In contrast the new system envisions coalitions of permittees that share a watershed operating in concert, under the coordination and leadership of a principal permittee. The present structure tends to bring about duplication in effort and staff, whereas cooperation should stimulate efficiencies that could defray at least part or even much of the extra local costs associated with new responsibilities for municipal permittees.

As explored in the preceding section, municipalities may not necessarily wish to join in co-permittee arrangements; and mechanisms are proposed to allow them to operate individually, as long as watershed objectives are met. However, the state could encourage participation through financial inducements, for example, by estimating the resources needed to meet the requirements of each watershed permit and pointing out to permittees how shared resources can save each contributor money. The state should also set preferences and better terms for grants in the favor of municipalities who join together.

To the questions of administrative vehicles and funding arrangements, stormwater utilities are the preferred mechanism, and regulations should support creating stormwater utilities. It should be added that, with watershed-based permitting as proposed here, utilities should also be regionalized on a watershed basis. A utility draws funds from the entities served in direct relation to the cost of providing the services, here management of the quantity and quality of stormwater discharged to natural waterbodies. These funds must be dedicated to that purpose and that purpose only, and cannot be redirected to general agency coffers or for any unrelated use.

Not only are more funds from more reliable sources needed, but monies should be redirected in ways differing from their allocation under the current system. It was proposed earlier that a lead municipal permittee, working with other municipal co-permittees, be given responsibility for coordinating permitting and management of municipal, industrial, and construction stormwater permits, and even permits involving other sources, such as industrial process and municipal wastewaters. Those entities would hence be doing work now devolving to individual private developers and industrial plants and other public authorities. They would need to attract the revenue from those other bodies in proportion to the added work taken on. A utility structure would provide a well-tested means of carrying out this reallocation.

Stormwater utility fees are generally assessed according to a simple formula, such as a flat rate for all single-unit dwellings and in proportion to impervious area for commercial property. Some municipalities have investigated charging more directly according to the estimated quantity and quality of stormwater discharged into the public drainage system. Municipal permittees may choose to formulate such a system, but the development process itself is not a trivial task and, being based on general (and usually quite simple) hydrologic and water quality models, can generate considerable arguments from rate payers. Going through this process is probably not necessary or even advisable for most municipal permittees, who will have many new functions should the proposed system be adopted. Instead, they should concentrate on implementing a fee structure based on a simple formula like the one above and then capture additional revenues for special functions that they will take over from industrial and construction permittees.

As discussed previously, in the proposed program municipal co-permittees, with leadership by a watershed lead permittee, will be asked to classify industries and construction sites within their borders according to risk and accordingly prioritize them for inspection and monitoring. It is proposed in the section on Measures of Achievement, below, that inspection include reviewing and approving industrial and construction site stormwater pollution prevention plans (SWPPPs). While many municipalities now inspect construction sites for stormwater compliance and some inspect industries, this work will increase significantly in the new system, and SWPPP review and approval will be a completely new element. Moreover, municipalities would perform some industrial monitoring now conducted by the industries themselves and may monitor high-risk construction sites. These special functions would require different institutional arrangements and substantial new revenue that could not be fairly charged to all rate payers. There are several possible sources for these funds. One way would be to increase industrial and construction permit fees and direct large proportions to municipalities to support inspection and monitoring. The permitting authority (designated state or EPA) would still hold ultimate authority, and municipalities could refer industrial and construction permittees found during inspection to be out of compliance to the permitting authority for enforcement. Another means would be to form consortia of industries of similar type and assess fees directly applicable to inspection and monitoring. For example, scrapyards under the jurisdiction of the California EPA Los Angeles Regional Water Board formed a monitoring consortium under which sample collection by a qualified contractor rotates among the members, with funding by all. While the members operate this system, it could be adapted to operation by municipal co-permittees.

A second-level funding concern is, once revenues are generated, how should they be put to use? It is very important that funds largely be devoted directly to the tasks at hand regarding the achievement of objectives instead of into excessive administrative and bureaucratic structure. These tasks are scientific and technical and are highly oriented toward what is actually going on in the drainage systems and their receiving waters. Thus, the majority of funds should be directed to making scientific and technical judgments based on observations and monitoring results obtained in the field (see the discussion below).

Measures of Achievement

Critique of the Current Monitoring System

No area exemplifies the differences between the present and proposed new stormwater permitting and monitoring systems more than the measures used to gauge achievement. The current monitoring system is characterized by scattered and uncoordinated measurements of discharges from Phase I MS4s and some industries, and some visual observations of construction sites. The system proposed to take its place would emphasize monitoring of receiving water biological conditions as a data source for prescribing management adaptations to meet specified biological objectives. The discussion here first critiques the prevailing system to construct part of the rationale for changing it. It then proceeds to outline a recommended monitoring structure to replace it.

To expand very briefly on the point that the present system is scattered and uncoordinated, monitoring under all three stormwater permits is according to minimum requirements not founded in any particular objective or question. It therefore produces data that cannot be applied to any question that may be of importance to guide management programs, and it is entirely unrelated to the effects being produced in the receiving waters. Phase I municipal permit holders are generally required to monitor some storms at some discharges for no stated purposes but to report periodically to the permitting agency (Phase II municipalities have no monitoring requirements, although they may represent the major or even only impact sources in a given watershed). The usual model for industries across the nation is to collect a few discharge grab samples a year and send the results to the permitting authority, plus occasionally to make observations for obvious signs of pollution (e.g., oil sheen, odor). Construction site monitoring is less standardized and often involves no water quality monitoring at all. Again, no permittee under any of the three programs is obligated according to national standards to check the effects of its discharges on receiving waters. Since the individual effects of any discharger are often not distinguishable from any other, the scattershot system would usually not be able to discern responsibility for negative effects in the receiving water ecosystem.

Input to the committee conveyed the strong sense that monitoring as it is being done is nearly useless, burdensome, and producing data that are not being utilized. For example, the City of Philadelphia conducts substantial amounts of wet weather monitoring, which is very expensive, but it can barely monitor for TSS in many of its heavily impacted streams (Crockett, 2007). The resources to monitor for the more exotic pollutants do not exist. Smaller municipal permittees without the resources and sophistication of a big-city program have difficulty performing even the most basic monitoring. City water managers believe that the traditional stormwater program places too much emphasis on monitoring of individual chemicals rather than looking at ecological results (Crockett, 2007).

Industry representatives have also described several problems they see in industrial stormwater monitoring as it is performed now (Bromberg, 2007; Longsworth, 2007; Smith, 2007). One concerns the high degree of variability, from the methods used to what is actually measured (Stenstrom and Lee, 2005; Lee et al., 2007). Opponents have been quite critical of the benchmarks to which industrial monitoring data are compared, believing that the benchmarks have no basis in direct measurements associating stormwater with impacts. Some have suggested replacing monitoring with an annual stormwater documentation report to the permitting authority. It seems that industry personnel disrespect the current monitoring framework for some good reasons and feel it conveys a burden for little purpose. There was some implication that industry would be receptive to measures offering more meaningful information in place of poorly conceived monitoring requirements (Bromberg, 2007; Longsworth, 2007; Smith, 2007).

Proposed Revised Monitoring System

A structure in several tiers is proposed as a monitoring system to serve the watershed-based permitting and management framework.

Progress Evaluation Tier. This tier would represent the ultimate basis for judgment on whether the objectives adopted for the watershed are being met. Because these objectives would mainly be expressed in terms related to direct support of beneficial uses, so too would monitoring in the Progress Evaluation Tier principally emphasize direct measurements of ecological health. The preferred model for this evaluation would be the paired watershed approach, which is based on the classic method of scientific experimentation and was developed for water resource management investigations by EPA (Clausen and Spooner, 1993). Ideally, conditions in the waterbody under evaluation would be compared to conditions in the same waterbody before imposition of a permit and management scheme (before versus after comparison), as well as to conditions in a similar waterbody not subject to human-induced changes (affected system versus reference system comparison). At least one of these comparisons must be made if both cannot. If the objectives involve improving conditions, and not just avoiding more degradation, the reference should represent that state to which the objective points.

This function has traditionally been the province of the permitting authority (i.e., the designated state or EPA). In the new program, the function is assigned to municipal permittees, guided by the lead permittee, to conduct or contract, but with a substantial contribution by the permitting authority in the form of material support and guidance. The primary vehicle envisioned to perform the progress assessment is a well-qualified monitoring consortium serving the watershed, and perhaps other watersheds in the vicinity. Case studies below present examples of successful joint ventures in monitoring that can serve as models. The proposal is based on the belief that monitoring should be more manageable and effective at the watershed compared to the state level and, furthermore, that utilizing a consortium approach should make it feasible for a coalition of municipal co-permittee partners to commission monitoring.

Findings of objective shortfall would trigger development of active adaptive management strategies. Generally, an assessment should be conducted to determine what additional measures should be put in place in regulating new development and redevelopment, as well as increasing coverage of existing developments with retrofits.

Diagnostic Tier. The second tier would be designed to provide the municipal permittees with the necessary information to formulate active adaptive management strategies, and they would be responsible for this second tier as well as the first. The Diagnostic Tier would be composed of assessment of information from the Compliance Reporting Tier, plus some specific field monitoring to determine the main reasons for ability or failure to meet objectives. Some highly directed monitoring of receiving water conditions could determine the need to improve management of water quantity, water quality, or both. A tool like the Vermont flow-duration curves is an example of a potentially useful device for diagnostic purposes. To allow the use of such a tool, it is important that continuous flow recorders be installed on key streams in the watershed. The techniques described in the Impact Sources section above, once they are further developed, would also be useful in Diagnostic Tier monitoring.

An important dimension of this tier would be prioritized inspection and monitoring of potentially high-risk industrial and construction sites. In addition, data submitted by the industrial and construction permittees according to the Compliance Reporting Tier would assist in targeting dischargers to bring about the necessary improvements in water quantity and/or quality management.

Compliance Reporting Tier. It is proposed that the first step in compliance reporting be submission of SWPPPs by all construction and industrial permittees (plus municipal corporation yards as an industrial-like activity) to the jurisdictional municipal permittee for review and approval. It is further proposed that the industrial permittees and municipal corporation yards be relieved of sample collection, *if* they develop SWPPPs making maximum possible use of ARCD practices, supplemented by active treatment as necessary, and the municipal permittee approves the SWPPP. Construction sites would be given a similar sampling dispensation if they develop an approved SWPPP along the lines of Box 5-3.

Otherwise, the permittees would be required to perform scientifically valid sampling and analysis and report results to the watershed co-permittees. This more comprehensive and meaningful monitoring would increase the burden already felt by permittees and create a strong incentive to apply excellent SCMs. This burden could be relieved to a degree through participation with other similar dischargers in the watershed in a monitoring coalition. As an example, in North Carolina coalitions of wastewater dischargers are working with the state Division of Water Quality (DWQ) to create and manage coalition-led watershed monitoring programs that operate in conjunction with DWQ's ambient chemistry and biological programs (Atkins et al., 2007). Lee et al. (2007), after an assessment of industrial stormwater and other monitoring data, concluded that selecting a subset of permittees from each monitored category would yield better results at lower overall cost compared to monitoring at every location. This strategy would permit the use of more advanced sampling techniques, such as flow-weighted composite samplers instead of grab sampling, to estimate representative loads from each category with improved accuracy and reduced variability.

All permittees would still make observations of the SCMs and discharges and keep records. The final proposed step in compliance reporting is an annual report covering observations, SCM operation and maintenance, SWPPP modifications, and monitoring results (if any), to be sworn as to correctness, notarized, and submitted to the lead municipal permittee. The Massachusetts Environmental Results Program (April and Greiner, 2000) offers a possible model for compliance reporting and verification. This program uses annual self-certification to shift the compliance assurance burden onto facilities. Senior-level company officials certify annually that they are, and will continue to be, in compliance with all applicable air, water, and hazardous waste management performance standards. The state regulatory agency reviews the certifications, conducts both random and targeted inspections, and performs enforcement when necessary.

Research Tier. The final tier would be outside the permit system and exist to develop broad mechanistic understanding of stormwater impacts and SCM functioning important to assist permittees in reaching their objectives. EPA and state agencies designated to operate the permit system would have charge of this tier. These agencies would develop projects and contract with universities and other qualified research organizations on a competitive basis to carry out the research.

Instructive Case Studies for the Proposed Revised Monitoring System

Many municipalities, even large ones, would be challenged and burdened by taking on comprehensive watershed monitoring. The Southern California Coastal Water Research Project Authority (SCCWRP, http://www.sccwrp.org) offers an excellent model of how co-permittees in a watershed or an even broader area could organize to diffuse these challenges and burdens. SCCWRP is a joint-powers agency, one that is formed when several government bodies have a common mission that can be better addressed by pooling resources and knowledge. In SCCWRP's case, the common mission is to gather the necessary scientific information so that member agencies can effectively and cost-efficiently protect the Southern California marine environment. Key goals adopted by SCCWRP are defining the mechanisms by which aquatic biota are potentially affected by anthropogenic inputs and fostering communication among scientists and managers. Comprised of a multidisciplinary staff, SCCWRP encompasses units specializing in analytical chemistry, benthic ecology, fish biology, watershed conditions, toxicology, and emerging research.

SCCWRP's current mission stems from the results of a 1990 NRC review of marine environmental monitoring programs in the Southern California Bight (NRC, 1990). It was determined that although $17 million was being spent annually on marine monitoring, it was not possible to provide an integrated assessment of the status of the Southern California coastal marine environment. Most monitoring was associated with NPDES permit requirements and directed toward addressing questions about site-specific discharge sources. As a result, most monitoring in the bight was restricted to an area covering less than 5 percent of the bight's overall watershed, making it difficult to draw conclusions about the system as a whole. The limited spatial extent of monitoring was also found to limit the quality of local-scale assessments, since the boundaries of most monitoring programs did not match the spatial and temporal boundaries of the important physical and biological processes in the bight.

NRC (1990) further found that there was a lack of coordination among existing programs, with substantial differences in the parameters measured among programs, preventing integration of data. Even when the same parameters were examined, they were often measured with different methodologies or with different (or unknown) levels of quality assurance. Moreover, the NRC found that even when the same parameters were measured in the same way, substantial differences in data storage systems among monitoring programs limited access to the data for more comprehensive assessment. To avoid repetition of these shortcomings, the SCCWRP example should be given very thorough consideration as a template for the Progress Evaluation, Diagnostic, and Research Tiers in the proposed revised monitoring program.

The San Gabriel River Regional Monitoring Program (SGRRMP, *http://www.lasgrwc.org/SGRRMP.html*) is a watershed-scale counterpart to the larger-scale regional monitoring efforts in Southern California. The SGRRMP incorporates local and site-specific issues within a broader watershed-scale perspective. The program exists to improve overall monitoring cost effectiveness, reduce redundancies within and between existing monitoring programs, target monitoring efforts to contaminants of concern, and adjust monitoring locations and sampling frequencies to better respond to management priorities in the San Gabriel River watershed. Five core questions provide the structure for the regional program:

- What is the environmental health of streams in the overall watershed?

- Are the conditions at areas of unique importance getting better or worse?
- Are receiving waters near discharges meeting water quality objectives?
- Are local fish safe to eat?
- Is body-contact recreation safe?

The workgroup convened to establish the program recommended monitoring designs to answer the core questions effectively and efficiently. The resulting program is a multilevel monitoring framework that combines probabilistic and targeted sampling for water quality, toxicity, and bioassessment and habitat condition.

The City of Austin, Texas, has more than 20 years of stormwater monitoring experience and offers additional guidance on designing and implementing watershed monitoring programs (City of Austin, 2006). Austin performs detailed periodic synoptic sampling in the watersheds it manages to track trends in stormwater quantity and quality. The city uses the results to evaluate the impacts of land development on stormwater quantity and pollution, establishing statistical relationships between measures of these conditions and the amount of impervious cover. Trend assessment over time leads to recommended changes to the City of Austin Environmental Criteria Manual as needed.

Creating Flexibility and Incentives Within a Watershed Approach

A watershed-based permitting approach to stormwater management focuses attention on watershed objectives and endpoints. To be able to achieve these goals, observable performance measures beyond the success of an individual SCM need to be identified that are consistent and necessary to meet designated uses. These might include watershed-level numeric limits on the amount of a particular pollutant allowed to enter a waterbody (e.g., pounds of phosphorus) or various measures of allowable volume of discharge. A watershed focus shifts attention away from specific SCM performance and site-specific technological requirements to achieving a larger watershed goal. As a consequence, there is considerable management flexibility in deciding how these goals will be achieved. Indeed, this flexibility was cited by the NRC (1999) as a prerequisite to successful watershed management.

One way of exercising this flexibility is to create an “incentive-based” or “market-based” approach to choose how watershed goals are met. It is recognized throughout the environmental management field that entities subject to regulation do not necessarily have equal opportunities and qualifications to comply sufficiently to sustain resources. To compensate for this, the market-based approach allows individual discretion to select how effluent (or runoff volume) will be controlled (choice of technology, processes, or practices) and where they will be controlled (on site or off site). That is, any discharger legitimately unable to meet discharge quantity and quality allocations would be able to finance offsets elsewhere to achieve the watershed goals. An important element and challenge is to couple this decision-making flexibility with personal (typically financial) incentives so that people willingly make choices supportive of the watershed objectives. Broadly stated, the idea is to create financial reasons and decision-making opportunities to lower compliance costs and create or implement new effluent/volume control options (Shabman and Stephenson, 2007).

Because incentive-based policies require a shift in emphasis from technologies and practices to outcomes (e.g., volume or quantity of effluents), the municipal manager would not be responsible for deciding what SCM will be implemented in specific areas or hand picking specific practices to promote. Rather the stormwater program manager's responsibilities shift to establishing watershed goals, developing metrics to measure outcomes and performance, and performing necessary inspection and enforcement activities.

Effluent trading, sometimes called "water-quality trading," is one type of incentive-based policy. In an ideal form, effluent trading requires government to establish a binding aggregate limit or cap on an outcome (e.g., mass load of effluent, volume of runoff) for an identified group of dischargers. The cap or aggregate allowable discharge is set to support and achieve a socially determined environmental goal. Because it is fixed, the cap provides the public assurances that environmental objectives will be achieved in the face of a growing and changing economy. The total allowable discharge is then divided into discrete and transferable units, called allowances, and either distributed or auctioned to existing dischargers. All dischargers must own sufficient allowances to cover their discharges. For instance, any new or expanding source must first purchase allowances (and hence effluent or volume reductions) from another source before legally discharging. The requirement to hold allowances on the condition to discharge and the positive allowance price creates financial incentives for pollution prevention. Dischargers holding allowances rather than reducing discharge face forgone revenues that could have been achieved from the sale of allowances. Conversely, expanding dischargers have incentives to invest in pollution prevention in order to avoid the cost of purchasing additional allowances.

In the context of the revised permit system advocated here, achievement of objectives (generally of a biological nature) will require some combination of strategies such as no net increases in hydrologic parameters (e.g., peak flow rates, durations, volumes), water pollutants, forest cover loss, and effective impervious area. If one entity is unable to contribute adequately to meeting its share of compliance, then it must obtain the necessary credit by buying it from another similar entity that is able to contribute more than its designated share. Ideally, all sources of a waterbody's problems, not only stormwater, would come under the trading system.

Implementing the market system requires development of a resource-based currency, a nontrivial exercise but one for which models are available in other fields, especially air emissions. For example, emission trading has been a critical element of the nation's strategy to limit sulfur dioxide and nitrogen oxide emissions (Ellerman et al., 2000). Carbon trading is a cornerstone policy in the European Union effort to limit greenhouse gas emissions. The EPA promotes the use of trading to help achieve the goals of the CWA and has issued several policy statements and recently published guidance on how trading programs can be grafted within existing NPDES permitting programs (EPA, 2003a, 2007b).

However, compared to the air program, experience and success with trading in the water program have been limited (Shabman et al., 2002). Furthermore, programs labeled trading have been implemented in a multitude of ways in the nation's water quality program (Woodward et al., 2002; Stephenson et al., 2005; Shabman and Stephenson, 2007). In many instances, trading programs are case-specific and isolated "trades" that do not fundamentally change the choice and incentives facing dischargers in a conventional permitting system. The extent to which trading policies can be effectively employed on a watershed scale is limited not only by the physical differences between air and water mediums, but also by the unique legal structure of the CWA (Stephenson et al., 1999). For example, the CWA is oriented around imposing technology-based performance requirements on specific subset of discharge sources. Individual NPDES permits require sources to achieve these agency-identified levels of performance and may specify how performance is achieved. The statute also places limits and disincentives on the degree to which permit agencies can deviate from these limits (e.g., "antibacksliding").

Thus, the focus of the NPDES permitting system has been on individual source control and technologies, unlike the air program, which has a stronger statutory orientation around achieving broader air quality goals (ambient air quality standards). The orientation of the NPDES program limits the flexibility and incentives for regulated parties that might make market-oriented trading possible. It turns out that some of the more successful applications of trading in the water program have occurred because of permitting innovations that effectively avoid some of these rigidities (see discussion of North Carolina point source control program on the Neuse River, above).

Trading programs of various types have been proposed or suggested for stormwater (Thurston et al., 2003; Parikh et al., 2006). Although conceptual models of a comprehensive trading program based on the total volume of allowable water to be discharged have been proposed, no working examples have yet to be implemented. More limited versions of trading programs, however, have been developed. These programs provide compliance flexibility for new sources of stormwater runoff. In some locations, new developments face a requirement to provide a specific level of volume or effluent control from the parcel to be developed. The regulated entity is typically obligated to meet this requirement with the applications of on-site SCMs. Trading programs create opportunities for regulated entities to meet their regulatory requirement off site (off the parcel to be developed), called here an offset. In some trading programs, the off-site controls can be accomplished by the creation of an in lieu fee program. Such programs typically occur for dischargers that are not required to hold or obtain individual NPDES permits.

In lieu fee programs offer some opportunity for regulated parties to make a financial payment (fee) to a local government entity in lieu of implementing on-site controls. The fees are collected and used to implement stormwater controls in other areas of the watershed. Controlling runoff at a regional level rather than through the construction of many small on-site controls may be more cost-effective given the economies of scale associated with some SCMs (see Chapter 5 pages 362–363). The option for off-site controls also allows the stormwater program to direct investments in stormwater control to specifically targeted areas of the watershed.

