Prepared for

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EVALUATION OF POST-CONSTRUCTION HYDROMODIFICATION REQUIREMENTS CONTAINED IN THE PRELIMINARY DRAFT GENERAL CONSTRUCTION PERMIT

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Project Number LA0159

March 2008

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1. EXECUTIVE SUMMARY

Changes in runoff characteristics and instream processes caused by changes in land use conditions are termed hydromodification. Unless managed, hydromodification can cause geomorphic and biologic impacts to stream systems and impairment of beneficial uses.

The California State Water Resources Control Board (SWRCB) issued a Preliminary Draft revision to the General Construction Permit ("Preliminary General Construction Permit" or "PGCP") in March 2007 (SWRCB 2007) which contains new development and re-development stormwater performance standards that relate to post-construction hydromodification control (Table 1-1). This report evaluates the technical merits of those hydromodification control requirements in light of the current scientific literature and other regulatory program approaches, as well as Geosyntec's extensive hydromodification-related project experience and research findings.

Table 1-1. Post-Construction Hydromodification Standards in the PGCP

PAGE / SECTION	STANDARDS
Page 24 of 79 Section K. New Development and Re-development Storm Water Performance Standards	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. The discharger shall obtain Regional Water Board approval for the use of any structural control measures used to comply with this requirement.
	2. For projects whose disturbed project area exceeds two acres, the discharger shall preserve the post-construction [sic] drainage divides for all drainage areas serving a first order stream or larger and ensure that post-project time of concentration is equal to or greater than post-project [sic] 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 a first order stream or larger and ensuring that post-project time of concentration is equal to or greater than post-project [sic] time of concentration.
	4. The discharger shall demonstrate compliance with these requirements by submitting with their NOT a map and worksheets in accordance with the instructions in Attachment G.

This report contains the following sections:

- A summary of the current scientific literature regarding the causes and impacts of hydromodification and implications for effective management controls
- A review and comparison of existing and proposed hydromodification control programs
- An alternative standard for hydromodification control

- An example project which compares the effectiveness of a PGCP-based design to a design based on the alternative standard

- A summary of findings and conclusions

A comprehensive literature review was performed by Geosyntec in 2002 for the Santa Clara Valley Urban Runoff Pollution Prevention Program (Geosyntec 2002). The findings of that literature review provided the technical basis for the development of the Santa Clara Valley Urban Runoff Pollution Prevention Program's Hydromodification Management Plan for the Santa Clara Valley. Since that initial review, numerous publications have been issued relating to the extent, causes, and impacts of hydromodification, and the effectiveness of control measures.

For the development of this report, Geosyntec reviewed peer-reviewed journal articles, agency publications, reports from research organizations, and conference proceedings primarily issued since 2002, with particular interest in work specific to California and similar climates. Over 100 documents were reviewed; Appendix A contains an annotated bibliography of the 82 publications which were determined to be the most relevant and significant. Geosyntec also reviewed a number of existing and proposed hydromodification regulations and implementation plans, including recently issued and draft revised municipal separate storm sewer system (MS4) Permits throughout Southern California.

Based upon the scientific literature and regulatory review, Geosyntec identified the following key conclusions:

- Hydromodification is best addressed with a suite of control strategies and should be integrated with other watershed-level planning elements including clustered development, integrated land use planning, and stream restoration efforts. While Low Impact Design (LID) principles should be incorporated wherever technically and economically feasible, it is unlikely that LID alone will be able to fully address hydromodification in all cases.

- The current scientific understanding of hydromodification recognizes the need to address the full range and variability of hydrologic and geomorphic processes and their complex interactions with stream ecology. Long-term, continuous hydro-geomorphic modeling provides the best approach to develop an understanding of the complex inter-relationships between watershed and stream processes.

- Although it is desirable to have a simple standard that is easy to understand and implement, the proposed standard of "runoff volume matching" is too ambiguous and could be implemented in a number of ways, not all of which would ensure that the goals of the requirement are achieved. Further clarification of the standard is required that provides specific metrics reflecting the relevant characteristics of the hydrologic and geomorphic processes which affect stream stability and beneficial uses.

- Measures of development such as impervious area, or metrics based on "effective" impervious area in the absence of a quantitative definition of "ineffective," fail to quantify the processes that contribute to hydromodification impacts, and would therefore result in high levels of variability in site design and uncertain outcomes with respect to stream protection.