Examples of in lieu fee programs include Santa Monica, California, the Neuse River Basin in North Carolina, and Williamsburg, Virginia. Santa Monica's program requires new and redevelopment projects to treat a specific volume of runoff. The program first requires the regulated entity to take all feasible steps to meet the requirement through the implementation of on-site infiltration practices. If the regulated party can demonstrate why it is economically and physically infeasible to install any type of infiltration or treatment SCM, the regulated party can pay a fee based on the volume of water that needs to be controlled (the total mitigation volume is the volume that would have been attenuated via an SCM). The fee set by Santa Monica is $18/gallon of total required mitigation volume. The $18 reflects the cost of constructing an SCM and maintaining it over 40 years (DeWoody, 2007). Presumably these fees are used to construct infiltration measures elsewhere.

The Neuse River Program requires all new land development to meet a nitrogen export standard of 3.6 pounds per acre per year (North Carolina Division of Water Quality, 1999). The water quality goal for the Neuse basin is to reduce mass nitrogen loads by 30 percent in order to improve water quality in the estuary. The export standard was set to achieve a 30 percent reduction from the average nitrogen load from lands prior to development. Developers have the option to meet this export standard either through the application of on-site SCMs or by paying a fee into a state-administered Riparian Buffer Restoration Fund (see 15A North Carolina Administrative Code 02B .0240), which would be used to reduce nitrogen loads elsewhere in the basin. Developer discretion, however, is not unlimited. Under no circumstances may developers discharge more than an estimated 6.0 pounds per acre per year from a residential site.

The Williamsburg program has an in lieu fee program for total phosphorus loads created by new development (Frie et al., 1996; Stephenson et al., 1998). For every new development, the increase in total phosphorus load from stormwater runoff from impervious surfaces is estimated. Developers have the choice to meet the phosphorus load reduction requirement through the application of on-site controls or by paying a fee to the city. The fee is set at $5,000/lb of phosphorus, with the fees earmarked to the construction of regional stormwater facilities or for the preservation of open space within the city. The presence of a fee option could also provide incentives for developers to implement source reduction practices.

The above programs differ in some important ways. For example, the Santa Monica program requires regulated entities to undergo a "sequencing" process that places regulatory preference on on-site controls before being able to use the fee option. The Williamsburg program allows regulated entities the option to select between constructing on-site controls and paying the fee without a regulatory preference for on-site controls. Sequencing rules tend to limit control options and thus the cost-effectiveness of these types of programs.

In lieu fee programs are distinguished from other offset programs in that it is the responsibility of the local government (or more generally, any designated fee service provider such as a nongovernmental organization) to provide the off-site SCMs. In lieu fee programs, common in the U.S. wetlands program, face a number of implementation and design challenges (Shabman and Scodari, 2004). For example, enforcement sometimes becomes a concern because the local stormwater management agency responsible for constructing and maintaining the SCMs is also responsible for monitoring and enforcement. These dual responsibilities create potential conflicts of interest; if an off-site mitigation project fails, there maybe no apparent overseeing agency to enforce corrective actions. The lack of transparency in accounting to determine whether the offset projects provide enough compensation is also sometimes a challenge. Finally, the ability to fully offset the volume of effluent discharge from a new development is contingent on collecting enough revenue from the fee to pay for the construction and maintenance of offsite SCMs. The delay between impacts and compensation and lack of full public cost accounting complicate the challenges of setting an appropriate fee.

Ensuring that in lieu fee programs provide the necessary mitigation could be accomplished in a number of ways. For example, an oversight agency may be designated to establish tracking and reporting requirements and monitor in lieu fee program performance. Or, the potential conflicts of interest inherent in the lieu fee program design could be avoided by separating the provision of the off-site mitigation service from the monitoring and enforcement. It is possible to imagine that the private sector, rather than an in lieu fee administrator, could provide off-site stormwater reduction services to those subject to the stormwater control requirements. In this case, the private sector would provide stormwater detention/retention services above and beyond what is required by law. These private service providers would receive stormwater runoff credits for these investments ("above baseline") that could be sold to developers who might wish to meet their control obligations in ways other than on-site controls. In essence, the role of searching, designing, and constructing offsite SCMs would be transferred to the private-sector stormwater credit providers. The local stormwater managers, however, would retain full authority to monitor, verify, and enforce to ensure that these offsets are successfully implemented.

The flexibility provided by in lieu fee and trading programs requires that pollutant loads or runoff volume created at one site be reduced at another site. Thus, a design issue confronting these types of programs is the consideration of the spatial extent in which offsetting activities can occur. The extent of the spatial range of offsetting activities in turn will depend partly on the nature and type of service being offset. For example, in the Neuse example nitrogen is a regional, basinwide concern with minimal localized effects. In such cases, the offsetting activities might be allowed basinwide (after adjusting for nitrogen attenuation through the basin). In other situations where localized concerns maybe a greater concern (say from localized flooding), the flexibility offered by such programs may be more limited. However, such spatial flexibility might also be a way to implement and achieve watershed planning objectives. For example, development may be encouraged in high-impact areas, and offsetting fees could be used to protect and enhance water quality objectives in other areas.

This last point deserves further explanation. Although this chapter advocates that biological conditions in waterbodies should be maintained or improved, there are many urban areas where local waterbodies cannot achieve the same designated uses as less developed areas. If a goal-setting entity chose to do so, beneficial uses for waters in these areas could be set at levels that acknowledge this highly altered condition, such that these streams would not be expected to achieve the same biological condition as streams outside the urban core (see Chapter 5 pages 364-366). This might be done to encourage development in high impact areas; San Jose, CA, provides an example (see Chapter 2). In that city's stormwater program, in urban areas where on-site control is either technically impossible (due to soil or space constraints) or prohibitively costly, the developers can meet the post-construction treatment standard by providing volume control either through participation in a regional stormwater project or by providing equivalent projects off site (e.g., stream restoration).

It is also possible to design a stormwater offset program that allows the different functions of stormwater management to be separated to achieve watershed objectives. For example, management of peak flow serves mostly to prevent localized flooding while more stringent volume control maybe required to protect stream channels and aquatic life. Control of peak flow might be required on site or within a narrow geographic region. In areas targeted for development, however, the volume control needed for channel protection might be transferred off site and into areas where watershed planning has identified the need for higher levels of stream channel protection or enhancement (more stringent water quality standards). A similar watershed approach based on functional assessment was recommended for wetland compensation (NRC, 2001b).

Regulatory and Legal Implications of Proposed Watershed-Based Permitting Framework for Managing Stormwater

EPA, the states, and municipal permittees would all have tasks to perform to transform the framework set forth in this report to a fully developed and functioning program. These efforts would be rewarded with a program that is rooted in science, transparent in its aims, fairer for all than the current program, and better for the aquatic environment. This section of the report outlines the tasks necessary to carry the proposal forward to full development.

EPA should seek significant congressional funding to support the states and municipalities in undertaking this new program, in the nature of the support distributed to upgrade municipal WWTPs after the 1972 passage of the Federal Water Pollution Control Act. Beyond financial support, EPA's tasks emphasize broad policy formulation, regulatory modifications and adaptations necessary to initiate the new program, and guidance to the states and permittees. The principal adaptation needed in the regulatory arena involves converting the current TMDL program to a form suitable for the new system. Guidance would be needed in a number of crucial areas, and it is EPA's natural role to develop it.

States (or EPA for states without delegated authority) would have broad responsibilities to translate policies and federal regulations into their own regulatory and management systems. A key task in this regard would be to recast water quality standards into objectives most directly supporting sustenance and improvement of beneficial uses. States already have considerable background for performing this task through their present definitions of beneficial uses, the Section 303(d) process for assessing waterbody compliance with water quality standards, and the triennial review of those standards. However, the added prominence of biological aspects of beneficial uses and associated objectives will require additional analysis. Other prominent state tasks will involve defining the watersheds subject to permits, forming bodies of co-permittees associated with the watersheds, and appointing the lead permittee. Many other state tasks entail cooperative work with the permittees to support and assist them in funding and conducting their activities.

Many aspects of the municipal permittees' roles in implementing strategies were explored above in a section titled accordingly. That section especially focused on activities to advance the use of ARCD methods. More broadly, the permittees will be coordinators of all permits pertaining to the watershed's aquatic resources, collectively pointed toward meeting objectives that the permittees adopt under state oversight. Other categories of tasks assigned to the municipalities under the proposed system include monitoring, in the contexts of both inspections and sampling performed through a consortium, and enforcement actions and program adaptations to promote progress toward achieving objectives. Box 6-4 provides a listing of anticipated tasks for the municipal permittees as well as the states and EPA.

A Pilot Program as a Stepping Stone

The shift of responsibility for stormwater regulation to municipalities under the watershed-based approach may lead to some surprises in implementation and enforcement. Primarily because of this, EPA is well advised to institute a pilot

BOX 6-4
Government Agencies Roles during the Operation of a Watershed-Based Permitting System

EPA

1. Petition Congress for significant funding support for states and municipal permittees, and develop a program of fairly distributing funds based on environmental and financial needs at the watershed level.
2. Initiate regulatory modifications and clarifications necessary to establish the system.
3. Set policies for watershed permitting based on this report's recommendations.
4. Adapt TMDL program for use in the new program.
5. Produce guidance to assist the states and municipal permittees in the areas of:
    a. Developing a rotating basin approach;
    b. Developing an integrated municipal NPDES permit incorporating the full range of sources;
    c. Developing stormwater utilities and other funding mechanisms;
    d. Using impact source analysis (e.g., using reasonable potential analysis and new research results, industrial and construction site risk assessment);
    e. Using ARCD techniques for new development, redevelopment, and retrofitting;
    f. Developing monitoring consortia;
    g. Developing a credit trading system;
    h. Developing an active adaptive management program

Designated States (or EPA otherwise)

1. Define watersheds for which permits will be issued and set up a rotating basin approach to govern watershed analysis in support of subsequent steps.
2. Formulate and formally adopt goals relative to avoiding any further loss or degradation of designated beneficial uses in each watershed's component waterbodies and recovering lost beneficial uses.
3. Use the results of the existing Section 303(d) process and supplementary work to assess the extent of designated beneficial use achievement in each watershed and set goals for protection and recovery.
4. Match municipal permittees to watersheds and designate a lead permittee for each watershed.
5. Estimate resource needs to fulfill permit requirements in each watershed.
6. Develop a grant program, drawing on EPA and state funds, to support municipal permittees, with incentives for joining co-permittee associations.
7. Identify areas outside the jurisdictions of permitted municipalities that should be brought into the program because of projected development or the existence of problem sources that would compromise the protection and recovery of beneficial uses.
8. Use the triennial review process to modify water quality standards to the objective basis, emphasizing biological outcomes recommended in this report.
9. Revise the TMDL program in accord with the needs of the new program.
10. Set requirements for credit trading systems.
11. Set up an integrated municipal NPDES permit incorporating the full range of sources.
12. Work with municipal permittees to establish specific objectives as the basis for progress assessment.
13. Work with municipalities to develop adaptive management programs responding to progress assessment results.

14. Write municipal permits incorporating the above elements.
15. Write industrial and construction general or individual permits incorporating the recommendations in this report.
16. Allocate a substantial portion of industrial and construction permit fees to municipal permittees to oversee those sectors.
17. Set requirements for municipalities and private properties to opt out of the defined program without compromising the achievement of objectives.
18. Provide consultation, support, and guidance (adapted from EPA materials or originally produced) to municipal permittees in the areas of:
    a. Developing stormwater utilities and other funding mechanisms;
    b. Using impact source analysis (e.g., industrial and construction site risk assessment);
    c. Using ARCD techniques for new development, redevelopment, and retrofitting;
    d. Developing monitoring consortia;
    e. Developing a credit trading system
19. Perform enforcement actions on non-complying dischargers referred by municipal permittees.
20. Assess performance of municipal permittees and specify corrections, rewards, and penalties accordingly.

Municipal Co-permittees (led by Lead Permittee)

1. Adopt specific objectives as the basis for program progress assessment.
2. Convert ordinances and regulations as needed to implement the modified program.
3. Supplement and reorganize staffing to emphasize progress and compliance assessment as the principal functions of the program.
4. Perform or contract detailed scientifically and technically based watershed analysis as a foundation for permit compliance.
5. Assemble existing data on soils and hydrogeologic properties and supplement with additional data collection as necessary to assess infiltration prospects across the municipality.
6. Create incentives for private property owners to maximize the use of ARCD methods in new development and redevelopment.
7. Build subwatershed-scale, publicly owned ARCD works to supplement on-site management measures and as retrofits.
8. Develop capacity for stormwater management in municipal WWTPs by reducing groundwater inflows to sanitary sewer lines.
9. In areas experiencing excessive infiltration and groundwater table rise resulting from non-stormwater flows, develop capacity for stormwater management through infiltration by formulating water conservation programs.
10. Identify industries and construction sites that are required to apply for permits but have not done so and compel their filing.
11. Establish or enhance existing programs to inspect and oversee industries and construction sites; report non-complying dischargers to the state for enforcement actions.
12. Set up or join a monitoring consortium structured to implement the progress evaluation and diagnostic tiers of the proposed monitoring program.
13. Annually report monitoring results to the permitting authority; submit a comprehensive progress assessment triennially.

program that provides some experience in municipality-based stormwater regulation before instituting a nationwide program. This pilot program will also allow EPA to work through more predictable impediments to this watershed-based approach. The most obvious impediment arises from the inevitable limits of an urban municipality's responsibility within a larger watershed: substantial growth and accompanying stormwater loading may occur on the outside periphery of a municipality's designated boundaries. If an urban authority lacks legal authority over this future growth, and if this growth contributes significantly to water quality degradation, then a considerable share of the urban stormwater problem could remain poorly addressed. A pilot program should help identify the extent of this jurisdictional slippage and help identify ways to overcome it. Second, it is possible that some municipalities will balk at the added responsibility involved with the watershed-based approach, even with adequate funding. Unless the objective performance standards are rigid, the monitoring requirements substantial, and the rewards for compliance compelling for municipalities that meet the standards, it is quite possible that noncompliance or bare minimal compliance will be the norm. A pilot program provides a less politically charged atmosphere to experiment with the benefits of watershed-based regulation at the local level and to generate local government support for the approach. Finally, because the watershed-based approach necessitates legislative amendments to the CWA, instituting a pilot program in the interim—both to improve the design of a watershed-based program as well as to generate enthusiasm for it—seems a sensible course.

The pilot program should target those local governments that are most eager to redress water quality degradation in their watersheds, but feel stymied by what they perceive as inadequate legal authority and flexibility to make the necessary improvements. Willing municipalities or regional governments would thus opt-in to the program. The pilot program entices these more progressive municipalities to participate by allowing them to serve as the lead authority and providing them with much greater flexibility to determine how to meet their performance-based water quality goals with fewer legal constraints.

Under the pilot program, a municipal government or similar legal authority would apply to EPA or a delegated state to be designated as the lead agency for that portion of the watershed within its legal jurisdiction. In the application itself the municipality would establish—using modeling and ambient data—how it plans at a general level to maintain or exceed its water quality goals (objective performance standards). These goals must be at or above the state water quality goals, or if they are different (i.e., use biological criteria when the state adopts chemical criteria), the municipality must demonstrate how its performance standards will attain the equivalent of the state water quality goals at the downstream edge of the municipality's border. The municipality would also be required to provide assurance of sufficient infrastructure and funding to allow it to develop a water quality plan, implement that plan, issue permits, and enforce the requirements within its boundaries. Finally, municipal plans, once finalized, would need to meet minimum federal procedural requirements. For example, the plans must be transparent and provide opportunities for public comment; they must be enforceable; and they must establish monitoring programs that will track whether they in fact meet the objective performance standards. If a municipality fails to meet any of its performance standards by the requisite deadline, the state and EPA would have the option of revoking the municipality's program, and reinstituting federal requirements. Ideally, federal guidance would also be available to municipalities to provide direction on how they might institute a watershed-based plan within their boundaries, while still reserving considerable flexibility to allow them to develop creative and progressive stormwater solutions. For example, municipalities would be encouraged to form stormwater utilities that are financed from point and even nonpoint sources that assist them in establishing rigorous permitting and enforcement of their water quality plan.

Municipalities that voluntarily take on this role as lead authority will be rewarded with few legal constraints on how they meet their performance-based objectives. NPDES permits for major sources will still be required and must meet federal minima (technology-based controls) to avoid possible hot spots surrounding large dischargers, and states would remain listed as the lead permittee for these permits, but the lead municipality or other regional government would be able to propose new, more stringent limits that are presumptively favored in revised NPDES permits. Stormwater permits would also be mandatory, but their substantive requirements would be left wholly within the discretion of the lead municipality. Finally, states and municipalities would *not* be required to comply with all of the federal regulations governing TMDLs (they would make a basic load calculation for pollutants contributing to degraded conditions, 33 U.S.C. § 1313(d), but would not be required to do more). Instead, the watershed-based program would be considered the functional equivalent of TMDLs for at least the municipality's portion of the watershed since the program ensures that water quality objectives are met. Municipalities could even be allowed to set interim goals over a period of a decade or more so that TMDLs need not be achieved in a single permit cycle.

Other than federal minimum standards for major NPDES sources, municipalities would have primary if not exclusive authority to decide what types of sources (including nonpoint) require permits, whether certain land uses might be taxed for stormwater management fees, and whether and how to create trading programs among the contributors to water quality impairments within their watershed. Municipalities would also have legal authority to petition EPA to restrict upstream sources that contribute significantly to water quality degradation in ways that make it difficult for them to reach their goals. Upstream governments or sources could be subject to more rigorous federal or state TMDLs and could be vulnerable to tort and related claims from downstream municipalities.

This added flexibility and authority for municipalities to control water quality problems within their legal jurisdiction—coupled with objective performance standards—should lead to more creative approaches to stormwater management that create significant benefits to the municipality (i.e., more green-space buffers along waterways for recreation) and stronger planning and taxation of new developments that otherwise might be uncontrolled. Municipal green space, parks, and a variety of other public goods that both reduce stormwater and enhance the public enjoyment of the surface waters could result from allowing a municipality the freedom to determine how best to regulate sources within its local boundaries. For example, rather than automatically allowing federally approved SCMs that have little aesthetic or recreational qualities, alternative approaches to SCMs that retain their effectiveness but provide other qualities (particularly qualities that draw the public outdoors for recreation or relaxation) are more likely to be encouraged or even required by a municipality that serves as lead over implementation of its water quality program.

Although a national watershed-based approach to stormwater regulation is likely to require legislative amendments, the pilot program may not necessitate additional legislative authorization. It is possible that through regulation, EPA may be able to develop "in lieu of" or "functional equivalent" requirements that allow a rigorous watershed plan to substitute for the bare federal requirements governing stormwater regulation, general permits, and TMDL planning laid out in the CWA. This type of intricate legal analysis, however, is beyond the scope of this document.

Final Thoughts

The watershed-based stormwater permitting program outlined above is ultimately essential if the nation is to be successful in arresting aquatic resource depletion stemming from sources dispersed across the landscape. EPA is called upon to adopt the framework now and set in motion a process to move it toward implementation over the next five to, at most, ten years. This chapter deals with some but not the entire realm of political, legal, regulatory, and logistical issues raised by converting to a fundamentally different system of management and permitting. Ideas are contributed regarding piloting and transitioning toward the new program, altering institutional arrangements to accommodate it, and incentives for effective participation. For watershed-based permitting to take hold, specific actions will have to be undertaken by EPA, state permitting authorities, and municipal permittees during the adoption and transition process.

The proposed program could be implemented by EPA in a number of ways, ranging from making it mandatory without any exception in all states and jurisdictions to leaving it entirely voluntary. The committee recommends neither extreme and believes the best course would be: (1) pilot test and refine the program as described in the report section titled "A Pilot Program as a Stepping Stone;" (2) make the refined program the default to be followed by all designated states (and EPA in others) and all municipal, industrial, and construction permittees, unless a state permitting authority convincingly demonstrates to EPA's satisfaction than an alternative approach will accomplish the program's overall goal of retaining and recovering aquatic resource beneficial uses; (3) develop very significant incentives for states and permittees to participate; and

(4) require objective demonstration by any state opting for an alternative that it is broadly achieving the goal to at least the same extent as states within the program, with appropriate sanctions for noncompliance.

ENHANCEMENT OF EXISTING PERMITTING BASIS

The current federal stormwater regulatory framework has been in place since 1990, and the point source NPDES program under which it is being implemented has existed since 1972. The U.S. Congress deliberately acted in 1987 to amend the federal CWA with the goal of addressing stormwater pollution because it had been identified as a leading cause of surface water impairments, and regulations were inadequate to address it effectively. The total rethinking of the current framework of regulating stormwater pollution described above may require changes in statute and take a long time to implement. Thus, in addition to the longer-term approach that integrates a watershed-wide planning and permitting strategy into the program, several near-term solutions are also offered, with the objective of improving the current regulatory implementation and which at most might require changes in regulation.

Problems Complying with Both Municipal and General Industrial Permits

The NPDES permitting authority issues (1) separate individual permits or general permits to impose discharge requirements on small, medium, and large MS4s; (2) general permits that require construction activity operators who discharge stormwater to waters of the United States, including those who discharge via MS4s, to implement SCMs; and (3) general permits for operators of stormwater discharges associated with industrial activity who discharge to waters of the United States, including those who discharge via MS4s, to implement SCMs. The MS4 operators in turn are also required under the terms of their MS4 permits to require industries and construction site operators who discharge stormwater via the MS4 to implement controls to reduce pollutants in stormwater discharges to the maximum extent practicable, including those covered under the permitting authority's NPDES general permits. This dual-coverage scheme appears intended to recognize the separation of governmental authorities. Unfortunately, in practice it is duplicative, inefficient, and ineffective in controlling stormwater pollution that enters the MS4 from diffuse and dispersed sources. Particularly in the area of monitoring of water quality, the dual approach seems to have resulted in a lack of prioritization of high-risk industrial sources and the purposeless collection of industrial stormwater monitoring data or the poor use of it to strategically reduce the discharge of stormwater pollutants to the MS4.

The preference of EPA to use general NPDES permits to alleviate the administrative burden associated with permitting more than a 100,000 point sources discharging stormwater is understandable. It would have been prudent to have some form of prioritization to select some subset of the whole as high-risk or have a strategy for identifying a subset for individual NPDES permits to better achieve the objective of ensuring compliance with water quality standards on the basis of potential risk. As discussed in Chapter 2, there are no federal guidelines for prioritization (determining what industries are high-risk for stormwater discharges), and the state permitting authorities have largely not prioritized because of the overwhelming burden of administering a very expansive stormwater permitting program.