- The most technically sound approach to managing direct physical impacts to stream systems is one based on the evaluation of the post-project, long-term sediment transport capacity compared to the pre-project capacity. The Erosion Potential (Ep) metric is a well-developed tool based on this approach that can be used as a standard for designing on-site, regional, or instream flow controls with the objective of eliminating, reasonably reducing, or managing direct physical impacts to stream systems. It is a time-integrated metric based on long-term continuous modeling, which quantifies the alteration of both the hydrologic and geomorphic processes that contribute to stream instability.

- Because changes to the flow regime can have direct impacts on riparian ecosystems beyond their effects on channel stability, as well as impacts on groundwater recharge and local evapotranspiration,[1] an Ep-based standard may not completely mitigate for all physical and ecological hydromodification impacts. A water balance analysis that addresses seasonality or other life cycle factors has the potential to identify additional hydrologic changes which may impact riparian ecosystems. Further development of this approach should be encouraged and potential applications at regional scales and for major project planning should be explored. The development of additional metrics to quantify biotic impacts and establish control standards should be encouraged.

- Additional challenges remain, key among which include: quantifying the effects of LID through hydrologic modeling, designing infiltration systems for Type "C" and "D" soils,[2] assessing model validity and effectiveness through long-term monitoring and continuous streamflow data, and understanding and reducing uncertainty in models and the selection of values for key variables. Simplification of the Ep approach would facilitate its application, within the available resources and technical expertise, to the projects that will fall under the revised PGCP (i.e., outside of the Phase I and II MS4 Permit jurisdictional area).

Mandating the incorporation of hydromodification control measures into already planned, entitled, and environmentally reviewed and approved projects via the Construction General Permit is inefficient and inappropriate. However, utilizing existing authorities, the State and Regional Boards can successfully address post-construction hydromodification impacts at the appropriate time—during the development planning process—and at the local level.

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[1] Evapotranspiration refers to the process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants.

[2] Hydrologic groups are groups of soils having similar runoff potential under similar storm and cover conditions. Type C soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. Type D soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material.

Geosyntec has proposed two alternative standards for hydromodification management which integrate the findings and discussions of this report. The first alternative is presented as permit language for inclusion in an MS4 Permit; this would ensure the most technically defensible approach is being applied throughout all Phase I and Phase II urban areas in California. This standard could also be applied to large projects that fall outside of the MS4 Permit areas through the 401 certification, CEQA, or land use approval mechanisms listed above. The second alternative applies to small projects that lie outside of Phase I and Phase II areas. In these cases, where project proponents and municipalities have far fewer resources for program development, we recommend a standard based on implementation of specific LID measures until a more quantitative methodology is developed that can be readily implemented in these areas.

A modeling study was performed comparing the proposed PGCP numeric criteria to those contained in the first alternative standard. Results showed that runoff controls sized to meet the proposed PGCP criteria based on hydrograph matching for selected events would likely lead to stream instability. In contrast, the flow duration control design (representing the alternative approach) closely matched the pre-urban distribution of instream flows and as a result maintained the pre-urban capacity to transport sediment.

Maintaining stream stability requires an approach to controlling urban runoff that addresses the long-term change in flow duration across the full range of geomorphically-significant flows. Standards based on discrete events or on only a subset of the factors affecting hydrologic response such as time of concentration, as proposed in the PGCP, will not be able to achieve this requirement.

2. INTRODUCTION

2.1 Background

Changes in runoff characteristics caused by changes in land use conditions are termed hydromodification. Urbanization can result in hydromodification by increasing runoff volumes, frequency, duration, and peak flows, as well as by changing the overall water balance affecting groundwater recharge and baseflows. Unless managed, hydromodification can cause geomorphic and biologic impacts to stream systems and impairment of beneficial uses, including flood management.

The California State Water Resources Control Board (SWRCB) issued a preliminary draft revision to the General Construction Permit ("Preliminary Construction General Permit" or "PGCP") in March 2007 (SWRCB 2007) which contains new development and re-development stormwater performance standards that relate to post-construction hydromodification control. Table 2-1 below lists the standards for post-construction hydromodification that are contained in the PGCP. Appendix D contains a copy of Attachment G of the PGCP.