In the existing permitting scheme, the MS4 operator cannot be faulted for having a reasonable expectation that the permitting authority's general NPDES permits that regulate industrial activities and construction that discharge to the MS4 would require, at a minimum, a sufficient level of identification and implementation of SCMs to facilitate the MS4 operator's compliance with the MS4 permit. However, such controls are not identified by the NPDES permitting authority and rather are left to the choice of the industrial facility and construction site operators. Furthermore, the NPDES permitting authority imposes weak to no discharge sampling requirements on industrial facility and construction activity operators, which greatly impairs the MS4's ability to determine and control the worst regulated stormwater discharges to the MS4. Similarly, the NPDES permitting authority's general permit for construction activity encourages construction facility operators to consider post-construction stormwater controls, but it does not require them, even though the MS4 permit's programmatic measures mandate new development planning and post-construction controls as essential elements of the MS4 program. The lack of integration among stormwater permits and the absence of objective measures of compliance that are quantifiable is a glaring shortcoming in current stormwater permits and renders them difficult to enforce for water quality protection.

The California EPA State Water Board asked an expert panel to evaluate the extent of implementation success of the stormwater program in California and the feasibility of numeric effluent limits in stormwater permits. In its report (CA SWB, 2006), the panel concluded that the flexible approach of allowing a permittee to self-select SCMs for the purpose of controlling stormwater pollution was largely ineffective. The reasons stated were: (1) the SCMs were selected without proper consideration of design, performance, hydraulics, and function; (2) the MS4 permittees were not accountable for the performance of the SCMs; (3) the industrial and construction permittees were not responsible for the performance of the SCMs; and (4) the SCMs were seldom maintained properly except for aesthetic purposes. In other words, the flexibility provided by self-determination, self-evaluation, and self-reporting did not assure that SCMs were being implemented to effectively reduce stormwater pollutants to the MEP. Rather, the flexibility resulted in a lack of coordination of purpose and accountability between the MS4 permittees who owned or operate the MS4 and the industry and construction permittees who discharge to the MS4. Although typically enforcement by the permitting authority would have restored the integrity of the stormwater program, that remedy is likely to be ineffective here because the choice of SCMs is left too much to discretion and there are no quantifiable performance or design criteria for water quality purposes.

Integration and Dissemination of Authority

This section offers a near-term alternative solution to the problem cited above that utilizes the existing framework of the NPDES stormwater program. The strategy builds on the authority of MS4s over industry and construction sites to implement an integrated permitting scheme to reduce stormwater pollution into the waters of the United States. Unlike the first section of this chapter, it does not take a watershed approach to protecting water quality, even though the municipal stormwater programs may be more cost-effective if implemented on a watershed scale. It also addresses a significant shortcoming of the current scheme, that is, failure to recognize the enormous staff resources that it would take at the federal and state level for successful implementation in the absence of the leadership of local governments. Further, federal and state NPDES permitting authorities do not presently have, and can never reasonably expect to have, sufficient personnel under the principles of democratic governance, such as in the United States, to inspect and enforce stormwater regulations on more than 100,000 discrete point source facilities discharging stormwater. A better structure would be one where the NPDES permitting authority empowers the MS4 permittees, who are local governments working for the public good, to act as the first tier of entities exercising control on stormwater discharges to the MS4 to protect water quality—an approach here called "integration."

The central concept of integration is to give the MS4s controlling jurisdiction and responsibility over discharges from construction and industry to the MS4 in addition to their responsibility to implement the programmatic minimum measures identified in regulation. This approach would be similar to the current NPDES permitting scheme for publicly owned WWTPs, where a WWTP operator controls the quality of wastewater inputs (industrial waste streams) to make sure that the total output will not exceed water quality standards (see Box 6-5 on the National Pretreatment Program). The WWTP operators establish additional criteria such as local limits, require discharge monitoring of industrial wastes, and conduct inspections to make sure industrial discharges implement adequate wastewater treatment technologies, so that treated effluent from the wastewater treatment can comply with water quality standards to protect receiving waters. The same could be done for stormwater, except here the WWTP is replaced by the MS4, and the other inputs in this case are all industrial and construction discharges of stormwater into the MS4. The criteria by which the outputs of the industries are judged could be either water quality- or technology-based criteria. This arrangement puts the burden on the MS4 to identify high-risk industries because the MS4 is now responsible for the overall output (which could be, for example, the concentration of pollutants in stormwater monitored during

BOX 6-5
National Pretreatment Program

EPA's NPDES Permitting Program requires that all point source discharges to waters of the United States (i.e., "direct discharges") must be permitted. To address "indirect discharges" from industries to Publicly Owned Treatment Works (POTWs), EPA, through CWA authorities, established the National Pretreatment Program as a component of the NPDES Permitting Program. The National Pretreatment Program requires industrial and commercial dischargers to treat or control pollutants in their wastewater prior to discharge to POTWs.

In 1986, more than one-third of all toxic pollutants entered the nation's waters from POTWs through industrial discharges to public sewers. Certain industrial discharges, such as slug loads, can interfere with the operation of POTWs, leading to the discharge of untreated or inadequately treated wastewater into rivers, lakes, etc. Some pollutants are not compatible with biological wastewater treatment at POTWs and may pass through the treatment plant untreated. This "pass through" of pollutants impacts the surrounding environment, occasionally causing fish kills or other detrimental alterations of the receiving waters. Even when POTWs have the capability to remove toxic pollutants from wastewater, these toxics can end up in the POTW's sewage sludge, which in many places is land-applied to food crops, parks, or golf courses as fertilizer or soil conditioner.

The National Pretreatment Program is unique in that the general pretreatment regulations require all large POTWs (i.e., those designed to treat flows of more than 5 MGD) and smaller POTWs with significant industrial discharges to establish local pretreatment programs. These local programs must enforce all national pretreatment standards (effluent limitations) and requirements, in addition to any more stringent local requirements necessary to protect site-specific conditions at the POTW. More than 1,500 POTWs have developed and are implementing local pretreatment programs designed to control discharges from approximately 30,000 significant industrial users.

EPA has supported the pretreatment program through development of more than 30 manuals that provide guidance to EPA, states, POTWs, and industry on various pretreatment program requirements and policy determinations. Through this guidance, the pretreatment program has maintained national consistency in interpretation of the regulations.

The general pretreatment regulations establish responsibilities of federal, state, and local government, industry, and the public to implement pretreatment standards to control pollutants that pass through or interfere with POTW treatment processes or that may contaminate sewage sludge. The general pretreatment regulations apply to all non-domestic sources that introduce pollutants into a POTW. These sources of "indirect discharge" are more commonly referred to as industrial users (IUs). Since IUs can be as simple as an unmanned coin-operated car wash to as complex as an automobile manufacturing plant or a synthetic organic chemical producer, EPA developed four criteria that define a significant industrial user (SIU). Many of the general pretreatment regulations apply to SIUs as opposed to IUs, based on the fact that control of SIUs should provide adequate protection of the POTW.

Unlike other environmental programs that rely on federal or state governments to implement and enforce specific requirements, the Pretreatment Program places the majority of the responsibility on local municipalities**.** Specifically, Section 403.8(a) of the general pretreatment regulations states that any POTW (or combination of treatment plants operated by the same authority) with a total design flow greater than 5 million MGD and smaller POTWs with SIUs must establish a local pretreatment program. As of early 1998, 1,578 POTWs were required to have local programs. Although this represents only about 15 percent of the total treatment plants nationwide, these POTWs account for more than 80 percent (i.e., approximately 30 billion gallons a day) of the national wastewater flow.

Consistent with Section 403.8(f), POTW pretreatment programs must contain the six minimum elements described below (EPA, 1999):

1. Legal Authority

The POTW must operate pursuant to legal authority enforceable in federal, state, or local courts, which authorizes or enables the POTW to apply and enforce any pretreatment regulations developed pursuant to the CWA. At a minimum, the legal authority must enable the POTW to:

i. deny or condition discharges to the POTW,
ii. require compliance with pretreatment standards and requirements,
iii. control IU discharges through permits, orders, or similar means,
iv. require IU compliance schedules when necessary to meet applicable pretreatment standards and/or requirements and the submission of reports to demonstrate compliance,
v. inspect and monitor IUs,
vi. obtain remedies for IU noncompliance, and
vii. comply with confidentiality requirements.

2. Procedures

The POTW must develop and implement procedures to ensure compliance with pretreatment requirements, including:

i. identify and locate IUs subject to the pretreatment program,
ii. identify the character and volume of pollutants contributed by such users,
iii. notify users of applicable pretreatment standards and requirements,
iv. receive and analyze reports from IUs,
v. sample and analyze IU discharges and evaluate the need for IU slug control plans,
vi. investigate instances of noncompliance, and
vii. comply with public participation requirements.

3. Funding

The POTW must have sufficient resources and qualified personnel to carry out the authorities and procedures specified in its approved pretreatment programs.

4. Local Limits

The POTW must develop local limits or document why those limits are not necessary.

5. Enforcement Response Plan (ERP)

The POTW must develop and implement an ERP that contains detailed procedures indicating how the POTW will investigate and respond to instances of IU noncompliance.

6. List of SIUs

The POTW must prepare, update, and submit to the approval authority a list of all significant industrial users (SIUs).

In addition to the six specific elements, pretreatment program submissions must include:

- A statement from the city solicitor (or the like) declaring the POTW has adequate authority to carry out program requirements;
- Copies of statutes, ordinances, regulations, agreements, or other authorities the POTW relies upon to administer the pretreatment program, including a statement reflecting the endorsement or approval of the bodies responsible for supervising and/or funding the program;

continues next page

BOX 6-5 Continued

- A brief description and organizational chart of the organization administering the program; and
- A description of funding levels and manpower available to implement the program.

The objectives of the National Pretreatment Program are achieved by applying and enforcing three types of discharge standards: (1) prohibited discharge standards, (2) categorical standards, and (3) local limits.

Prohibited Discharge Standards

All IUs, whether or not subject to any other national, state, or local pretreatment requirements, are subject to the general and specific prohibitions identified in 40 C.F.R. §§403.5(a) and (b), respectively. General prohibitions forbid the discharge of any pollutant(s) to a POTW that cause pass-through or interference. These prohibited discharge standards are intended to provide general protection for POTWs. Examples of these include prohibitions on discharges of pollutants that can create fire or explosion hazards, cause corrosive structural damage, obstruct flow within the POTW, and interfere with the POTW's biological treatment activity. However, their lack of specific pollutant limitations creates the need for additional controls, namely categorical pretreatment standards and local limits.

Categorical Standards

Categorical pretreatment standards (i.e., categorical standards) are national, uniform, technology-based standards that apply to discharges to POTWs from specific industrial categories (i.e., indirect dischargers) and limit the discharge of specific pollutants. Categorical pretreatment standards for both existing and new sources are promulgated by EPA pursuant to Section 307(b) and (c) of the CWA. Limitations developed for indirect discharges are designed to prevent the discharge of pollutants that could pass through, interfere with, or otherwise be incompatible with POTW operations. The categorical pretreatment standards can be concentration based or mass based. For example, the pretreatment standard for the electrical and electronic component manufacturing industry (40 C.F.R. Part 469, Subparts A-D) are concentration-based daily maximum and monthly average limits that vary by subpart and pollutant parameter.

Local Limits

Prohibited discharge standards are designed to protect against pass-through and interference generally. Categorical pretreatment standards, on the other hand, are designed to ensure that IUs implement technology-based controls to limit the discharge of pollutants. Local limits, however, address the specific needs and concerns of a POTW and its receiving waters**.** Federal regulations at 40 CFR §§403.8(f)(4) and 122.21(j)(4) require control authorities to evaluate the need for local limits and, if necessary, implement and enforce specific limits as part of pretreatment program activities. Local limits are developed for pollutants (e.g., metals, cyanide, BOD_5, TSS, oil and grease, organics) that may cause interference, pass-through, sludge contamination, and/or worker health and safety problems if discharged in excess of the receiving POTW treatment plant's capabilities and/or receiving water quality standards.

events). If put in this position, municipalities will make intelligent choices and adopt effective strategies to identify which industries and sources to focus upon. Each of these issues is discussed in greater detail below.

Determination of High-Risk Dischargers

At present, the federal stormwater regulations do not specifically identify which sources would be considered high risk given the common pollutants in MS4 stormwater discharges. With the exception of the category of municipal landfills and hazardous waste treatment, storage, and disposal facilities, it does not even state that the other nine categories of industry singled out in the regulations for permitting under the multi-sector industrial stormwater general permit (MSGP) are really high risk. The devolution of this responsibility to the municipality is sensible because the municipality, as the land-use authority, already conducts development review and issues industrial conditional-use permits. The permitting authority would still be responsible for inspecting high-risk state, federal, and other facilities over which the MS4 permittee has no jurisdiction. In addition, the permitting authority would inspect municipal facilities such as airports, ports, landfills, and waste storage facilities to avoid the situation of self-inspection. Methods for ranking industries according to risk are discussed in a subsequent section.

It is likely that some of the designated high-risk facilities would be better regulated by individual stormwater NPDES permits. In particular, good candidates for individual NPDES permits include international ports, airports, and multiphase construction land developments, which are similar (in the potential risk they pose to water quality) to traditional major wastewater facilities such as petroleum refineries and large POTWs.

SCM Design Parameters, Numerical SCM Performance Criteria, and Monitoring

For the integration approach to work, the permitting authority and the MS4 permittee must better delineate SCM design parameters, numerical performance criteria, and default SCMs based on best available technology or water quality standards for the discharge of industrial and construction stormwater. Both the ASCE International Storm Water Database (which is now called the WERF International Storm Water Database because it is maintained by the Water Environment Research Foundation) and the National Stormwater Quality Database (NSQD), which were developed with EPA funding, are comprehensive datasets that can be used to develop numeric technology-based effluent criteria or limits for industrial and construction stormwater discharges. The MS4 can then determine the compliance of industry and construction activity with its requirements by using either some numeric criteria or a suite of SCMs that have been presumptively determined as capable of achieving the performance criteria. The EPA MSGP includes a general list of sector-specific SCMs, but these presently have no performance criteria associated with them. It is important that the EPA continue to support both the WERF and the NSQD databases as the repositories of SCM performance and MS4 monitoring data, so that MS4s can use them to establish local limits and update the performance criteria periodically to fully effectuate the iterative approach to ensuring that MS4 discharges eventually will meet water quality standards.

The proposed integration scheme will also facilitate the MS4 permittee's implementation of a purpose-oriented stormwater monitoring program directed toward identifying problematic industrial or construction stormwater discharges or high-risk industrial facility sectors. The current benchmark monitoring conducted by MSGP facilities would be eliminated. Instead, MSGP facilities would have the option of performing scientifically valid stormwater discharge sampling to demonstrate their compliance with performance criteria or to participate in an MS4-led monitoring program by paying in lieu fees to support the cost of the purpose-oriented MS4 monitoring program. The net effect of this alternative is to pool the resources to come up with an optimal sampling strategy to replace what is now a stormwater monitoring strategy that is haphazard and not useful.

MS4 Responsibilities

Under integration, the MS4 permittee would be primarily responsible for the quality of stormwater discharges that exit the MS4 to the waters of the United States. The MS4 permittee would not be responsible for stormwater discharges from federal and state facilities or for facilities that have been issued an individual NPDES permit for stormwater discharges. The MS4 permittee would be responsible for implementing the six minimum program measures, assisting in the oversight and inspection of facilities covered under the MSGP and the construction general permit (CGP), and implementing a strategic water quality monitoring program to identify and control pollutant discharges from high-risk sites. The permitting authority would share any fees collected under the MSGP and CGP with the MS4, and facilities covered by them would have the option to opt-out of self-monitoring and contribute equivalent funds to an MS4-led monitoring program. Similarly, the permitting authority would be expected to support research and special studies that address issues of regional or national significance through partnerships with the MS4 permittees.

Some MS4s may balk at taking on more responsibility for the control of stormwater pollution, as required for integration to succeed. However, there are already several case examples that exist. The State of Oregon requires facilities that discharge industrial stormwater to file a Notice of Intent (NOI) for coverage under the MSGP with both the state and the local MS4 (Campbell, 2007). The state has an agreement with the local MS4s for the inspection of the facilities covered under the MSGP and the sharing of NOI fees. The State of Tennessee has a statewide pilot program to partner with local MS4s for the inspection of construction sites that are covered under the CGP.

Analogy to the WWTP Pretreatment Program

It is certainly true that the MS4s are a more challenging point source to regulate for the discharge of pollutants than WWTPs. WWTPs have fewer outfalls discharging to waters of the United States than MS4s, and inputs into them are through discrete rather than diffuse sources as in the case of MS4s. It is thus expected to be more difficult to identify problem stormwater sources and to hold them accountable for discharges in excess of standards. This problem is not insurmountable, however. Watershed and land-use hydrologic models can be developed and refined by strategic sampling of pollutant sources for use by MS4 permittees and regulatory agencies. If EPA and state permitting authorities establish measurable outcomes as expected endpoints of progress, MS4 permittees will make intelligent choices about which measures to implement in order to meet these endpoints. In large part, the lack of progress nationally towards controlling pollutants in stormwater discharges from the MS4s has been due to the absence of national SCM design standards, MS4 discharge performance criteria, and stormwater effluent guidelines. Presently, the MS4 permittees as owners and operators of the MS4 affirmatively approve connections to the conveyance system for rainfall runoff. Historically the issuance of the MS4 connection permit has been based on the sizing of the pipes for the conveyance of flood waters. There are few barriers to including water quality considerations in reauthorizing these connections and adding new ones.

Note that EPA did initially consider using the WWTP pretreatment approach for stormwater discharges by requiring MS4 permittees to be primarily responsible for discharges of stormwater associated with industrial activity through the MS4 (53 Fed. Reg. 49428; December 7, 1988). However, EPA deviated from this approach in issuing its Final Storm Water Rule (55 Fed. Reg. 48006; November 16, 1990). In the absence of regulations that specifically confer authority on MS4 permittees to establish local limits for stormwater discharges to the MS4 from industry and businesses, the EPA should promulgate specific SCMs and performance guidelines with rigorous requirements for self-monitoring and compliance in order to support the integrated framework for controlling stormwater pollution from MS4s.

Potential Legal Barriers

A revised stormwater program that requires MS4s to play a more significant role in enforcement and oversight and that provides greater specificity in permit requirements is not only contemplated, but arguably demanded by Congress in the CWA. Specifically, Congress directs that MS4 permits be conditioned on the requirement that the MS4s "shall require controls to reduce the discharge of pollutants to the maximum extent practicable" 42 U.S.C. § 1342(p)(3)(B)(iii). EPA has already conditioned Phase I MS4 permits on the requirement that the municipality establish that it has the legal authority to inspect discharges into the system and take regulatory and enforcement action against excessive or violating sources [40 C.F.R. § 122.26(d)(2)(i)]. Nevertheless, to ensure that MS4s play an even more active role, EPA should include several additional requirements in its implementing regulations. In addition to promulgating more detailed and specific SCM requirements as discussed above, EPA should also require that the Phase I MS4s establish that they possess sufficient funding and staff to effectuate their responsibilities [see, e.g., 40 C.F.R. § 403.8(f)(2) and (3) requiring this showing for the POTW program]. Like the POTW program, states should also be authorized as MS4 permittees when the local governments are unable or unwilling to carry out their mandatory stormwater permit responsibilities [see, e.g., 40 C.F.R. § 403.10(e) providing this authority for the POTW program].

Industrial Program

The industrial stormwater permit program presently incorporates a menu of SCMs that are to be selected by the facility operator, a rudimentary monitoring program that includes visual observations, some water quality sampling for selected parameters for certain types of industries subject to numerical effluent limitations (see Table 2-6) or a set of pollutant-level benchmarks that are to be used as a measure to appropriately revise the SWPPP (see Table 2-5), and annual reporting. Neither SCM performance criteria nor the characteristics of a design storm for water quality purposes have been established. Given the broad discretion that facility operators enjoy as a result, it has been difficult to gauge compliance with the MSGP and initiate enforcement for non-compliance even though industrial stormwater discharges are required to meet effluent limitations (technology- or water quality-based) that reflect water quality standards (Duke and Beswick, 1997; Duke and Augustenborg, 2006; Wagner, 2006). Several ideas to address some of the shortcomings in the implementation of the permitting program for industrial stormwater discharges are offered as *additions* to the concept of MS4 regulatory integration discussed previously. They would substantively improve the current industrial stormwater permitting program even if the integration recommendations were not acted upon.

Criteria for a Water Quality Design Storm and Subsequent SCM Selection

To improve the quality of stormwater discharges from industry, provide for better accountability, and advance the objectives of the CWA, it is important first to identify the criteria for a water quality design storm as opposed to one for flood control design, where the objective is to protect human life and real property. It is important that the permitting authority designate the basis for the determination of the water quality design storm, and explicitly state that it would form the criteria for evaluation of compliance with technology-based standards or water quality-based standards. This is essential because the engineering design decisions that determine how much stormwater is to be treated to remove toxic pollutants that pose a risk to human health or aquatic life is more a policy matter than a scientific one (Schiff et al., 2007). While modeling exercises using continuous simulation methods in theory could be performed for every project or subwatershed or region to support planning decisions on how much stormwater needs to be treated for optimum water quality benefits, such a detailed analysis will be too cumbersome and cost-prohibitive for routine planning and implementation purposes. Thus it is recommended that the EPA establish guidelines for the selection of water quality design storms for controlling pollution from MS4 and industrial stormwater discharges. This would not be a new practice for EPA because the agency has previously established design storms for certain industrial sectors when promulgating effluent guidelines (Table 2-6). Conceivably, unlike the technology limiting design storms that are set on rainfall recurrence intervals, the design storm to protect surface water quality and beneficial uses could be different for different eco-regions of the United States.

The water quality design storm, which may be expressed as total rainfall depth, runoff volume, or rainfall intensity, incorporates the concept that extreme rainfall events are rare, and that a few times each year the runoff volume or flow rate from a storm will exceed the design volume or rate capacity of an SCM. Therefore, for the purpose of best available technology and cost-effectiveness, industrial facility operators should not be held accountable for pollutant removal from storms beyond the size for which an SCM is designed.

For MS4 operators, the concept of designing MS4s for both flood control conveyance (capital flood design) and for water quality protection (water quality design) involves a fundamental shift. Whereas flood control engineers design conveyance systems with return frequencies of two years (streets), ten years (detention basins), 50 years, and 100 years (channels), the water quality design storm event is for a return frequency of six months to a year. The water quality design implicitly focuses on treating the first flush of runoff, which contains the highest load and concentration of pollutants and which occurs in the first half to one inch of runoff. In contrast, flood control designs are built to convey tens of inches of runoff.

In addition to issuing the guidelines to support the setting of stormwater criteria for water quality design, it is important that the EPA establish SCM performance criteria based on best technologies and identify the “presumptive technologies” that have been demonstrated to achieve the performance criteria. The water quality design storm and the best available technologies with their associated criteria can then form a basis for technology-based effluent limitations to be included in industrial stormwater permits. If the facility operator elects the identified presumptive technology, then compliance monitoring requirements can be scaled down to a minimum to ensure that the treatment systems are being properly maintained. On the other hand, if the operator elects to go with a suite of alternative SCMs, then the monitoring requirements sufficient to demonstrate that the suite of alternative SCMs are in fact achieving the effluent quality of the selected technology can be prescribed. In such a scheme, visual monitoring will serve to ensure that the treatment systems are being properly maintained, and compliance can be reported using the same procedures as required presently for the industrial wastewater permits.

How to Identify a High-Risk Industry

Both the watershed-based permitting approach described previously in this chapter and the integration approach call for municipal permittees, as part of their responsibilities, to identify high-risk industrial stormwater dischargers. This involves identifying the potential sources of concern, evaluating the extent of their potential impacts, and then prioritizing them for attention—a classic risk assessment. Municipalities would generally not be able to give equal and full attention to all sources, nor should they. Unfortunately, what constitutes high risk or any level of risk for industries covered by NPDES stormwater permits has not been defined by EPA, although the states have developed various interpretations (see Appendix C).

Two methodologies for identifying industrial and commercial facilities that are considered high-risk for discharging pollutants in stormwater are presented below. Box 6-6 describes the "intensity of industrial activity" method devised for the City of Jacksonville (Duke, 2007). This method uses telephone queries and a point scale system to visually score each facility based on the intensity of the industrial activities exposed to stormwater, and groups the results into categories A, B, C, or D in increasing order of intensity (Cross and Duke, 2008). The categories are designed to distinguish high-risk facilities from low-risk facilities, and not to make fine distinctions among facilities with similar characteristics. This typology is sufficient to distinguish facilities with little or no potential for discharging pollutants associated with stormwater from facilities that might discharge those pollutants. More than half of the facilities that were subject to Florida's MSGP were determined to be low-risk (Cross and Duke, 2008).

Box 6-7 outlines an empirical methodology used by the County of Los Angeles to rank the risk of industrial facilities for stormwater pollution on the basis of pollution potential P. The pollution potential P was computed as a product of the number of on-site sources, percent imperviousness, pollutant toxicity, degree of exposure, and the number of facilities (Los Angeles County, 2001). Based on this ranking scheme, five top high-risk industries were selected: (1) automobile dismantlers, (2) automobile repair, (3) metal fabrication, (4) motor freight, and (5) automobile dealers. Stormwater discharges from six facilities in each category were characterized over a two-year period, and the effectiveness of SCMs

BOX 6-6
Risk Assessment for Industrial Dischargers of Stormwater

The City of Jacksonville has had very good success in determining what industries pose the highest stormwater risks by starting with businesses having the Standard Industrial Classification (SIC) codes designated for permit coverage but using multiple lists of potential sources and cross checking them to target inspections and other interventions where they will have the best effect. Other clues to sources of interest include other environmental permits (e.g., wastewater NPDES permits, permits for discharge to sanitary sewer), tax records, records of fire code inspections, building permit filings, planning agency proceedings, contacts with business associations, marketing information put out by companies, Resource Conservation and Recovery Act hazardous waste reports, and telephone and field surveys.

Duke (2007) proposed a 0- to 8-point scoring scheme (shown below) to rate the intensity of industrial activities exposed to stormwater. The system is based on the relative amount of exposure to precipitation and runoff by industrial materials, processes, wastes, and vehicles. Once municipalities gather the data and then classify their industries accordingly, they would have a very useful tool to program inspections and monitoring emphasizing the industries most risking their success in achieving established objectives. A similar system could and should be developed for construction sites.

<u>0 points</u>
- Small bulk waste, e.g., covered dumpster: area <100 m^2
- Hazardous waste: containers not exposed to precipitation

<u>1 point</u>
- Outdoor vehicle use: 1-2 vehicles, outdoors occasionally/never, not used in precipitation
- Vehicle washing outdoors, 1-2 vehicles, rarely or occasionally done

<u>2 points</u>
- Outdoor vehicles, e.g., forklifts: 1-2, outdoors occasionally/never, used in precipitation
- Outdoor vehicles, e.g., forklifts: 1-2, outdoors every day, not used in precipitation
- Outdoor vehicles, e.g., forklifts: 3-4, outdoors occasionally/never, not used in precipitation
- Vehicle maintenance or re-fueling, 1-2 vehicles, rarely or occasionally done, outside
- Vehicle washing outdoors, 1-2 vehicles, regularly done
- Vehicles washing outdoors, 3 vehicles, rarely or occasionally done

<u>4 points</u>
- Storage of materials or products: area < 100m^2 and/or < five 55-gallon drums
- Fixed outdoor equipment: 1-2 small or large item(s)
- Outdoor vehicles, e.g., forklifts: 1-2, outdoors every day, used in precipitation
- Outdoor vehicles, e.g., forklifts: 3-4, outdoors occasionally/never, used in precipitation
- Outdoor vehicles, e.g., forklifts: 3-4, outdoors every day, not used in precipitation
- Uncovered shipping/receiving area: 1-2 docks
- Vehicle maintenance or re-fueling outdoors, 1-2 vehicles, regularly done
- Vehicle maintenance or re-fueling outdoors, vehicles, rarely or occasionally done
- Plant yard, rail lines, access roads: 1,000 ft^2
- Small process equipment, e.g., compressors, generators: exposed to precipitation

continues next page

BOX 6-6 Continued

6 points
- Outdoor vehicles, e.g., forklifts: 3-4, outdoors every day, used in precipitation
- Outdoor vehicles, e.g., forklifts: > 5 or heavy, outdoors occasionally, used in precipitation
- Outdoor vehicles, e.g., forklifts: > 5 or heavy, outdoors every day, not used in precipitation
- Vehicle maintenance or re-fueling outdoors, 3 vehicles, regularly done
- Plant yard, rail lines, access roads: 1,000 ft^2

8 points
- Storage of materials or products: area 100^2 and/or five 55-gallon drums
- Boneyard of scrap, disused equipment, similar
- Hazardous waste: containers exposed to precipitation
- Fixed outdoor equipment: small or 2 large items
- Outdoor vehicles, e.g., forklifts: > 5 or heavy, outdoors every day, used in precipitation
- Uncovered shipping/receiving area: 3 docks
- Plant yard, rail lines, access roads: 5,000 ft^2
- Manufacturing activities, e.g., cutting, painting, coating materials: exposed to precipitation

SOURCE: Duke (2007).

was assessed at a subset of them. However, the monitoring was minimal, and so much of the prioritization was based on best professional judgment about pollutant discharges.

Industrial Stormwater Discharge Monitoring

Monitoring data from Phase I MS4s have been compiled in the NSQD for several years, making possible a number of important findings about the quality of municipal stormwater (see Chapter 3). Although industry that occurs within MS4s is technically included in the NSQD, the data are lumped together and not sector specific. There is no comparable, reliable source of data specifically on industrial discharges, even though EPA requires benchmark monitoring for MSGP industrial permittees. The intent was that industrial facility operators would use benchmark exceedances as action levels to improve SCMs, but this self-directed approach has been largely a failure. Many industrial facilities reported repeated exceedances of benchmark values without action, and others have failed to report any monitoring data at all. In addition, the representativeness of single grab samples taken to characterize the discharge and less-than-rigorous sample collection and quality assurance procedures have resulted in monitoring data that are not very useful. One of the only analyses of benchmark monitoring data ever done evaluated California's program between 1992 and 2001 (see Box 4-2; Stenstrom and Lee, 2005; Lee et al., 2007). The study showed no relationship between facility type and stormwater discharge quality. The cited reasons for the poor relationship included variability in sampling parameters, sampling time, and sampling strategy—that is, poor data.

BOX 6-7
Los Angeles County Critical Facilities Monitoring Data

One of the few sources of data on industrial stormwater discharges comes from the County of Los Angeles. A stepwise process was used to identify the highest-risk industrial/commercial facilities, which were then monitored to measure the quality of their stormwater discharges and to evaluate the effectiveness of SCMs. The initial list of candidate facilities was identified from their relative numbers and the extent of their outdoor activities. This list was then refined using an empirical equation for pollutant potential P:

$$P = Q \times R \times T \times E \times N$$

where

Loading (*Q*) is the number of sources at a site and the likelihood of release;
Imperviousness (*R*) of a site is the percent of paved area;
Pollutant toxicity (*T*) denotes the number of toxic pollutants and the inherent toxicity of the mix;
An exposure factor (*E*) signifies if activities are exposed to rainfall; and
The Number (*N*) represents the total number of sites in the county.

Each variable was assigned a qualitative number from 1 to 10, with 10 representing the worst condition.

Based on this equation, five top "critical source" industries were determined: (1) automobile dismantlers; (2) automobile repair; (3) metal fabrication; (4) motor freight; and (5) automobile dealers. Six facilities from each of these categories were monitored during five storms a year for two years. The stormwater discharge samples were analyzed for general conventional pollutants, heavy metals, bacteria, and semi-volatile organic compounds. Half of the facilities were then fitted with SCMs, which were monitored to evaluate their effectiveness.

The highest median values were observed for total zinc (approx. 450 µg/L), dissolved zinc (approx. 360 µg/L), total copper (approx. 240 µg/L), and dissolved copper (approx. 110 µg/L) in stormwater discharges from fabricated metal sites. However, levels for total and dissolved zinc did not appear to be significantly different among the industry types. SCMs in the form of good housekeeping and spill containment measures were installed at half of the sites. For total and dissolved zinc, the median concentration lowered or stayed nearly the same with the implementation of SCMs at the auto dismantling, auto repair, and fabricated metals industries (i.e., in none of the circumstances was the difference significant). For total and dissolved copper, however, where the fabricated metal industry had displayed the highest median concentrations, levels were significantly reduced with the implementation of SCMs. The auto dismantling and auto repair businesses showed no significant differences in copper after the implementation of SCMs.

SOURCE: Los Angeles County (2001).

In the past, it has been proposed to EPA that it fund a project that would systematically collect the benchmark monitoring data across the nation, as has been done for MS4s, but these suggestions have been rejected. To get better data from specific industrial sectors, it is recommended that a small subset of industrial users and sectors be selected for composite sampling in a program directed by the MS4. Alternatively, making a trained team responsible for monitoring of small-business industrial dischargers would reduce, if not eliminate, current problems with quality assurance.

Monitoring of industrial stormwater discharges could be streamlined by considering the adoption of a Reasonable Potential Analysis (RPA), which is already part of the existing practice in developing limits for NPDES wastewater permits (EPA, 1991). The RPA is a procedure that uses statistical distribution assumptions in association with a limited number of wastewater discharge quality measurements to determine the likelihood that a receiving water quality standard would be violated, which assists the permitting authority in determining what permit limitations should be set to protect receiving water quality. The effluent data from any treatment system may be described using standard descriptive statistics such as the mean concentration and the coefficient of variation. Using a statistical distribution such as the lognormal, an entire distribution of values can be projected from limited data; limits on pollutant concentrations in discharge can then be set at a specified probability of occurrence so that the receiving water is protected. An RPA for stormwater pollutants may be particularly relevant in developing performance criteria for SCMs for facilities discharging stormwater within the integrated framework of MS4 permitting. Also, MS4 permittees could use the method to reduce the number of pollutants that high-risk industries would be required to monitor in order to demonstrate to the municipality that they are not the source of pollutants in MS4 discharges that are impairing surface waters.

Construction Program

The recommendations for stormwater discharges associated with construction activity are very similar to those offered for stormwater discharges associated with industrial activity. The integration with the MS4 program is less of a challenge because municipalities have always had primacy on land development planning and construction activity. Most municipalities have had requirements for soil erosion and sediment control plans on construction sites that precede the federal stormwater regulations. EPA regulations already allow permitting authorities to approve Phase I and Phase II MS4 permittee oversight of CGP construction sites under the qualifying local program provision (40 C.F.R. 122.44(s)) (Grumbles, 2006). The weakness in the implementation of this provision currently is the absence of rigorous SCM performance criteria guidelines for MS4s permittees to meet in order to be deemed as qualifying.

The construction stormwater general permit program requires the development and implementation of an SWPPP. The SWPPP, which must be prepared before construction begins, focuses on two major requirements: (1) describing the site adequately and identifying the sources of pollution to stormwater discharges associated with construction activity on site and (2) identifying and implementing appropriate measures to reduce pollutants in stormwater discharges to ensure compliance with the terms and conditions of this permit. The SWPPP must describe the sequence of major stormwater control activities and the kinds of SCMs that will be in place, and it must identify interim and permanent stabilization practices, including a schedule of their implementation. There is an expectation that the construction site operator will use good site planning, preserve mature vegetation, and properly stage major earth-disturbing activities to avoid sediment loss and prevent erosion. Post-construction stormwater controls need to be considered, but are not required. Construction site operators are required to visually inspect the construction site weekly and perform a walk through before predicted storm events. No annual reports are required, but records must be kept for a period of three years after permit coverage has been terminated. There are no SCM performance criteria, other than a suggestion that most SCMs should be able to achieve 80 percent TSS removal. As with industry, it is difficult to gauge compliance with the CGP except when inadequate SCMs result in a massive discharge of sediment from a construction site.

The pollutant parameters that are of concern in stormwater discharges from construction activity are TSS, settleable solids, turbidity, and nutrients from erosion; pH from concrete and stucco; and a wide range of metallic and organic pollutants from construction materials, processes, wastes, and vehicles and other motorized equipment. The permitting authority, in addition to guidelines for the water quality design storm, must establish SCM performance criteria for stormwater discharges associated with construction activity. The construction site operator should be given the option of implementing SCMs that are the presumptive technology, or equivalent SCMs that can achieve the performance criteria. For example, the recommended SCMs in Box 5-3 could serve as the presumptive construction SCMs on a typical construction site that is less than 50 acres in size. If the operator elects to go with a suite of alternative SCMs, then adequate monitoring must be performed to demonstrate that the alternative SCMs are in fact achieving the performance criteria. In addition, the CGP presently does not mandate or require that post-construction SCMs be integrated with the MS4 permittee requirements under its New Development/Redevelopment Program requirements. The proper planning for and implementation of SCMs that will help mitigate stormwater pollution from planned future use of the site will be critical to protecting water quality. Thus the post-construction requirements of the CGP should be strengthened and better integrated with the new development/redevelopment requirements of the MS4 permits.

Municipal Program

Several key enhancements to the MS4 permitting program are needed to ensure that resources are targeted to achieve the greatest on-the-ground implementation of SCMs to make incremental progress in meeting water quality standards. Six specific issues are discussed below; their implementation will require greater collaboration and flexibility among regulators and permitted parties. These recommendations are suggested for communities that are not ready for the integrated watershed approach proposed in the prior section, and represent a bridge toward building internal capacity to implement them.

Numeric Expression of "Maximum Extent Practicable"

The ambiguity of the term "maximum extent practicable" (MEP) has been a major impediment to achieving meaningful water quality results in the MS4 program. The EPA should develop numerical expressions of MEP in the next round of permit renewals that can be measured and tracked. A national numeric benchmark should be avoided; states should focus on regional benchmarks that are tied to their water quality problems. Four examples of methods to define MEP in a numeric manner are provided below: the first three are applied at a regional or state level, whereas the last (impervious cover-based TMDLs) offers more flexibility to be applied at individual sites.

Establish Municipal Action Levels. This approach relies on the use of a national database of stormwater runoff quality to establish reasonable expectations for outfall monitoring in highly developed watersheds. The NSQD (Pitt et al., 2004) allows users to statistically establish action levels based on regional or national event mean concentrations developed for pollutants of concern. The action level would be set to define unacceptable levels of stormwater quality (e.g., two standard deviations from the median statistic, for simplicity). Municipalities would then routinely monitor runoff quality from major outfalls. Where an MS4 outfall to surface waters consistently exceeds the action level, municipalities would need to demonstrate that they have been implementing the stormwater program measures to reduce the discharge of pollutants to the maximum extent practicable. The MS4 permittees can demonstrate the rigor of their efforts by documenting the level of implementation through measures of program effectiveness, failure of which will lead to an inference of noncompliance and potential enforcement by the permitting authority.

Site-Based Runoff and/or Pollutant Load Limits. This approach is primarily used for watersheds that are experiencing rapid development; it establishes numeric targets or performance standards for pollutant or runoff reduction that must be met on individual development sites. The numeric targets may involve specific pollutant load limits or runoff reduction volumes. For example, Virginia DCR (2007) and Hirschman et al. (2008) established a statewide computational method to ensure that SCMs are sized, designed, and sequenced to comply with specific nutrient-based load and runoff reduction limits. The nutrient load limits of 0.28 lb/acre/yr for total phosphorus and 2.68 lb/acre/yr for total nitrogen were computed using the Chesapeake Bay Model for Virginia tributaries to the bay. The design process also requires the computation of runoff reduction volumes achieved to promote the use of nonstructural SCMs. The basic concept is that new development on non-urban land must not exceed the average annual nutrient load and runoff volume for non-urban land using effective SCMs in the watershed. This blended site-based runoff and load limit approach has been advocated by the Office of Inspector General (2007) and Schueler (2008a) and is under active consideration by several other Chesapeake Bay states.

Wenger et al. (2008) reports on a no-net-hydrologic-increase strategy to protect endangered fish species in the northern Georgia Piedmont that sets specific on-site runoff reduction requirements for a range of land uses and design storm events. A similar approach has been incorporated into the recently enacted Energy Independence and Security Act of 2007 that contains provisions that require that the "sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow."

The challenge of defining MEP as a runoff reduction or pollutant load limit is that considerable scientific and engineering analysis is needed to establish the performance standards, evaluate SCM capability to meet them, and devise a workable computational approach that links them together at both the site and watershed levels. In addition, care must be taken to define an appropriate baseline to represent predevelopment conditions that does not unduly penalize redevelopment projects or make it impossible to comply with limits at new development sites after maximum effort to apply multiple SCMs is made.

Turbidity Limits for Construction Sites. Numeric enforcement criteria can be used to define what constitutes an egregious water quality violation at construction sites and provide a technical criterion to measure the effectiveness of erosion and sediment control practices. Currently, most states and localities do not specify either numeric enforcement criteria or a monitoring requirement within their CGP (see the survey data contained in Appendix C).

A maximum turbidity limit would establish definitive criteria as to what constitutes a direct sediment control violation and trigger an assessment for remediation and prevention actions. For example, local erosion and sediment control ordinances could establish a numeric turbidity limit of 75 Nephelometric Turbidity Units (NTU) as an instantaneous maximum for rainfall events less than an inch (or a 25 NTU monthly average) and would prohibit visible sediment in water discharged from upland construction sites. While the exact turbidity limit would need to be derived on a regional basis to reflect geology, soils, and receiving water sensitivity, research conducted in the Puget Sound of Washington indicates that turbidity limits in the 25 to 75 NTU can be consistently achieved at most highway construction sites using current erosion and sediment control technology that is properly maintained (Horner et al., 1990). If turbidity limits are exceeded, a detailed assessment of site conditions and follow-up remediation actions would be required. If turbidity limits continue to be exceeded, penalties and enforcement actions would be imposed. Enforcement of turbidity limits could be performed either by state, local, or third party erosion and sediment control inspectors, or—under appropriate protocols, training, and documentation—by citizens or watershed groups.

Impervious Cover Limits and IC-based TMDLs. MS4s that discharge into TMDL watersheds also require more quantitative expression of how MEP will be defined to reduce pollutant loads to meet water quality standards. Maine, Vermont, and Connecticut have recently issued TMDLs that are based on impervious cover rather than individual pollutants of concern (Bellucci, 2007). In such a TMDL, impervious cover is used as a surrogate for increased runoff and pollutant loads as a way to simplify the urban TMDL implementation process. Impervious cover-based TMDLs have been issued for small subwatersheds that have biological stream impairments associated with stormwater runoff but no specific pollutant listed as causing the impairment (in most cases, these subwatersheds are classified as impacted according to the Impervious Cover Model [ICM]—see Box 3-10). A specific subwatershed threshold is set for effective impervious cover, which means impervious cover reductions are required through removal of impervious cover, greater stormwater treatment for new development, offsets through stormwater retrofits, or other means.

Traditional pollutant-based TMDLs would continue to be appropriate for “non-supporting” and “urban drainage” subwatersheds, although they could be modified to focus compliance monitoring on priority urban source areas or subwatersheds that produce the greatest pollutant loads. Although EPA (2002) indicates that this analysis does not extend to demonstrating that changes will occur in receiving waters, it does outline a rigorous process for evaluating pollutant discharges and SCM performance. More recent EPA guidance (2007c) recommends that MS4s conduct a four-step analysis, which is distilled to its essence below:

Step 1: Estimate loads for pollutant of concern for the watershed.

Step 2: Provide a specific list of SCMs that will be applied in the listed watershed.

Step 3: Estimate the pollutant removal capability of the individual SCMs applied.

Step 4: Compute aggregate watershed pollutant reduction achieved by the MS4.

Although this is not a particularly new interpretation of addressing stormwater loads in watersheds listed as impaired and/or having written TMDLs, it is exceptionally uncommon for individual MS4s to document the link between their stormwater discharges and water quality standard exceedances, as modified by the system of SCMs that they used to reduce these pollutants. As of 2007, EPA could only document 17 TMDLs that addressed stormwater discharges using this sequential analysis. EPA and states need to provide more specific guidance for MS4s to comply with TMDLs in their permit applications and annual reports.

Focus MS4 Permit Implementation at the Subwatershed Level

Chapter 5 noted the importance of the watershed context for making better local stormwater decisions. This context can be formally incorporated into local MS4 permits by focusing implementation on a subwatershed basis, using the ICM, as described in Box 3-10 and outlined in Table 6-1. When urban streams are classified by the ICM, this basic subwatershed planning process can be used to establish realistic water quality and biodiversity goals for individual classes of subwatersheds, as shown in Table 6-2. As can be seen, goals for water and habitat quality become less stringent as impervious cover increases within the subwatershed. This subwatershed approach provides stormwater managers with more specific, measurable, and attainable implementation strategies than the one-size-fits-all approach that is still enshrined in current wet-weather management regulations.

Some examples of how to customize stormwater strategies for different subwatersheds are described in Table 6-3. This approach enables MS4s to utilize the full range of watershed planning, engineering, economic, and regulatory tools that can manage the intensity, location, and impact of impervious cover on receiving waters. In addition, the application of multiple tools in a given subwatershed class helps provide the maximum level of protection or restoration for an individual subwatershed when impervious cover is forecast to increase due to future growth and development. The conceptual management approach shown in Table 6-3 is meant to show how urban stream classification can be used to guide stormwater decisions on a subwatershed basis. The first column of the table lists some key stormwater management issues that lend themselves to a subwatershed approach and are explained in greater detail below.

Linkage with Local Land-Use Planning and Zoning. Given the critical relation between land use and the generation of stormwater, communities should ensure that their planning tools (e.g., comprehensive plans, zoning, and watershed planning) are appropriately aligned with the intended management classification for each subwatershed. For example, it is reasonable to encourage redevelopment, infill, and other forms of development intensification within non-

TABLE 6-1 Components of Subwatershed-Based Stormwater Management

1. Define interim water quality and stormwater goals (i.e., pollutants of concern, biodiversity targets) and the primary stormwater source areas and hotspots that cause them.

2. Delineate subwatersheds within community boundaries.

3. Measure current and future impervious cover within individual subwatersheds.

4. Establish the initial subwatershed management classification using the ICM.

5. Undertake field monitoring to confirm or modify individual subwatershed classifications.

6. Develop specific stormwater strategies within each subwatershed classification that will guide or shape how individual practices and SCMs are generally assembled at each individual site.

7. Undertakes restoration investigations to verify restoration potential in priority subwatersheds.

8. Agree on the specific implementation measures that will be completed within the permit cycle. Evaluate the extent to which each of the six minimum management practices can be applied in each subwatershed to meet municipal objectives.

9. Agree on the maintenance model that will be used to operate or maintain the stormwater infrastructure, assign legal and financial responsibilities to the owners of each element of the system, and develop a tracking and enforcement system to ensure compliance.

10. Define the trading or offset system that will be used to achieve objectives elsewhere in the local watershed objectives in the event that full compliance cannot be achieved due to physical constraints (e.g., indexed fee-in-lieu to finance municipal retrofits).

11. Establish sentinel monitoring stations in subwatersheds to measure progress towards goals.

12. Revise subwatershed management plans in the subsequent NPDES permitting cycle based on monitoring data.

supporting or urban drainage subwatersheds, whereas down-zoning, site-based IC caps, and other density-limiting planning measures are best applied to sensitive subwatersheds.

Stormwater Treatment and Runoff Reduction MEP. Subwatershed classification allows managers to define achievable numerical benchmarks to define treatment in terms of the maximum extent practicable. Thus, a greater level of treatment is required for less-developed subwatersheds and a reduced level of treatment is applied for more intensely developed subwatersheds. This is most frequently expressed in terms of a rainfall depth associated with a given design storm. Designers are required to treat and/or reduce runoff for all storm events up to the designated storm event. This flexibility recognizes the greater difficulty and cost involved in providing the same level of treatment in an in-

TABLE 6-2 Expectations for Different Urban Subwatershed Classes

Lightly Impacted Subwater-sheds (1 to 5% IC)	• Consistently attain scores for specific indicators for hydrology, biodiversity, and geomorphology that are comparable to streams whose entire subwatersheds are fully protected in a natural state (e.g., national parks). Should provide for healthy reproduction of trout, salmon, or other keystone fish species.
Moderately Impacted Subwater-sheds (6 to 10% IC)	• Consistently attain scores for specific stream indicators that are comparable to the highest 10 percent of streams in a population of rural watersheds in order to maintain or restore ecological structure, function, and diversity of the streams. The "good to excellent" indicator scores for this category of subwatersheds will be the benchmark against which the relative quality of more developed subwatersheds will be measured.
Heavily Impacted Sub-watersheds (11 to 25% IC)	• Consistently attain good stream quality indicator scores to ensure enough stream function to adequately protect downstream receiving waters from degradation. • Function is defined in terms of flood storage, in-stream nutrient processing, biological corridors, stable stream channels, and other factors.
Non-Supporting Subwater-sheds (26 to 60% IC)	• Consistently attain "fair to good" stream quality indicator scores. • Meet bacteria standards during dry weather and trash limits during wet weather. • Maintain existing stream corridor to allow for safe passage of fish and floodwaters.
Urban Drain-age Subwater-sheds (61 to 100% IC)	• Maintain "good" water quality conditions in downstream receiving waters. • Consistently attain "fair" water quality scores during wet weather and "good" water scores during dry weather. • Provide clean "plumbing" in upland land uses such that discharges of sewage and toxics do not occur.

Note: the objectives presume some portion of the subwatershed has already been developed, thereby limiting attainment of objectives. If a subwatershed is not yet developed, managers should shift expectations up one category (e.g., urban drainage should behave like non-supporting). Also, the specific ranges of IC that define each management category should always be derived from local or regional monitoring data. Note that the ranges in IC shown to define a subwatershed management category are illustrative and will vary regionally.

tensely developed subwatershed, as well as the fact that less treatment is needed to maintain stream condition in a highly urban subwatershed.

The other key element of defining MEP is to specify how much of the treatment volume must be achieved through runoff reduction. The runoff reduction volume has emerged as the primary performance benchmark to maintain predevelopment runoff conditions at a site after it is developed. In its simplest terms, this means achieving the same predevelopment runoff coefficient for each storm up to a defined storm event through a combination of canopy interception, soil infiltration, evaporation, rainfall harvesting, engineered infiltration, extended filtration, or evapotranspiration (Schueler, 2008b). Once again, the physical feasibility and need to provide treatment through runoff reduction becomes progressively harder as subwatershed impervious cover increases.

TABLE 6-3 Examples of Customizing Stormwater Strategies on a Subwatershed Basis

Stormwater Management Issue	Lightly Impacted Subwatershed (1 to 5% IC)	Moderately Impacted Subwatershed (6 to 10% IC)	Impacted (IC 11 to 25%)	Non-Supporting (IC 26 to 60%)	Urban Drainage (61% + IC)
Linkage with Local Land-Use Planning and Zoning	Utilize extensive land conservation and acquisition to preserve natural land cover	Implement site-based or watershed-based IC caps and maximize conservation of natural areas	Reduce the IC created for each zoning category by changing local codes and ordinances	Encourage redevelopment, development intensification and mass transit to decrease per-capita IC utilization in the urban landscape. Develop watershed restoration plans to maintain or enhance existing aquatic resources.	
Site-based Stormwater Reduction and Treatment Limits	Allow no net increase in runoff volume, velocity and duration up to the five-year design storm	Treat runoff from two-year design storm, using SCMs to achieve 100% runoff reduction		Treat runoff from the one-year design storm, using SCMs to achieve at least 75% runoff reduction	
Site-Based IC Fees	None	Establish Excess IC fee for projects that exceed IC for zoning category		Allow IC mitigation fee	
Subwatershed Trading	Receiving Area for Conservation Easements	Receiving Area for Restoration Projects and/or Retrofit		Receiving or Sending Area for Retrofit	Sending Area for Restoration Projects
Stormwater Monitoring Approach	Measure in-stream metrics of biotic integrity		Track subwatershed IC and measure SCM performance	Check outfalls and measure SCM performance	Check stormwater quality against municipal actions levels at outfalls
TMDL Approach	Protect using antidegradation provisions of the CWA	Use IC-based TMDLs that use flow or IC as a surrogate for traditional pollutants		Use pollutant TMDLs to identify problem subwatersheds	Use pollutant TMDLs to identify priority source areas
Dry Weather Water Quality	Perform in-stream grab sampling of water quality at sentinel stations	Check for failing septic systems	Screen outfalls for illicit discharges	Perform dry weather sampling in streams and outfall screening	Perform dry weather sampling in receiving waters
Addressing Existing Development	Protect or conserve natural areas, enhance riparian cover, assess road crossings, and ensure farm, forest, and pasture best practices are used		Perform stream repairs, riparian reforestation, and residential stewardship	Perform storage retrofits and stream repairs	Use pollution source controls and municipal housekeeping

Site-Based IC Fees. Several economic strategies can be used to promote equity and efficiency when it comes to managing stormwater in different kinds of subwatersheds. In lower-density subwatersheds, an excess impervious cover fee can be charged to individual sites that exceed a maximum threshold for impervious cover for their zoning category. Similarly, an impervious cover mitigation fee can be levied at individual development sites in more intensely developed subwatersheds when on-site compliance is not possible or it is more cost-effective to provide an equivalent amount of treatment elsewhere in the watershed. The type of fee and the frequency that is used is expected to be closely related to the subwatershed classification.

Subwatershed Trading. The degree of impervious cover in a subwatershed also has a strong influence on the feasibility, cost, and appropriateness of restoration projects. Consequently, any revenues collected from various site IC fees can be traded among subwatersheds to arrive at the least-cost, effective solutions. In general, the most intensely developed subwatersheds are sending areas and the more lightly developed subwatersheds are used as receiving areas for such projects.

Stormwater Monitoring Approach. Subwatershed classification can also be used to define the type and objectives for stormwater monitoring to track compliance over time. For example, in sensitive subwatersheds, it may be advisable to routinely measure in-stream metrics of biological integrity to ensure stream quality is being maintained or enhanced. As impervious cover increases, stormwater managers may want to shift toward tracking of subwatershed impervious cover and actual performance monitoring of select SCMs to establish their effectiveness (e.g., impacted subwatersheds). At even higher levels of impervious cover, streams are transformed into urban drainage, and monitoring becomes more focused on identifying individual stormwater outfalls with the worst quality during storm conditions.

TMDL Approach. Subwatershed classification may also serve as a useful tool to decide how to apply TMDLs to impaired waters, or how to ensure that healthy waters are not degraded by future land development. For example, most lightly developed subwatersheds will seldom be subject to a TMDL, or if so, urban stormwater is often only a minor component in the final waste load allocation. Antidegradation provisions of the CWA are often the best means to protect the quality of these healthy waters before they are degraded by future land development. By contrast, impaired watersheds appear to be the best candidates to apply impervious cover-based TMDLs, as described earlier in this section. As subwatershed impervious cover increases, more traditional pollutant-based TMDLs are warranted, with a focus on problem subwatersheds for non-supporting streams and priority source areas for urban drainage.

Dry Weather Water Quality. The type, severity, and sources of illicit discharges often differ among different subwatershed classifications, which can have a strong influence on the kind of dry weather detective work needed to isolate them. For example, in lightly developed subwatersheds, failing septic systems are often the most illicit discharges, which prompts assessments at the lot or ditch level. The storm-drain network and potential discharge source areas becomes progressively more complex as subwatershed impervious cover increases. Consequently, illicit-discharge assessments shift toward outfall screening, catchment analysis, and individual source analysis.

Addressing Existing Development. The need for, type of, and feasibility for restoration efforts shift as subwatershed impervious cover increases. In general, lightly developed watersheds have the greatest land area available for retrofits and restoration projects in the stream corridor. Consequently, unique restoration strategies are developed for different subwatershed classifications (Schueler, 2004).

Require More Quantitative Evaluation of MS4 Programs

The next round of permit renewals should contain explicit conditions to define and measure outcomes from the six minimum management measures that constitute a Phase II MS4 program. Measurable program evaluation is critical to develop, implement, and adapt effective local stormwater programs, and has been consistently requested in permits and application guidance. To date, however, only a small fraction of MS4 communities have provided measurable outcomes with regard to aggregate pollutant reduction achieved by their municipal stormwater programs.

CASQA (2007) defines a six-level pyramid to assess program effectiveness, beginning with documenting activities, raising awareness, changing behaviors, reducing loads from sources, improving runoff quality, and ultimately leading to protection of receiving water quality (see Figure 6-1).

At the current time, most MS4s are struggling simply to organize or document their program activities (i.e., the first level), and few have moved up the pyramid to provide a quantitative link between program activities and water quality improvements. The framework and methods to evaluate program effectiveness for each of the six minimum management measures has been outlined by CASQA (2007). Regulators are encouraged to work with permitted municipalities to define increasingly more specific quantitative measures of program performance in each succeeding permit cycle.

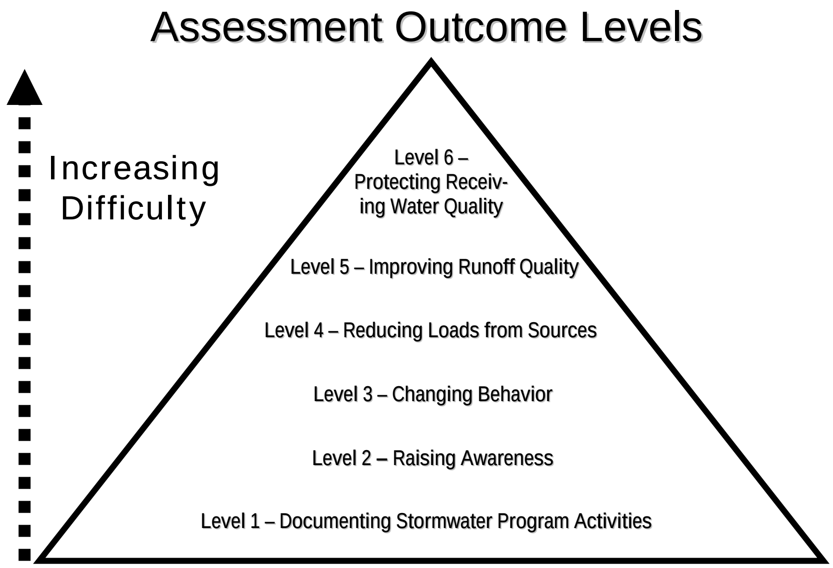

FIGURE 6-1 Pyramid of Assessment Outcome Levels for an MS4. SOURCE: CASQA (2007).

Shift Monitoring Requirements to Measure the Performance of Stormwater Control Measures

The lack of monitoring requirements in the Phase II stormwater program makes it virtually impossible to measure or track actual pollutant load or runoff volume reductions achieved. While the existing Phase I outfall monitoring requirements have improved our understanding of urban stormwater runoff quality, they are also insufficient to link program effort to receiving water quality. It is recommended that both Phase I and II MS4s shift to a more collaborative monitoring effort to link management efforts to receiving water quality, as described below:

- If a review of past Phase 1 MS4s stormwater outfall monitoring indicates no violations of the Municipal Action Limits, then their current outfall monitoring efforts can be replaced by pooled annual financial contributions to a regional stormwater monitoring collaborative or authority to conduct basic research on the performance and longevity of range of SCMs employed in the community.

- If some subwatersheds exceed Municipal Action Levels, outfall monitoring should be continued at these locations, as well as additional source area sampling in the problem subwatershed to define the sources of the stormwater pollutant of concern.

- Phase II MS4s should be encouraged to make incremental financial contributions to a state or regional stormwater monitoring research collaborative to conduct basic research on SCM performance and longevity. Although the committee knows of no examples where this has been accomplished, this pooling of financial resources by multiple MS4s should produce more useful scientific data to support municipal programs than could be produced by individual MS4s alone. Phase II communities that do not participate in the research collaborative would be required to perform their own outfall and/or SCM performance monitoring, at the discretion of the state or federal permitting authority.

- All MS4s should be required to indicate in their annual reports and permit renewal applications how they incorporated research findings into their existing stormwater programs, ordinances, and design manuals.

CONCLUSIONS AND RECOMMENDATIONS

The watershed-based permitting program outlined in the first part of this chapter is ultimately essential if the nation is to be successful in arresting aquatic resource depletion stemming from sources dispersed across the landscape. Smaller-scale changes to the EPA stormwater program are also possible. These include integration of industrial and construction permittees into municipal permits ("integration"), as well as a number of individual changes to the current industrial, construction, and municipal programs.

Improvements to the stormwater permitting program can be made in a tiered manner. Thus, individual recommendations specific to advancing one part of the municipal, industrial, or construction stormwater programs could be implemented immediately and with limited additional funds. "Integration" will need additional funding to provide incentives and to establish partnerships between municipal permittees and their associated industries. Finally, the watershed-based permitting approach will likely take up to ten years to implement. The following conclusions and recommendations about these options are made:

The greatest improvement to the EPA's Stormwater Program would be to convert the current piecemeal system into a watershed-based permitting system. The proposed system would encompass coordinated regulation and management of all discharges (wastewater, stormwater, and other diffuse sources), existing and anticipated from future growth, having the potential to modify the hydrology and water quality of the watershed's receiving waters.

The committee proposes centralizing responsibility and authority for implementation of watershed-based permits with a municipal lead permittee working in partnership with other municipalities in the watershed as co-permittees, with enhanced authority and funding commensurate with increased responsibility. Permitting authorities would adopt a minimum goal in every watershed to avoid any further loss or degradation of designated beneficial uses in the watershed's component waterbodies and additional goals in some cases aimed at recovering lost beneficial uses. The framework envisions the permitting authorities and municipal co-permittees working cooperatively to define careful, complete, and clear specific objectives aimed at meeting goals.

Permittees, with support from the permitting authority, would then move to comprehensive scientific and technically based watershed analysis as a foundation for targeting solutions. The most effective solutions are expected to lie in isolating, to the extent possible, receiving waterbodies from exposure to those impact sources. In particular, low-impact design methods, termed Aquatic Resources Conservation Design in this report, should be employed to the full extent feasible and backed by conventional SCMs when necessary. This report also outlines a monitoring program structured to assess progress toward meeting objectives and the overlying goals, diagnosing reasons for any lack of progress, and determining compliance by dischargers. The new concept further includes market-based trading of credits among dischargers to achieve overall compliance in the most efficient manner and adaptive management to program additional actions if monitoring demonstrates failure to achieve objectives.

Integration of the three permitting types, such that construction and industrial sites come under the jurisdiction of their associated municipalities, would greatly improve many deficient aspects of the stormwater program. Federal and state NPDES permitting authorities do not presently have, and can never reasonably expect to have, sufficient personnel to inspect and enforce stormwater regulations on more than 100,000 discrete point source facilities discharging stormwater. A better structure would be one where the NPDES permitting authority empowers the MS4 permittees to act as the first tier of entities exercising control on stormwater discharges to the MS4 to protect water quality. The National Pretreatment Program, EPA's successful treatment program for municipal and industrial wastewater sources, could serve as a model for integration.

Short of adopting watershed-based permitting or integration, a variety of other smaller-scale changes to the EPA stormwater program could be made now, as outlined below.

EPA should issue guidance for MS4, MSGP, and CGP permittees on what constitutes a design storm for water quality purposes. Precipitation events occur across a spectrum from small, more frequent storms to larger and more extreme storms, with the latter being a more typical focus of guidance manuals to date. Permittees need guidance from regional EPA offices on what water quality considerations to design SCMs for beyond issues such as safety of human life and property. In creating the guidance there should be a good faith effort to integrate water quality requirements with existing stormwater quantity requirements.

EPA should issue guidance for MS4 permittees on methods to identify high-risk industrial facilities for program prioritization such as inspections. Two visual methods for establishing rankings that have been field tested are provided in the chapter. Some of these high-risk industrial facilities and construction sites may be better covered by individual NPDES stormwater permits rather than the MSGP or the CGP, and if so would fall directly under the permitting authority and not be part of MS4 integration.

EPA should support the compilation and collection of quality *industrial* stormwater effluent data and SCM effluent quality data in a national database. This database can then serve as a source for the agency to develop technology-based effluent guidelines for stormwater discharges from industrial sectors and high-risk facilities.

EPA should develop numerical expressions to represent the MS4 standard of Maximum Extent Practicable. This could involve establishing municipal action levels based on expected outfall pollutant concentrations from the National Stormwater Quality Database, developing site-based runoff and pollutant load limits, and setting turbidity limits for construction sites. Such numerical expressions would create improved accountability, bring about consistency, and result in implementation actions that will lead to measurable reductions in stormwater pollutants in MS4 discharges.

Communities should use an urban stream classification system, such as a regionally adapted version of the Impervious Cover Model, to establish realistic water quality and biodiversity goals for individual classes of subwatersheds. The goals for water and habitat quality should become less stringent as impervious cover increases within the subwatershed. This should not become an excuse to work less diligently to improve the most degraded waterways—only to recognize that equivalent, or even greater, efforts to improve water quality conditions will achieve progressively less ambitious results in more highly urbanized watersheds. This approach would provide stormwater managers with more specific, measurable, and attainable implementation strategies than the one-size-fits-all approach that is promoted in current wet weather management regulations.

Better monitoring of MS4s to determine outcomes is needed. Only a small fraction of MS4 communities have provided measurable outcomes with regard to aggregate flow and pollutant reduction achieved by their municipal stormwater programs. A framework and methods to evaluate program effectiveness for each of the six minimum management measures have been outlined by CASQA (2007) and should be adopted. In addition, the lack of monitoring requirements in the Phase II stormwater program makes it virtually impossible to measure or track actual pollutant load or runoff volume reductions achieved. It is recommended that both Phase I and II MS4s shift to a more collaborative monitoring paradigm to link management efforts to receiving water quality.

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Watershed-based permitting will require additional resources and regulatory program support. Such an approach shifts more attention to ambient outcomes as well as expanded permitting coverage. Additional resources for program implementation could come from shifting existing programmatic resources. For example, some state permitting resources may be shifted away from existing point source programs toward stormwater permitting. Strategic planning and prioritization could shift the distribution of federal and state grant and loan programs to encourage and support more watershed-based stormwater permitting programs. However, securing new levels of public funds will likely be required. All levels of government must recognize that additional resources may be required from citizens and businesses (in the form of taxes, fees, etc.) in order to operate a more comprehensive and effective stormwater permitting program.

REFERENCES

April, S., and T. Greiner. 2000. Evaluation of the Massachusetts Environmental Results Program. Washington, DC: National Academy of Public Administration..

Atkins, J. R., C. Hollenkamp, and J. Sauber. 2007. Testing the watershed: North Carolina's NPDES Discharge Coalition Program enables basinwide monitoring and analysis. Water Environment & Technology 19(6).

Bellucci, C. 2007. Stormwater and Aquatic Life: Making the Connection Between Impervious Cover and Aquatic Life Impairments for TMDL Development in Connecticut Streams. Pp. 1003-1018 *In:* TMDL 2007. Alexandria, VA: Water Environment Federation.

Bromberg, K. 2007. Comments to the NRC Committee on Stormwater Discharge Contributions to Water Pollution, January 22, 2007, Washington, DC.

Burton, G. A., and R. E. Pitt. 2002. Stormwater Effects Handbook. Boca Raton, FL: Lewis/CRC Press.

California EPA, State Water Board. 2006. Storm Water Panel Recommendations—The Feasibility of Numeric Effluent Limits Applicable to Discharges of Storm Water Associated with Municipal, Industrial, and Construction Activities. Available at http://www.cacoastkeeper.org/assets/pdf/StormWaterPanelReport_06.pdf.

Campbell, R. M. 2007. Achieving a Successful Storm Water Permit Program in Oregon. Natural Resources & Environment 21(4):39-44.

CASQA (California Stormwater Quality Association). 2007. Municipal Stormwater Program Effectiveness Assessment Guidance. Los Angeles. Available at info.casqa@org.

Chapman, C. 2006. Performance Monitoring of an Urban Stormwater Treatment System. Master's Thesis, University of Washington, Seattle.

City of Austin. 2006. Stormwater Runoff Quality and Quantity from Small Watersheds in Austin, TX. Austin, TX: Watershed Protection Department, Environmental Resources Management Division.

City of San Diego. 2007. Strategic Plan for Watershed Activity Implementation. San Diego, CA: Stormwater Pollution Prevention Division.

Clark, S., R. Pitt, S. Burian, R. Field, E. Fan, J. Heaney, and L. Wright. 2006. The Annotated Bibliography of Urban Wet Weather Flow Literature from 1996 through 2005. *Note: Publisher not shown.*

Clausen, J. C., and J. Spooner. 1993. Paired Watershed Study Design, 841-F-93-009. Washington, DC: EPA Office of Water.

Connecticut Department of Environmental Protection. 2007. A Total Maximum Daily Load Analysis for Eagleville Brook, Mansfield, CT. Hartford: State of Connecticut Department of Environmental Protection. Available at http://www.ct.gov/dep/lib/dep/water/tmdl/tmdl_final/eaglevillefinal.pdf.

Cosgrove, J. F. 2002. TMDLs: A simplified approach to pollutant load determination. WEFTEC 2002 Conference Proceedings September 2002. Alexandria, VA: Water Environment Federation.

Crockett, C. 2007. The regulated perspective of stormwater management. Presentation to the NRC Committee on Stormwater Discharge Contributions to Water Pollution. January 22, 2007. Washington, DC.

Cross, L. M., and L. D. Duke. 2008. Regulating industrial stormwater: state permits, municipal implementation, and a protocol for prioritization. Journal of the American Water Resources Association 44(1):86-106.

Cutter, W. B., K. A. Baerenklau, A. DeWoody, R. Sharma, and J. G. Lee. 2008. Costs and benefits of capturing urban runoff with competitive bidding for decentralized best management practices. Water Resources Research, doi:10.1029/2007WR006343.

DeWoody, A. E. 2007. Determining Net Social Benefits from Optimal Parcel-Level Infiltration of Urban Runoff: A Los Angles Analysis. M.S. Thesis. University of California, Riverside.

Doll, A., and G. Lindsey. 1999. Credits bring economic incentives for onsite stormwater management. Watershed and Wet Weather Technical Bulletin 4(1):12-15.

Duke, L. D. 2007. Industrial stormwater runoff pollution prevention regulations and implementation. Presentation to the National Research Council Committee on Reducing Stormwater Discharge Contributions to Water Pollution, Seattle, WA, August 22, 2007.

Duke, L. D., and C. A. Augustenborg. 2006. Effectiveness of self identified and self-reported environmental regulations for industry: the case of storm water runoff in the U.S. Journal of Environmental Planning and Management 49:385-411.

Duke, L. D., and P. Beswick. 1997. Industry compliance with storm water pollution prevention regulations: the case of transportation industry facilities in California and the Los Angeles region. Journal of the American Water Resources Association 33:825-838.

Ellerman, A. D., P. L. Joskow, R. Schmalensee, J. P. Montero, and E. M. Bailey. 2000. Markets for Clean Air: the U.S. Acid Rain Program. New York: Cambridge University Press.

EPA (U. S. Environmental Protection Agency). 1991. Technical Support Document for Water Quality-Based Toxics Control. EPA-505/2-90-001. Washington, DC: EPA Office of Water Enforcement and Permits.

EPA. 1999. Introduction to the National Pretreatment Program. EPA-833-B-98-002. Washington, DC: EPA Office of Wastewater Management.

EPA. 2002. Establishing total maximum daily load (TMDL) Wasteload allocations (WLAs) for storm water sources and NPDES permit requirements based on those WLAs. Memorandum from Robert Wayland, Director, Office of Wetlands, Oceans, and Watersheds to Jim Hanlon, Director, Office of Water, November 22, 2002. Available at www.epa.gov/npdes/pubs/final-wwtmdl.pdf.

EPA. 2003a. Watershed-Based NPDES Permitting Policy Statement. In Watershed-Based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation Guidance. EPA, Washington, DC.

EPA. 2003b. Watershed-Based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation Guidance. EPA, Washington, DC.

EPA. 2007a. Watershed-Based NPDES Permitting Technical Guidance (draft). EPA, Washington, DC.

EPA. 2007b. Water Quality Trading Toolkit for Permit Writers. EPA 833-R-07-004. Washington, DC: EPA Office of Wastewater Management, Water Permits Division.

EPA. 2007c. Understanding Impaired Waters and Total Maximum Daily Load (TMDL Requirements for Municipal Stormwater Programs. EPA 883-F-07-009. Philadelphia, PA: EPA Region 3.

Freedman, P., L. Shabman, and K. Reckhow. 2008. Don't Debate; Adaptive implementation can help water quality professionals achieve TMDL goals. WE&T Magazine August 2008:66-71.

Frie, S., L. Curtis, and S. Martin. 1996. Financing regional stormwater facilities. *In:* Managing Virginia's Watersheds in the 21st Century: Workable Solutions. Proceedings from the 9th Annual Virginia Water Conference, Staunton.

Grumbles, B. 2006. Qualifying Local Programs for Construction Site Storm Water Runoff. Memorandum from EPA Assistant Administrator Ben Grumbles to James Mac Indoe, Alabama Dept. of Environmental Management. May 8.

Hetling, L .J., A Stoddard, and T. N. Brosnan. 2003. Effect of water quality management efforts on wastewater loadings during the past century. Water Environment Research 75(1):30.

Hirschman, D., K. Collins, and T. Schueler. 2008. Draft Virginia Stormwater Management Nutrient Design System. Prepared for Technical Advisory Committee and Virginia Department of Conservation and Recreation. Ellicott City, MD: Center for Watershed Protection.

Holling, C. S., ed. 1978. Adaptive Environmental Assessment and Management. Caldwell, NJ: Blackburn Press.

Holling, C. S., and A. D. Chambers. 1973. Resource science: The nurture of an infant. BioScience 23:13-20.

Horner, R. R., and C. Chapman. 2007. NW 110th Street Natural Drainage System Performance Monitoring, with Summary of Viewlands and 2nd Avenue NW SEA Streets Monitoring. Report to Seattle Public Utilities by Department of Civil and Environmental Engineering, University of Washington, Seattle.

Horner, R. R., H. Lim, and S. J. Burges. 2002. Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects, Water Resources Series Technical Report No. 170. Department of Civil and Environmental Engineering, University of Washington, Seattle.

Horner, R. R., H. Lim, and S. J. Burges. 2004. Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects: Summary of the 2000-2003 Water Years. Water Resources Series Technical Report 181. Department of Civil and Environmental Engineering, University of Washington, Seattle.

Horner, R., C. May, E. Livingston, D. Blaha, M. Scoggins, J. Tims, and J. Maxted. 2001. Structural and non-structural BMPs for protecting streams. Pp. 60-77 *In:* Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation. Proceedings Engineering Research Foundation Conference. American Society of Civil Engineers.

Horner, R., J. Guedry, and M. Kortenhof. 1990. Improving the Cost-Effectiveness of Highway Construction Site Erosion and Sediment Control. Washington State Department of Transportation. Seattle, WA: Department of Civil Engineering, University of Washington.

Keller, B. 2003. Buddy can you spare a dime? What is stormwater funding. Stormwater 4:7.

LaFlamme, P. 2007. Presentation to the Committee on Stormwater Discharge Contributions to Water Pollution, January 22, 2007, Washington, DC.

Lee, H., X. Swamikannu, D. Radulescu, S. Kim, and M. K. Stenstrom. 2007. Design of stormwater monitoring programs. Journal of Water Research, doi:10.1016/j.watres.2007.05.016.

Longsworth, J. 2007. Comments to the NRC Committee on Stormwater Discharge Contributions to Water Pollution. January 22, 2007, Washington, DC.

Los Angeles County Department of Public Works. 2001. Los Angeles County 1994-2000 Integrated Receiving Water Impacts Report. Available at http://ladpw.org/wmd/NPDES/IntTC.cfm.

Maimone, M. 2002. Prioritization of contaminant sources for the Schuylkill River source water assessment. Presentation at the Watershed 2002 Specialty Conference, Ft. Lauderdale, FL, February 23-27.

NRC (National Research Council). 1990. Monitoring Southern California's Coastal Waters. Washington, DC: National Academy Press.

NRC. 1999. New Strategies for America's Watersheds. Washington, DC: National Academy Press.

NRC. 2001a. Assessing the TMDL Approach to Water Quality Management. Washington, DC: National Academy Press.

NRC. 2001b. Compensating for Wetland Losses Under the Clean Water Act. Washington, DC: National Academy Press.

Natural Resources Conservation Service. 2007. Part 630 Hydrology, National Engineering Handbook, Chapter 7, Hydrologic Soil Groups. Washington, DC: U.S. Department of Agriculture.

Nirel, P. M., and R. Revaclier. 1999. Assessment of sewage treatment plant effluents impact on river water quality using dissolved Rb:Sr ratio. Environmental Science and Technology 33(12):1996.

North Carolina Division of Water Quality. 1999. Neuse River Basin Model Stormwater Program for Nitrogen Control. Available at http://h2o.enr.state.nc.us/su/Neuse_SWProgram_Documents.htm. Last accessed November 2007.

Office of Inspector General. 2007. Development Growth Outpacing Progress in Watershed Efforts to Restore the Chesapeake Bay. Report 2007-P-000031. Washington, DC: U.S. Environmental Protection Agency.

Parikh, P., M. A. Taylor, T. Hoagland, H. Thurston, and W. Shuster. 2005. Application of market mechanism and incentives to reduce stormwater runoff: an integrated hydrologic, economic, and legal approach. Environmental Science and Policy 8:133-144.

Pitt, R., A, Maestre, and R. Morquecho. 2004. National Stormwater Quality Database. Version 1.1. Available at http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html. Last accessed January 28, 2008.

Schiff, K., D. Ackerman, E. Strecker, and M. Leisenring. 2007. Concept development: design storm for water quality in the Los Angeles region. Southern California Coastal Water Research Project. Costa Mesa.

Schueler, T. 2008b. Technical Support for the Baywide Runoff Reduction Method. Baltimore, MD: Chesapeake Stormwater Network. Available at www.chesapeakestormwater.net.

Schueler, T. 2004. An Integrated Framework to Restore Small Urban Watersheds. Manual 1. Urban Subwatershed Restoration Manual Series. Ellicott City, MD: Center for Watershed Protection.

Schueler, T. 2008a. Final Bay-wide Stormwater Action Strategy: Recommendations for Moving Forward in the Chesapeake Bay. Baltimore, MD: Chesapeake Stormwater Network.

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban

Stormwater Retrofit Practices. Ellicott City, MD: Center for Watershed Protection.

Shabman, L., and K. Stephenson. 2007. Achieving nutrient water quality goals: bringing market-like principles to water quality management. Journal of American Water Resources Association 43(4):1076-1089.

Shabman, L., and P. Scodari. 2004. Past, Present, and Future of Wetland Credit Sales. Discussion Paper 04-48. Washington, DC: Resources for the Future.

Shabman, L., K. Reckhow, M. B. Beck, J. Benaman, S. Chapra, P. Freedman, M. Nellor, J. Rudek, D. Schwer, T. Stiles, and C. Stow. 2007. Adaptive Implementation of water quality improvement plans: opportunities and challenges. Durham, NC: Duke University.

Shabman, L., K. Stephenson, and W. Shobe. 2002. Trading programs for environmental management: reflections on the air and water experiences. Environmental Practice 4:153-162.

Shaver, E., R. Horner, J. Skupien, C. May, and G. Ridley. 2007. Fundamentals of Urban Runoff Management: Technical and Institutional Issue, 2nd Ed. Madison, WI: North American Lake Management Society.

Smith, B. 2007. Comments to the NRC Committee on Stormwater Discharge Contributions to Water Pollution. January 22, 2007, Washington, DC.

Stenstrom, M. K., and H. Lee. 2005. Final Report. Industrial Stormwater Monitoring Program. Existing Statewide Permit Utility and Proposed Modifications.

Stephenson, K., and L. Shabman. 2005. The use and opportunity of cooperative organizational forms as an innovative regulatory tool under the Clean Water Act. Paper presented at the Southern Agricultural Economics Association Annual Meetings Little Rock, AK, February 5-9, 2005.

Stephenson, K., L. Shabman, and J. Boyd. 2005. Taxonomy of trading programs: Concepts and applications to TMDLs. Pp. 253-285 *In:* Total Maximum Daily Loads: Approaches and Challenges. Tamim Younos (ed.). Tulsa, OK: Pennwell Press.

Stephenson, K., L. Shabman, and L. Geyer. 1999. Watershed-based effluent allowance trading: Identifying the statutory and regulatory barriers to implementation. Environmental Lawyer 5(3):775-815.

Stephenson, K., P. Norris, and L. Shabman. 1998. Watershed-based effluent trading: the nonpoint source challenge. Contemporary Economic Policy 16:412-421.

Thurston, H. W., H. C. Goddard, D. Szlag, and B. Lemberg. 2003. Controlling storm-water runoff with tradable allowances for impervious surfaces. Journal of Water Resources Planning and Management 129(5):409-418.

Vermont Department of Environmental Conservation. 2006. Total Maximum Daily Load to Address Biological Impairment Potash Brook (VT05-11). Chittenden County, Vermont.

Virginia DCR (Virginia Department of Conservation and Recreation). 2007. Virginia Stormwater Management Program Permit Regulations, Chapter 60.

Wagner, W.E. 2006. Stormy regulations: The problems that result when storm water (and other) regulatory programs neglect to account for limitations in scientific and technical programs. Chapman Law Review 9(2):191-232.

Wenger, S., T. Carter, R. Vick, and L. Fowler. 2008. Runoff limits: an ecologically based stormwater management program. Stormwater April/May. Available at http://www.stormh2o.com/march-april-2008/ecologically-stormwater-management.aspx.

Woodward, R. T., R. A. Kaiser, and A. B. Wicks. 2002. The structure and practice of water quality trading markets. Journal of the American Water Resources Association 38:967-979.

Zeng, X., and T. C. Rasmussen. 2005. Multivariate statistical characterization of water quality in Lake Lanier, Georgia, USA. Journal of Environmental Quality 34(6):1980-1991.

Appendixes

Appendix A
Acronyms

BAC	best attainable conditions
BAT	best available technology
BCG	Biological Condition Gradient
BCT	best control technology
BOD	biochemical oxygen demand
CAFO	concentrated animal feeding operation
CBWM	Chesapeake Bay Watershed Model
CCI	Census of Construction Industries
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CGP	Construction General Permit
CN	Curve Number
COD	chemical oxygen demand
COV	coefficient of variability
CWA	Clean Water Act
DHSVM	Distributed Hydrology, Soil, and Vegetation Model
EIA	effective impervious area
EMC	event mean concentration
ERP	Enforcement Response Plan
ETV	Environmental Technology Verification Program
EWH	exceptional warmwater habitat
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GIS	Geographic Information System
GWLF	General Watershed Loading Function
HRU	Hydrologic Response Unit
HSPF	Hydrologic Simulation Program–Fortran
HUC	hydrologic unit code
ICM	Impervious Cover Model
KCRTS	King County Runoff Time Series
LDC	least disturbed conditions
LEED	Leadership in Energy and Environmental Design
LID	low-impact development
MDC	minimally disturbed conditions
MEP	maximum extent practicable
MGD	million gallons per day
MSGP	multi-sector industrial stormwater general permit
MTBE	methyl tert-butyl ether
NCSI	Normalized Channel Stabilization Index
NOI	Notice of Intent

NPDES	National Pollutant Discharge Elimination System
NRDC	Natural Resources Defense Council
NRI	National Resource Inventory
NSQD	National Stormwater Quality Database
NTU	Nephelometric Turbidity Unit
NURP	National Urban Runoff Program
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyl
POTW	publicly owned treatment works
PUD	planned unit development
RCRA	Resource Conservation and Recovery Act
RPA	Reasonable Potential Analysis
SBUH	Santa Barbara Unit Hydrograph
SCCWRP	Southern California Coastal Water Research Project Authority
SCM	stormwater control measure
SIC	Standard Industrial Classification
SLAMM	Source Loading and Management Model
SMDR	Soil Moisture Distributed and Routing
SWAT	Soil and Water Assessment Tool
SWMM	Stormwater Management Model
SWPPP	stormwater pollution prevention plan
TALU	tiered aquatic life use
TARP	Technology Acceptance and Reciprocity Partnership
TIA	total impervious area
TKN	total Kjedahl nitrogen
TMDL	total maximum daily load
TND	traditional neighborhood development
TOD	transit-oriented development
TSCA	Toxic Substances Control Act
TSS	total suspended solids
UAA	Use Attainability Analysis
UDC	unified development code
ULARA	Upper Los Angeles River Area
USLE	Universal Soil Loss Equation
WERF	Water Environment Research Foundation
WQA	Water Quality Act
WQS	water quality standard
WWH	warmwater habitat
WWHM	Western Washington Hydrologic Model
WWTP	wastewater treatment plant

Appendix B
Glossary

Antidegradation: Policies which ensure protection of water quality from a particular waterbody where the water quality exceeds levels necessary to protect fish and wildlife propagation and recreation on and in the water. This also includes special protection of waters designated as outstanding natural resource waters. Antidegradation plans are adopted by each state to minimize adverse effects on water.

Best Management Practice (BMP): Physical, structural, and/or managerial practices that, when used singly or in combination, reduce the downstream quality and quantity impacts of stormwater. The term is synonymous with Stormwater Control Measure (SCM).

Biofiltration: The simultaneous process of filtration, infiltration, adsorption, and biological uptake of pollutants in stormwater that takes place when runoff flows over and through vegetated areas.

Bioinfiltration: A particular SCM that is like bioretention but has more infiltration, and thus would be categorized as an infiltration process.

Bioretention: A stormwater management practice that utilizes shallow storage, landscaping, and soils to control and treat urban stormwater runoff by collecting it in shallow depressions before filtering through a fabricated planting soil media. This SCM is often categorized under "filtration" although it has additional functions.

Buffer: The zone contiguous with a sensitive area that is required for the continued maintenance, function, and structural stability of the sensitive area. The critical functions of a riparian buffer (those associated with an aquatic system) include shading, input of organic debris and coarse sediments, uptake of nutrients, stabilization of banks, interception of fine sediments, overflow during high-water events, protection from disturbance by humans and domestic animals, maintenance of wildlife habitat, and room for variation of aquatic system boundaries over time due to hydrologic or climatic effects. The critical functions of terrestrial buffers include protection of slope stability, attenuation of surface water flows from stormwater runoff and precipitation, and erosion control.

> **Stream buffers** are zones of variable width that are located along both sides of a stream and are designed to provide a protective natural area along a stream corridor.

Combined Sewer Overflow (CSO): A discharge of untreated wastewater from a combined sewer system at a point prior to the headworks of a publicly owned treatment works. CSOs generally occur during wet weather (rainfall or snowmelt). During periods of wet weather, these systems become overloaded, bypass treatment works, and discharge directly to receiving waters.

Combined Sewer System: A wastewater collection system that conveys sanitary wastewaters (domestic, commercial, and industrial wastewaters) and stormwater through a single pipe to a publicly owned treatment works for treatment prior to discharge to surface waters.

Constructed Wetland: A wetland that is created on a site that previously was not a wetland. This wetland is designed specifically to remove pollutants from stormwater runoff.

Created Wetland: A wetland that is created on a site that previously was not a wetland. This wetland is created to replace wetlands that were unavoidably destroyed during design and construction of a project. This wetland cannot be used for treatment of stormwater runoff.

Detention: The temporary storage of stormwater runoff in an SCM with the goals of controlling peak discharge rates and providing gravity settling of pollutants.

Detention Facility/Structure: An above- or below-ground facility, such as a pond or tank, that temporarily stores stormwater runoff and subsequently releases it at a slower rate than it is collected by the drainage facility system. There is little or no infiltration of stored stormwater, and the facility is designed to not create a permanent pool of water.

Drainage: Refers to the collection, conveyance, containment, and/or discharge of surface and stormwater runoff.

Drainage Area: That area contributing runoff to a single point measured in a horizontal plane, which is enclosed by a ridge line.

Drainage Basin: A geographic and hydrologic subunit of a watershed.

Dry Pond: A facility that provides stormwater quantity control by containing excess runoff in a detention basin, then releasing the runoff at allowable levels. Synonymous with detention basin, it is intended to be dry between storms.

Effluent Limitation: Any restriction imposed by the EPA director on quantities, discharge rates, and concentrations of pollutants that are discharged from point sources into waters of the United States, the waters of the contiguous zone, or the ocean.

Effluent Limitation Guidelines: A regulation published by the EPA Administrator under Section 304(b) of the Clean Water Act that establishes national technology-based effluent requirements for a specific industrial category.

Exfiltration: The downward movement of water through the soil; the downward flow of runoff from the bottom of an infiltration SCM into the soil.

Extended Detention: A stormwater design feature that provides for the gradual release of a volume of water in order to increase settling of pollutants and protect downstream channels from frequent storm events. When combined with a pond, the settling time is increased by 24 hours.

Filter Strip: A strip of permanent vegetation above ponds, diversions, and other structures to retard the flow of runoff, causing deposition of transported material and thereby reducing sedimentation. As an SCM, it refers to riparian buffers, which run adjacent to waterbodies and intercept overland flow and shallow subsurface flow (both of which are usually sheet flow rather than a distinct influent pipe). The term is borrowed from the agricultural world.

Flood Frequency: The frequency with which the flood of interest may be expected to occur at a site in any average interval of years. Frequency analysis defines the n-year flood as being the flood that will, over a long period, be equaled or exceeded on the average once every n years.

Frequency of Storm (Design Storm Frequency): The anticipated period in years that will elapse, based on average probability of storms in the design region, before a storm of a given intensity and/or total volume will recur; thus, a 10-year storm can be expected to occur on the average once every 10 years. Sewers designed to handle flows which occur under such storm conditions would be expected to be surcharged by any storms of greater amount or intensity.

General Permit: A single permit issued to a large number of dischargers of pollutants in stormwater. General permits are issued by the permitting authority, and interested parties then submit a Notice of Intent (NOI) to be covered. The permit must identify the area of coverage, the sources covered, and the process for obtaining coverage. Once the permit is issued, a permittee may submit an NOI and receive coverage within a very short time frame.

Grab Sample: A sample which is taken from a stream on a one-time basis without consideration of the flow rate of the stream and without consideration of time.

Hotspot: An area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

Hydrograph: A graph of runoff rate, inflow rate, or discharge rate, past a specific point as a function of time.

Hydroperiod: A seasonal occurrence of flooding and/or soil saturation; it encompasses depth, frequency, duration, and seasonal pattern of inundation.

Hyetograph: A graph of measured precipitation depth (or intensity) at a precipitation gauge as a function of time.

Impervious Surface or Impervious Cover: A hard surface area which either prevents or retards the entry of water into the soil. Common impervious surfaces include roof tops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled surfaces.

Infiltration: The downward movement of water from the surface to the subsoil.

Infiltration Facility: A drainage facility designed to use the hydrologic process of runoff soaking into the ground, commonly referred to as percolation, to dispose of stormwater.

Infiltration Pond: A facility that provides stormwater quantity control by containing excess runoff in a detention facility, then percolating that runoff into the surrounding soil.

Level Spreader: A temporary SCM used to spread stormwater runoff uniformly over the ground surface as sheet flow. The purpose of level spreaders is to prevent concentrated, erosive flows from occurring. Levels spreaders will commonly be used at the upstream end of wider biofilters to ensure sheet flow into the biofilter.

Municipal Separate Storm Sewer System: A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) owned by a state, city, town, or other public body that is designed or used for collecting or conveying stormwater, which is not a combined sewer and which is not part of a publicly owned treatment works.

National Pollutant Discharge Elimination System: A provision of the Clean Water Act that prohibits the discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or, where delegated, a tribal government on an Indian reservation. The permit applies to point sources of pollutants to ensure that their pollutant discharges do not exceed specified effluent standards. The effluent standards in most permits are based on the best available pollution technology or the equivalent.

Nonpoint Source: Diffuse pollution source, but with a regulatory connotation; a source without a single point of origin or not introduced into a receiving stream from a specific outlet. The pollutants are generally carried off the land by stormwater. Some common nonpoint sources are agriculture, forestry, mining, dams, channels, land disposal, and saltwater intrusion.

Nonstructural SCM: Stormwater control measure that uses natural measures to reduce pollution levels, does not require extensive construction efforts, and/or promotes pollutant reduction by eliminating the pollutant source.

Peak Discharge Rate: The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

Point Source: Any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fixture, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged.

Pollutant: A contaminant in a concentration or amount that adversely alters the physical, chemical, or biological properties of the natural environment. Dredged soil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended), heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water (EPA, 2008).

Polutograph: A graph of pollutant loading rate (mass per unit time) as a function of time.

Predevelopment Conditions: Those conditions that existed at a site just prior to the development in question, which are not necessarily pristine conditions.

Pretreatment: The removal of material such as gross solids, grot, grease, and scum from flows prior to physical, biological, and chemical treatment processes to improve treatability. The reduction of the amount of pollutants, the elimination of pollutants, or the alteration of the nature of pollutant properties in wastewater prior to or in lieu of discharging or otherwise introducing such pollutants into a publicly owned treatment works [40 C.F.R. § 403.3(q)]. Pretreatment may include screening, grit removal, stormwater, and oil separators. With respect to stormwater, it refers to techniques employed in stormwater SCMs to help trap coarse materials and other pollutants before they enter the SCM.

Recharge: The flow of groundwater from the infiltration of stormwater runoff.

Recharge Volume: The portion of the water quality volume used to maintain groundwater recharge rates at development sites.

Retention: The process of collecting and holding stormwater runoff with no surface outflow. Also, the amount of precipitation on a drainage area that does not escape as runoff. It is the difference between total precipitation and total runoff.

Retention/Detention Facility: A type of drainage facility designed either to hold water for a considerable length of time and then release it by evaporation, plant transpiration, and/or infiltration into the ground, or to hold stormwater runoff for a short period of time and then release it to the stormwater management system.

Runoff: The term is often used in two senses. For a given precipitation event, direct *storm runoff* refers to the rainfall (minus losses) that is shed by the landscape to a receiving waterbody. In an area of 100 percent imperviousness, the runoff equals the rainfall. Over greater time and space scales, *surface water runoff* refers to streamflow passing through the outlet of a watershed, including base flow from groundwater that has entered the stream channel.

Soil Stabilization: The use of measures such as rock lining, vegetation, or other engineering structure to prevent the movement of soil when loads are applied to the soil.

Source Control: A type of SCM that is intended to prevent pollutants from entering stormwater. A few examples of source control are erosion control practices, maintenance of stormwater facilities, constructing roofs over storage and working areas, and directing wash water and similar discharges to the sanitary sewer or a dead end sump.

Stormwater: That portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, channels, or pipes into a defined surface water channel or a constructed infiltration facility. According to 40 C.F.R. § 122.26(b)(13), this includes stormwater runoff, snow melt runoff, and surface runoff and drainage.

Stormwater Control Measure (SCM): Physical, structural, and/or managerial measures that, when used singly or in combination, reduce the downstream quality and quantity impacts of stormwater. Also, a permit condition used in place of or in conjunction with effluent limitations to prevent or control the discharge of pollutants. This may include a schedule of activities, prohibition of practices, maintenance procedures, or other management practices. SCMs may include, but are not limited to, treatment requirements; operating procedures; practices to control plant site runoff, spillage, leaks, sludge, or waste disposal; or drainage from raw material storage.

Stormwater Drainage System: Constructed and natural features which function together as a system to collect, convey, channel, hold, inhibit, retain, detain, infiltrate, divert, treat, or filter stormwater.

Stormwater Facility: A constructed component of a stormwater drainage system, designed or constructed to perform a particular function or multiple functions. Stormwater facilities include, but are not limited to, pipes, swales, ditches, culverts, street gutters, detention basins, retention basins, constructed wetlands, infiltration devices, catch basins, oil/water separators, sediment basins, and modular pavement.

Structural SCMs: Devices which are constructed to provide temporary storage and treatment of stormwater runoff.

Swale: A shallow drainage conveyance with relatively gentle side slopes, generally with flow depths of less than one foot.

> **Biofilter (**same as a **Biofiltration Swale):** A sloped, vegetated channel or ditch that provides both conveyance and water quality treatment to stormwater runoff. It does not provide stormwater quantity control but can convey runoff to SCMs designed for that purpose.
>
> **Dry Swale**: An open drainage channel explicitly designed to detain and promote the filtration of stormwater runoff through an underlying fabricated soil media. It has an underdrain.
>
> **Wet Swale:** An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment.

Technology-Based Effluent Limit: A permit limit for a pollutant that is based on the capability of a treatment method to reduce the pollutant to a certain concentration.

Time of Concentration: The time period necessary for surface runoff to reach the outlet of a subbasin from the hydraulically most remote point in the tributary drainage area.

Total Maximum Daily Load (TMDL): The amount, or load, of a specific pollutant that a waterbody can assimilate and still meet the water quality standard for its designated use. For impaired waters the TMDL reduces the overall load by allocating the load among current pollutant loads (from point and nonpoint sources), background or natural loads, a margin of safety, and sometimes an allocation for future growth.

Volumetric Runoff Coefficient (R_v): The value that is applied to a given rainfall volume to yield a corresponding runoff volume based on the percent impervious cover in a drainage basin.

Water Quality-Based Effluent Limit (WQBEL): A value determined by selecting the most stringent of the effluent limits calculated using all applicable water quality criteria (e.g., aquatic life, human health, and wildlife) for a specific point source to a specific receiving water for a given pollutant.

Water Quality SCM: An SCM specifically designed for pollutant removal.

Water Quantity SCM: An SCM specifically designed to reduce the peak rate of stormwater runoff.

Water Quality Volume (W_{qv}): The volume needed to capture and treat 90 percent of the average annual stormwater runoff volume equal to 1 inch times the volumetric runoff coefficient (R_v) times the site area.

Wetlands: Those areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. This includes wetlands created, restored, or enhanced as part of a mitigation procedure. This does not include constructed wetlands or the following surface waters of the state intentionally constructed from sites that are not wetlands: irrigation and drainage ditches, grass-lined swales, canals, agricultural detention facilities, farm ponds, and landscape amenities.

Wet Pond: A facility that treats stormwater for water quality by utilizing a permanent pool of water to remove conventional pollutants from runoff through sedimentation, biological uptake, and plant filtration. Synonymous with a retention basin.

SOURCES: Most of the definitions are from EPA (2003), “BMP Design Considerations,” 600/R-03/103, or EPA (2008), “Handbook for Developing Watershed Plans to Restore and Protect Our Waters,” EPA 841-B-08-002.

Appendix C
Summary of Responses from State Stormwater Coordinators

On February 21, 2007, on behalf of the committee, Jenny Molloy of EPA's Office of Wastewater Management sent the following questions to a group of state stormwater program managers and received six responses (found in Tables C-1 and C-2).

1. For industrial and/or construction: do you have information on non-filers, i.e., folks who should have submitted NOIs, but did not? If so, how old are these data, and how do they compare to overall numbers of those with permit coverage? How did you find and/or estimate the number of non-filers?

2. Also for industrial and/or construction: do you have information on compliance rates? Yes, this is a really broad question, but something along the lines of: based on inspections (or monitoring data, or whatever metric you use), have you made any determinations on numbers of facilities out of compliance, or alternatively, in compliance? If so, define what you mean by compliance (paper violations, SWPPP/BMP inadequacies, water quality standards violations, etc.).

TABLE C-1 Nonfilers

State	Information on Industrial Non-Filers	Estimate Percent Non-Filers as of Total	Basis of Estimate	Period of Estimate	Comment
CA	Yes	50 percent of heavy industry statewide 69 percent Of industry within City of Los Angeles	Study—CA Water Board, 1999; Duke and Shaver, 1999. Study—Swamikannu et al., 2001	1995–1998 1998–2000	
MN	No				Study in progress
OH	No				Plan outreach to business
OR	No				Do not compile data
VT	Yes	88–90 percent of industry	Mass mailing	2006	No response from 2,400 of 3,000 mailings
WI	No				

TABLE C-2 Compliance

State	Information on Compliance Rates	Estimate of Covered Facilities Non-Compliant	Basis of Estimate	Period of Estimate	Comment
CA	Yes (Construction)	40 percent deficient in paperwork; 30 percent with inadequate E&S controls	MS4 construction audit in Los Angeles and Ventura counties, and large CGP construction sites	2002, 2004, and 2005	Prioritized large CGP sites for inspection
	Yes (Industrial)	60 percent poor housekeeping practices; 40 percent incomplete SWPPPs	Transportation sector, plastics manufacturing inspections in Los Angeles County	2005 and 2007	
NH	No				Inspect in response to complaints
OH	No				Inspect construction sites as a priority
OR	No				Do not compile data
VT	No				Plan to inspect for compliance
WV	Yes (Industrial)	66 percent failed to submit report	Monitoring report submittal tracking	2007	Mailed deficiency notices
WI	Yes (Construction)	38 percent with minor and 43 percent with major violations	A subsample of 1 percent of CGP sites	2007	Perform inspections annually; no central database tracking

In September 2007, the NRC Committee on Reducing Stormwater Discharge Contributions to Water Pollution sent the following survey to 50 state stormwater program managers. Responses were received from 18 states, including at least one from every EPA region. The blank survey is shown below, and Tables C-3 through C-9 contain the states' responses.

The NRC committee members will greatly appreciate receiving the following information from State Stormwater Coordinators. Please complete both sides of this form and return to Xavier Swamikannu, CalEPA, Los Angeles Regional Water Board, xswamikannu@waterboards.ca.gov or Fax: (213) 576-6625.

State:
Name of information provider:

Please summarize your State's Stormwater Permit Program

	Municipal Permit	Industrial General Permit	Construction General Permit
What are the monitoring requirements?			
How is compliance demonstrated (monitoring or other activity)?			
To whom is the SWPPP submitted?			
Can an MS4 perform an inspection of an industry within its boundary?			
What industries are considered "high-risk"?			
Do BMP manuals exist for implementation guidance?			
No. of dedicated staff or FTEs			

Does your State Storm Water BMP Manual contain the following, and what are they?

WQ sizing criteria	
Recharge criteria	
Channel protection criteria	
Overbank flood criteria	
Extreme flows	
Acceptable BMP list	
Detailed engineering specs for BMPs	
Soil and erosion control requirements (unless this is left to the local government)	

TABLE C-3 Monitoring Requirements

State	Municipal	Industrial	Construction
Alabama	Monitoring requirements are specific to the Phase I MS4. MS4 Phase II permit does not require monitoring.	Monitoring is specific to the General Permit type and associated discharge. Alabama has 18 NPDES Industrial Stormwater General Permits. http://www.adem.state.al.us/genpermits.htm	Monitoring is required under specific conditions, but in general compliance with the permit does not require monitoring. ADEM Admin. Code Chapter 335-6-12 is attached.
California	Monitoring requirements are specific to the Phase 1 MS4 permits. MS4 Phase II permit monitoring is discretionary.	2 wet weather sampling events per year – 4 basic parameters and other pollutants known to be on site. Quarterly visual monitoring.	Visual monitoring before, during, and after rain events. Analytical monitoring for discharges to sediment-impaired waterbodies.
Connecticut	Sample six outfalls once a year. Twelve chemical parameters.	Sample all outfalls once a year. Ten chemical parameters plus aquatic toxicity.	None, yet. Soon to modify permit to sample for turbidity.
Georgia	Dry weather outfall screening.	Standard monitoring from the EPA MSGP. Additional monitoring for the pollutant of concern for industries that may be causing or contributing to stream impairment.	Monitoring is required for a qualifying rain event (0.5 inch) once after clearing and grubbing, and once after mass grading.
Hawaii	Visual and water chemistry sampling.	Visual and water chemistry sampling.	Visual
Maine	None	No benchmark monitoring, only effluent limitations. Additional monitoring upon request based on discharges, complaints, audits, or inspections	None
Minnesota	The Phase I MS4 permits for Minneapolis and St. Paul require monitoring. MS4 Phase II permit does not require monitoring.	The current state MSGP does not have monitoring requirements. The proposed next term draft permit would require at least 4 stormwater monitoring events per year.	The current state CGP does not require monitoring. The proposed next term draft permit is not expected to include monitoring.

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TABLE C-3 Continued

State	Municipal	Industrial	Construction
Nebraska	Stormwater monitoring required on different use sites. BMP monitoring.	None. Monitoring can be required by the director through permit.	None. Monitoring can be required by the director through permit.
Nevada	Required for storm events that produce runoff.	None	None
New York	Ad hoc	Similar to monitoring in the EPA MSGP.	None. Self-inspection.
Ohio	Phase I MS4 permits require some chemical and biological monitoring. Phase II MS4 permit does not require mandatory monitoring, although recommended as part of IDDE program.	Similar to monitoring in the EPA MSGP, except annually. No priority chemical monitoring required.	For the state CGP, no chemical monitoring. For special watershed CGPs associated with TMDLs, TSS monitoring required.
Oklahoma	Phase 1 MS4s permits require dry weather monitoring, floatables monitoring, and watershed characterization monitoring, including biological assessments.	Quarterly visual monitoring and annual analytical monitoring.	None
Oregon	Monitoring requirements are specific to the Phase I MS4. The Phase II MS4 permit does not require monitoring, though some permittees do monitor on their own accord. The average frequency is 2-4 times a year.	Industrial facilities required to sample their stormwater discharge 4 times per year. Also required to conduct visual monitoring of their discharge on a monthly basis when discharge is present. Mining sites in addition are subject to the same requirements as in the state CGP since sediment is the main pollutant of concern.	None. However, permittees discharging stormwater to waters listed specifically for turbidity/sedimentation on the most recent 303(d) list or that have a TMDL for turbidity/sedimentation have the option of either monitoring for turbidity or implementing additional BMPs.

State	Municipal	Industrial	Construction
Vermont	None other than the development of an IDDE program and follow-up until elimination occurs	Benchmark monitoring for individual sectors, quarterly for the first year. Visual inspection 4 times per year. Effluent limitations (if applicable) once per year.	None at present. Turbidity monitoring for moderate-risk projects included in draft CGP.
Virginia	Monitoring requirements are specific to the Phase I MS4 permit. The Phase II MS4 permit does not require monitoring.	Benchmark and effluent limitation (the same as EPA's 2000 MSGP), except we only require one sample per year for benchmark samples.	None
Washington	Monitoring requirements are specific to the Phase I MS4, *Outfall conveyance system monitoring*. Selected outfalls for representative land uses are monitored intensively for a wide range of chemical constituents including toxicity. *BMP effectiveness monitoring*. Selected stormwater BMPs are monitored to determine performance and how effective the designs are. The Phase II MS4 permit does not require monitoring, except as required under the IDDE program or for a TMDL.	Industry required to sample for turbidity, pH, zinc, and petroleum oil and grease. If exceeds zinc benchmark, then also need to monitor for total copper, total lead, and hardness. There are additional monitoring requirements for different industry categories. For discharges to impaired 303(d) waters monitor required for the pollutants for which the waterbody is impaired.	All state CGP sites are required to do weekly monitoring for turbidity and pH. If benchmark exceeded, specific actions/responses are triggered. For sites which discharge to waters impaired by phosphorous, turbidity, fine sediments, or high pH, monitoring required for these parameters additionally.
West Virginia	NA	Benchmark monitoring. Sector specific.	None
Wyoming	None	Benchmark monitoring for timber, metal mining, concrete and gypsum, junkyards and recycling. Effluent limitation monitoring for coal piles, concrete manufacture, and asphalt emulsion.	None

NOTE: NA, not answered

TABLE C-4 How is Compliance Demonstrated?

State	Municipal	Industrial	Construction
Alabama	MS4 Phase I – monitoring and BMPs MS4 Phase II – BMPs	Monitoring reporting and BMP implementation	Inspections. Monitoring; SWPPP implementation during inspection; aerial reconnaissance
California	Annual and monitoring reporting. MS4 audits and inspections.	Annual and monitoring reporting. Inspections.	Annual certifications. Inspections
Connecticut	Annual and monitoring reporting.	Annual and monitoring reporting. Inspections.	Inspections. SWPPP review and implementation for large projects.
Georgia	Annual and monitoring reporting.	Annual and monitoring reporting.	Reporting.
Hawaii	Annual and Monitoring reporting. Inspections.	Annual and monitoring reporting. Inspections.	Inspections. Reporting.
Maine	Annual reporting and municipal audits.	Inspections and audits, at least two per 5-year permit term.	NA
Minnesota		Annual reporting and inspections.	
Nebraska	MS4 audits and annual reporting.	Inspections and SWPPP implementation.	Inspections and SWPPP implementation—complaint only.
Nevada	Annual reporting, MS4 audits, inspections.	Annual reporting, inspections	Inspections.
New York	Annual reporting and MS4 audits.	Annual and monitoring reporting. Inspections.	Inspections and SWPPP implementation.
Ohio	Annual reporting.	SWPPP implementation.	SWPPP implementation.
Oklahoma	Annual reporting. MS4 audits and compliance schedules.	Annual and monitoring reporting. Inspections.	SWPPP implementation and inspections based on complaints received.

State	Municipal	Industrial	Construction
Oregon	Annual and monitoring reporting.	Annual and monitoring reporting. Action Plan approval.	Inspections and SWPPP implementation.
Vermont	Annual reporting and MS4 audits.	Monitoring reporting.	Inspections, recordkeeping.
Virginia	Registration statement BMP implementation.	Monitoring reporting and inspections.	Inspections. SWPPP and E&S plan implementation.
Washington	Implementation of prescriptive stormwater management program.	Monitoring reporting and inspections.	Inspections and monitoring reporting.
West Virginia	NA	SWPPP implementation and monitoring reporting.	Inspections. SWPPP implementation.
Wyoming	Periodic MS4 audits.	Inspections, monitoring reporting.	Inspections.

NOTE: NA, not answered.

TABLE C-5 To Whom Is the SWPPP Submitted?

State	Municipal	Industrial	Construction
Alabama	MS4 Phase I – Storm Water Management Program (SWMP) sent to state. Should be available for review at the time of inspection. (SWPPP information should also be provided to the department.) MS4 Phase 2 – SWMP submitted with the Notice of Intent (NOI).	No submittal to state. The SWPPP must be kept on site and made available for review at the time of inspection.	No submittal to state. The SWPPP must be kept on site and made available for review at the time of inspection. SWPPP required to be submitted under certain circumstance during registration and re-registration.
California	MS4 Phase 1 – SWMP incorporated as prescriptive requirements in the permit. MS4 Phase 2 – SWMP submitted to state with NOI	No submittal to state. The SWPPP must be kept on site and made available for review at the time of inspection.	No submittal to state. The SWPPP must be kept on site and made available for review at the time of inspection.
Connecticut	NA	The SWPPP is submitted to the state only if requested.	The SWPPP is submitted to the state only if requested.
Georgia	The SWMP is submitted to the state.	The SWPPP is submitted to the state only if requested. Otherwise it is kept on-site.	The E&S Control Plan equivalent to the SWPPP is submitted to the Local Issuing Authority. It is also submitted to the state if the project disturbs more than 50 ac, or if there is no LIA.
Hawaii	NA	The SWMP is submitted to the state.	The SWMP is submitted to the state.
Maine	NA	The SWPPP is submitted to the state only if requested.	The E&S Control Plan equivalent to the SWPPP is submitted to the state for review.

State	Municipal	Industrial	Construction
Minnesota	Phase 1 MS4 - The SWMP is submitted to the state for review and public notice.	The SWPPP is not required to be submitted to the state.	The SWPPP must be must be submitted to the state for review for projects disturbing 50 acres or more, and has a discharge point within 2,000 feet of an impaired or special water listed in the state CGP. A SWPPP must also be submitted for projects proposing to use alternative method(s) for the permanent stormwater management system.
Nebraska	NA	The SWPPP is submitted to the state only if requested.	The SWPPP is submitted to the MS4 permittee and to the state when requested.
Nevada	NA	No submittal to state. The SWPPP must be kept on site.	No submittal to state. The SWPPP must be kept on site.
New York	NA	Some SWPPPs submitted to state (very few).	About 1/6 SWPPPs submitted to state.
Ohio	NA	The SWPPP is submitted to the MS4 permittee and to the state when requested.	The SWPPP is submitted to the state.
Oregon	NA	The SWPPP is submitted to the state on first application and when renewing coverage under the state MSGP.	The SWPPP is submitted to the state on first application and when renewing coverage under the state CGP. Projects that are greater than 5 acres are subject to public notice and comment.

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TABLE C-5 Continued

State	Municipal	Industrial	Construction
Vermont	NA	A copy of the SWPPP is submitted to the state, and the original kept on site.	The E&S Control Plan is submitted to the state. Low-risk projects have a standard assigned E&S Control Plan – "Low Risk Handbook".
Virginia	NA	No submittal to the state. The SWPPP must be kept on-site.	No submittal to the state. The SWPPP must be kept on-site.
Washington	NA	The SWPPP is submitted to the state upon first application only. Otherwise, the SWPPP must be kept on site and must be made available to the state, the MS4 permittee, or the public upon request.	The SWPPP is not submitted to the state. The SWPPP must be kept on site and must be made available to the state, the MS4 permittee or the public upon request.
West Virginia	NA	The SWPPP is submitted to the state upon first application only.	The SWPPP is submitted to the state.
Wyoming	NA	The SWPPP is submitted to the state for facilities >50 ac. Class 1 waters not eligible for coverage under the state MSGP.	The SWPPP is submitted to the state for projects >100 ac or on Class 1 waters.

NOTE: NA, not applicable.

TABLE C-6 Can an MS4 Inspect Industries Within Its Boundary?

Alabama	Yes, if adequate legal authority exists.
California	Yes. Local agencies inspection to ensure compliance with local stormwater or municipal ordinance.
Connecticut	Yes. Nothing specific. State MSGP requires industries to comply with the stormwater management program of the MS4 in which they are located.
Georgia	Yes
Hawaii	Yes
Maine	Yes
Minnesota	Yes. Capability to do this varies with the MS4.
Nebraska	Yes. Phase 1 MS4s only.
Nevada	Yes
New York	Yes. MS4s can inspect for illicit discharge detection and elimination. Industries can be inspected under local authority, but local inspections are infrequently conducted.
Ohio	Yes. Phase I MS4s can check for MSGP coverage and that a SWPPP exists in conjunction with pretreatment inspections.
Oklahoma	Yes
Oregon	Yes, under various authorities. Pretreatment, industrial stormwater, construction stormwater, etc.
Vermont	Yes. The MS4 can request an inspection but can be denied access.
Virginia	No. No state statute for private property access to inspect for stormwater management. Some do use Fire Marshall's authority through the fire code.
Washington	Yes
West Virginia	NA
Wyoming	Yes. If the MS4 has authority.

NOTE: NA, not answered.

TABLE C-7 What Industries Are Considered High Risk?

Alabama	Metal foundries.
California	None specified in the state MSGP. Some MS4 permits may specify high-risk industries. Construction activity discharging to sediment-impaired waterbodies are identified as high risk in the state CGP.
Connecticut	None specified in the state MSGP.
Georgia	None specified in the state MSGP. Facilities that may be causing or contributing to stream impairment are high risk.
Hawaii	None specified in the state MSGP
Maine	Auto salvage, scrap metal recycling, boatyards and marinas, concrete and asphalt, batch plants, vehicle maintenance facilities.
Minnesota	None specified in the state MSGP. Heavy industries are considered higher risk.
Nebraska	Ethanol, scrap metal recycling.
Nevada	Waste oil recyclers, auto salvage, aggregate mines, cement plants.
New York	Auto salvage, scrap recycling.
Ohio	None specified in the state MSGP. Individual stormwater permits required for some airports, landfills, sand and gravel operations, and bulk terminals.
Oklahoma	None specified in the state MSGP.
Oregon	None specified in the state MSGP.
Vermont	None specified in the state MSGP. Gravel pits, salvage yards, scrap recycling facilities are considered high risk.
Virginia	None specified in the state MSGP.
Washington	MS4 permit identifies a list of industries and land uses that the permittee must inspect (See Permit appendix 8).
West Virginia	None specified in the state MSGP. Mills and auto salvage yards are considered high risk.
Wyoming	None specified in the state MSGP. Case by case based on proximity to high class waters and industry type.

TABLE C-8 Do State BMP Manuals Exist for Implementation Guidance?

State	Municipal	Industrial	Construction
Alabama	No. Use EPA materials.	No. Use EPA Materials.	Yes. State E&S Manual. http://swcc.state.al.us/erosion_handbook.htm
California	Yes. CASQA and Caltrans manuals. Not officially adopted.	Yes. CASQA and Caltrans manuals. Not officially adopted	Yes. CASQA and Caltrans manuals. Not officially adopted.
Connecticut	No	No. An SWPPP guidance document is available online.	Yes. E&S Guidelines (2002) and CT Stormwater Quality Manual (2004).
Hawaii	No. Use EPA materials.	No. Use EPA materials.	No. Use EPA materials.
Georgia	Yes. Georgia Stormwater Management Manual.	No. Use EPA materials.	Yes. Manual for Erosion and Sediment Control in Georgia.
Maine	Yes	Yes	Yes
Minnesota	Yes. The Minnesota Stormwater Manual at: http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html Stormwater BMPs – Protecting Water Quality in Urban Areas at: http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	No. Plan to develop one.	Yes. Fact sheets and guidance at: http://www.pca.state.mn.us/water/stormwater/stormwater-ms4.html#bmp
Nebraska	No	No	No
Nevada	Yes	Yes	Yes
New York	Yes	Yes. A few state materials.	Yes

continued next page

TABLE C-8 Continued

State	**Municipal**	**Industrial**	**Construction**
Ohio	No. Use EPA materials.	No. Use EPA materials.	Yes. http://www.dnr.state.oh.us/water/rainwater/default/tabid/9186/Default.aspx
Oklahoma	No. Use EPA materials.	No. Use EPA materials.	No. Use EPA materials.
Oregon	No	No. Have BMP technical assistance guidance documents.	Yes. Use of Oregon BMP manual is optional.
Vermont	Yes	No	Yes. Standards for designers, a field guide for contractors (2006), and the Low Risk Handbook.
Virginia	Yes. E&S control and stormwater handbooks.	No	Yes. E&S control and stormwater handbooks.
Washington	Yes. Stormwater Management Manual for Western Washington (2005) and Stormwater Management Manual for Eastern Washington (2004)	Yes. http://www.ecy.wa.gov/programs/wq/stormwater/manual.html	Yes. http://www.ecy.wa.gov/programs/wq/stormwater/eastern_manual/index.html
West Virginia	No	No	Yes
Wyoming	No	No. Refer to manuals from other states.	No. Refer to manuals from other states.

TABLE C-9 Full-Time Staff Dedicated to the Stormwater Program

State	**Municipal**	**Industrial**	**Construction**	**Total Statewide**
Alabama	1.5	7	25–30	33.5–38.5
California				89
Connecticut				5
Georgia	4.5	2.5	46	53
Hawaii	0.5	1	2	3.5
Maine	0.7	2.5	NA	
Minnesota		4.3	14	36
Nebraska				3
Nevada	1	1.5	3	5.5
New York	7	1	11	19
Ohio				18
Oklahoma				7
Oregon	1	4–5 (shared with construction)	4–5 (shared with industrial)	5–6
Vermont	0.5	2	5	7.5
Virginia	3	8 (shared with other programs)	10	13
Washington	10	17	16	43
West Virginia	NA	1	5	
Wyoming				4

NOTE: NA, not answered.

Appendix D
Biographical Information for the Committee on Reducing Stormwater Discharge Contributions to Water Pollution

Claire Welty, *Chair*, is the Director of the Center for Urban Environmental Research and Education and Professor of Civil and Environmental Engineering at University of Maryland, Baltimore County (UMBC). Dr. Welty's work has primarily focused on transport processes in aquifers; her current research interest is in watershed-scale urban hydrology, particularly in urban groundwater. Prior to her appointment at UMBC, Dr. Welty was a faculty member at Drexel University for 15 years, where she taught hydrology and also served as Associate Director of the School of Environmental Science, Engineering, and Policy. Dr. Welty is the chair of the National Research Council's (NRC's) Water Science and Technology Board and has previously served on three NRC study committees. She is the Chair-Elect of the Consortium of Universities for the Advancement of Hydrologic Science Inc. Dr. Welty received a B.A. in environmental sciences from the University of Virginia, an M.S. in environmental engineering from the George Washington University, and a Ph.D. in civil and environmental engineering from the Massachusetts Institute of Technology.

Roger T. Bannerman has been an environmental specialist for the Wisconsin Department of Natural Resources for over 30 years. For most of that time he has directed research projects investigating urban runoff. Topics addressed by his studies over the years include the quality of urban streams, identification of problem pollutants in stormwater, toxicity of stormwater pollutants, effectiveness of different stormwater control practices, sources of stormwater pollutants, selection of cost-effective control practices, and benefits of low-impact development. He has applied these results to management plans developed for most urban areas in Wisconsin. This includes the calibration of the urban runoff model called the Source Loading and Management Model. The results of his research projects have been used to develop Wisconsin's new administrative rules that regulate stormwater management. Mr. Bannerman received his B.S. in chemistry from Humboldt State College and an M.S. from the University of Wisconsin in water chemistry.

Derek B. Booth has joint positions as Senior Geologist at Stillwater Sciences, Inc., and Adjunct Professor at the University of Washington where he is senior editor of the international journal *Quaternary Research* and holds faculty appointments in Civil Engineering and Earth & Space Sciences. Prior to this, he was director of the Center for Urban Water Resources Management (and its successor, the Center for Water and Watershed Studies) at the university. He maintains active research into the causes of stream-channel degradation, the effectiveness of stormwater mitigation strategies, and the physical effects of urban development on aquatic systems, with over a dozen publications and a wide range of national and international invited presentations on the topic. Dr. Booth received a B.A. in literature from Hampshire College, a B.A. in geology from the University of California at Berkeley, an M.S. in geology from Stanford University, and a Ph.D. in geological sciences from the University of Washington.

Richard R. Horner is a professor in the Department of Civil and Environment Engineering at the University of Washington, with adjunct appointments in Landscape Architecture and in the College of Forest Resources' Center for Urban Horticulture. He received his Ph.D. from the University of Washington's Department of Civil and Environmental Engineering and previous engineering degrees from the University of Pennsylvania. Dr. Horner splits his time between university research and private practice. In both cases his work concerns how human occupancy of and activities on the landscape affect natural waters, and how negative effects can be reduced. He has been involved in two extended research projects concerning the ecological response of freshwater resources to urban conditions and the urbanization process. The first studied the effect of human activities on freshwater wetlands of the Puget Sound lowlands and led to a comprehensive set of management guidelines to reduce negative effects. A ten-year study involved the analogous investigation of human effects on Puget Sounds' salmon spawning and rearing streams. In addition, he has broad experience in all aspects of stormwater management, having helped design many stormwater programs in Washington, California, and British Columbia. He previously served on the NRC's Committee on the Comparative Costs of Rock Salt and Calcium Magnesium Acetate for Highway Deicing.

Charles R. O'Melia (NAE) is the Abel Wolman Professor of Environmental Engineering and Chair of the Geography and Environmental Engineering Department at the Johns Hopkins University, where he has served on the faculty for over 25 years. Dr. O'Melia's research areas include aquatic chemistry, environmental colloid chemistry, water and wastewater treatment, modeling of natural surface and subsurface waters, and the behavior of colloidal particles. He has served on the advisory board and review committees for the environmental engineering departments of multiple universities. He has served in a range of advising roles to professional societies including the American Water Works Association and Research Foundation, the Water Pollution Control Federation, the American Chemical Society, and the International Water Supply Association. He has served on several NRC committees, including chairing the Steering Committee, Symposium on Science and Regulation, and the Committee on Watershed Management for New York City. He was also a member of the

NRC Water Science and Technology Board and the Board on Environmental Studies and Toxicology. Dr. O'Melia earned a Ph.D. in Sanitary Engineering from the University of Michigan. In 1989, Dr. O'Melia was elected to the National Academy of Engineering for significant contributions to the theories of coagulation, flocculation, and filtration leading to improved water-treatment practices throughout the world.

Robert E. Pitt is the Cudworth Professor of Urban Water Systems in the Department of Civil, Construction, and Environmental Engineering at the University of Alabama (UA). He is also Director of the UA interdisciplinary Environmental Institute. Dr. Pitt's research concerns the effects, sources, and control of urban runoff, which has resulted in numerous development management plans, stormwater ordinances, and design manuals. Dr. Pitt has also developed and tested procedures to recognize and reduce inappropriate discharges of wastewaters to separate storm drainages. He has investigated the sources and control of stormwater toxicants and examined stormwater effects on groundwater. He has also carried out a number of receiving water impact studies associated with stormwater. These studies have included a variety of field monitoring activities, including water and sediment quality, fish and benthos taxonomic composition, and laboratory toxicity tests. His current research includes developing a nationwide database of national stormwater permit information and conducting comprehensive evaluations of these data. Dr. Pitt received a B.S. in engineering science from Humboldt State University, an M.S. in civil engineering from San Jose State University, and a Ph.D. in civil and environmental engineering from the University of Wisconsin.

Edward T. Rankin is an Environmental Management Associate with Ohio University at the Institute for Local Government Administration and Rural Development (ILGARD) which is the Voinovich School of Leadership and Public Affairs located in Athens, Ohio. He had previously been a Senior Research Associate in the Center for Applied Bioassessment and Biocriteria within the Midwest Biodiversity Institute (MBI). Prior to 2002, he was an aquatic ecologist with Ohio EPA for almost 18 years. Mr. Rankin's research centers around the effects of stormwater and other urban stressors on aquatic life, development and application of stream habitat assessment methodologies, development and application of biological criteria and biological-based chemical criteria for aquatic life, and improving the accuracy of total maximum daily loads for nutrients and sediment. He is particularly interested in the application of research to management of aquatic life issues and has extensive experience with the development of tiered aquatic life uses and use attainability analyses in streams. Mr. Rankin received his B.S. in biology from St. Bonaventure University and his M.S. in zoology from The Ohio State University.

Thomas R. Schueler founded the Center for Watershed Protection in 1992 as a nonprofit organization dedicated to protecting our nation's streams, lakes and wetlands through improved land management. In 2007, he launched the Chesapeake Stormwater Network, whose mission is to improve on-the-ground implementation of more sustainable stormwater management and environmental site design practices in each of 1,300 communities and seven states in the Chesapeake Bay Watershed. He has conducted extensive research on the pollutant removal performance, cost, and longevity of stormwater control measures, and he has developed guidance for both Phase I and Phase II communities to meet minimum management measures to comply with municipal stormwater permits, including development of a national stormwater monitoring database and national guidance on illicit discharge detection and elimination. Mr. Schueler has written several widely referenced manuals that describe how to apply the tools of watershed protection and restoration, and he is working on a wide range of research projects and watershed applications across the United States. Prior to founding the Center, he worked for ten years at the Metropolitan Washington Council of Governments, where he led the Anacostia Watershed Restoration Team, one of first efforts to comprehensively restore an urban watershed. He received his B.S. in environmental science from the George Washington University.

Kurt Stephenson is an associate professor of Environmental and Natural Resource Economics in the Department of Agricultural and Applied Economics at the Virginia Polytechnic Institute and State University. His professional objective is to better integrate economic perspectives and analysis into decision making related to water resource issues. Particular emphasis is placed on the application of economic analysis to interdisciplinary research of policy issues. The design and implementation of market-based policies to secure environmental objectives is a primary area of study within this context. He is currently involved in determining effective strategies for reducing nutrient loads in the Opequon Watershed in Virginia and West Virginia, including evaluating the cost effectiveness and feasibility of using urban nonpoint source controls (including stormwater management) as an offset to growth in point source loads. He is a member of the Virginia Department of Environmental Quality's Nutrient Trading Technical Advisory Committee and the Academic Advisory Committee. Dr. Stephenson received his B.S. in economics from Radford University, his M.S. in agricultural economics from Virginia Tech, and his Ph.D. in economics from the University of Nebraska.

Xavier Swamikannu is Chief of the Stormwater Permitting Program for the Los Angeles Regional Water Board and the California EPA, where he has worked for nearly 20 years. He has extensive experience with the implementation of municipal and industrial stormwater programs in Southern California, including the evaluation of pollutant discharges, determining the effectiveness of stormwater control measures in treating stormwater runoff, developing performance criteria and better understanding of their costs. He has participated on EPA's General Permits and Total Maximum Daily Load Work Groups and he has served on many state and regional technical advisory committees concerned with stormwater regulations. He was recognized by the California Water Boards in 2007 for his national leadership in the stormwater program, and by the California State Senate for his service on the technical advisory committee of the Santa Monica Bay Restoration Commission. Dr. Swamikannu received his B.S. in natural and chemical sciences from St. Joseph's College in Bangalore, India, his M.S. in environmental sciences from Texas Christian University, and his Ph.D. in environmental science and engineering from the University of California, Los Angeles.

Robert G. Traver is a professor of Civil and Environmental Engineering at Villanova University and the Director of the Villanova Urban Stormwater Partnership. He conducts research on topics that include modeling of stream hydraulics, urban hydrology, water quality, and measures to mitigate stormwater effects of urbanization. Most recently he has created a Stormwater Best Management Practice Demonstration and Research Park on the Villanova Campus. Dr. Traver is also involved with the implementation of stormwater policy. He has participated in a team study to review the effects of Pennsylvania's water regulation from a watershed sustainability viewpoint, acted as a reviewer for Pennsylvania's 1995 Best Management Practice Handbook, and has served as Chair for the 1998, 1999, 2001, 2003, and 2005 Pennsylvania Stormwater Management Symposiums held at Villanova. More recently he was selected to serve on the American Society of Civil Engineers' External Review Panel of the Corps investigation of Hurricane Katrina. Dr. Traver is a retired LTC in the Army Reserves and a veteran of Operation Desert Storm. He received his B.S. in civil engineering from the Virginia Military Institute, his M.S. in civil engineering from Villanova, and his Ph.D. in civil engineering from Pennsylvania State University.

Wendy E. Wagner is the Joe A. Worsham Centennial Professor at the University of Texas School of Law. Before joining the UT faculty, she was a professor at Case Western Reserve University School of Law and a visiting professor at Columbia Law School and the Vanderbilt School of Law. Wagner's research focuses on the interface between science and environmental law, and her articles have appeared in numerous journals, including the Columbia, Cornell, Duke, Georgetown, Illinois, Texas, Wisconsin, and Yale Law Reviews. She has published on the practical problems with EPA's current approach to stormwater regulation. She has also written several articles on the challenges of regulating media like stormwater, on restoring polluted waters with public values, on the legal aspects of the regulatory use of environmental modeling, and on technology-based standards. Ms. Wagner received a master's degree in environmental studies from the Yale School of Forestry and

Environmental Studies and a law degree from Yale Law School. She clerked for the Honorable Judge Albert Engel, Chief Judge of the U.S. Court of Appeals for the 6th Circuit.

William E. Wenk is founder and president of Wenk Associates, Inc., a Denver-based landscape architectural firm. He is also an Adjunct Associate Professor of Landscape Architecture at the University of Colorado in Denver. For over 20 years, he has been influential in the restoration and redevelopment of urban river and stream corridors, the transformation of derelict urban land, and the design of public parks and open spaces. Mr. Wenk was the Principal Urban Designer for the Menomonee River Valley Redevelopment, an award-winning "green infrastructure" redevelopment in Milwaukee that integrated a network of parks and open spaces through stormwater infrastructure, regional and local trails, and a restored river corridor into a proposed 130-acre mixed-use and light industrial development. Other projects of his include the Prairie Trail Community Master Plan in Ankeny, Iowa (a surface stormwater system designed to provide flood control and water quality for a new 1000-acre mixed-use community), and the Stapleton Airport Parks and Open Space Redevelopment (a surface stormwater drainage design for the 4,500-acre redevelopment), as well as the Stapleton Water Quality Guidelines book to guide planners and developers on how to integrate stormwater best management practices into redevelopment. Mr. Wenk received a B.S.L.A. and M.L.A. from Michigan State University and the University of Oregon, respectively.

Laura J. Ehlers is a senior staff officer for the Water Science and Technology Board of the National Research Council. Since joining the NRC in 1997, she has served as the study director for eleven committees, including the Committee to Review the New York City Watershed Management Strategy, the Committee on Bioavailability of Contaminants in Soils and Sediment, the Committee on Assessment of Water Resources Research, and the Committee on Public Water Supply Distribution Systems: Assessing and Reducing Risks. Ehlers has periodically consulted for EPA's Office of Research Development regarding their water quality research programs. She received her B.S. from the California Institute of Technology, majoring in biology and engineering and applied science. She earned both an M.S.E. and a Ph.D. in environmental engineering at the Johns Hopkins University. Her dissertation, entitled RP4 Plasmid Transfer among Strains of *Pseudomonas* in a Biofilm, was awarded the 1998 Parsons Engineering/Association of Environmental Engineering Professors award for best doctoral thesis.