Table 2-1 Post-Construction Hydromodification Standards in the PGCP

PAGE / SECTION	STANDARDS
Page 24 of 79 Section K. New Development and Re-development Storm Water Performance Standards	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. The discharger shall obtain Regional Water Board approval for the use of any structural control measures used to comply with this requirement.
	2. For projects whose disturbed project area exceeds two acres, the discharger shall preserve the post-construction [sic] drainage divides for all drainage areas serving a first order stream or larger and ensure that post-project time of concentration is equal to or greater than post-project [sic] time of concentration.
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	4. The discharger shall demonstrate compliance with these requirements by submitting with their NOT a map and worksheets in accordance with the instructions in Attachment G.

2.2 Report Scope and Organization

This report evaluates the technical merits of the hydromodification control requirements contained in the PGCP in light of the current scientific literature and other regulatory program approaches, as well as Geosyntec's extensive hydromodification-related project experience and research findings.

Following the executive summary and this introductory section, the report is organized as follows:

- Section 3 of the report summarizes the current scientific literature regarding the causes and impacts of hydromodification associated with urbanization and the implications for effective management controls.
- Section 4 reviews existing and proposed hydromodification control programs and compares selected programs that represent a range of management approaches.
- Section 5 presents two alternative standards for hydromodification control.
- Section 6 presents an example project which compares the effectiveness of a PGCP -based design to a design based on one of the alternative standards presented in Section 6.
- Section 7 summarizes the report findings and conclusions.
- References are included in Section 8 and Appendices in Section 9.

3. LITERATURE REVIEW – SCIENTIFIC FINDINGS

3.1 Introduction

A comprehensive literature review was performed by Geosyntec in 2002 for the Santa Clara Valley Urban Runoff Pollution Prevention Program (Geosyntec 2002). At the time, 80 publications were obtained as potential candidates and 50 were ultimately included in the final review document. These included peer reviewed journal articles, agency publications and reports, and conference proceedings. Key findings from that review included the following:

1. A range of factors must be considered when evaluating and controlling the potential for hydromodification impacts. These include climate, watershed characteristics, development characteristics, sediment supply, channel hydraulics and channel boundary resilience, the combination of which determines erosion and transport characteristics.

2. Local variations in rainfall, soils, slope, channel geometry, bed and bank materials, and vegetation necessitate the use of watershed-level planning and development of region-specific management approaches.

3. Channel stability and habitat integrity reflect continuous, long-term hydrologic and geomorphic processes.

4. Time integrated metrics provide the closest reproduction of these processes.

5. Recent practices of managing only peak flows can be more damaging to receiving channels than no controls at all on urban runoff, because the reduction in peak flows is more than offset by the increased duration of erosive flows.

6. Management strategies should consider the full range of geomorphically significant flows in order to have the greatest chance of being effective.

These findings provided the technical basis for the development of a Hydromodification Management Plan for the Santa Clara Valley. Since that initial review, numerous publications have been issued relating to the extent, causes, and impacts of hydromodification, and the effectiveness of control measures.

For the development of this report, Geosyntec reviewed peer reviewed journal articles, agency publications, reports from research organizations, and conference proceedings (primarily issued since 2002), with particular focus on work specific to California and similar climates. The summary which follows is based on the Santa Clara Valley Urban Runoff Pollution Prevention Program literature review, updated as appropriate to reflect new information and continued support of the original findings. Over 100 documents were evaluated; Appendix A contains an annotated bibliography of the 82 publications which were determined to be the most relevant and significant to this report.

3.2 Organization

This section is organized according to the following progression of topics: first, basic hydrologic and geomorphic processes are discussed, as these provide the foundation for understanding hydromodification. This is followed by a discussion of natural channel form and stability as the direct outcome of these processes; this section also includes a focus on streams in arid and semi-arid areas, an important component of California's climate regions. Riparian ecology is covered next, as it is determined directly by the hydrologic regime and has an intimate and mutually influencing relationship with stream morphology.

After laying this groundwork on natural processes, the effects of development / land use changes are covered; this section addresses the mechanisms of change in terms of the specific hydrologic and geomorphic process components which are being altered. This leads to a discussion of the impacts to stream morphology and riparian ecosystems resulting from these altered processes. A section on local influences covers the important regional and watershed-specific characteristics that affect how a watershed or stream will respond to land use changes.

The next sections focus on management strategies, starting with a discussion of the use of impervious surfaces as a metric to predict hydromodification impacts. Subsequent sections cover emerging developments in planning and site design and then, in light of these changes, the issue of metrics is raised again, with a discussion of recent and emerging strategies to quantify land use effects and relate them to stream impacts and control measures.

The final section provides a synthesis of technical strategies and related management tools that reflect the current scientific understanding summarized in the preceding sections.

3.3 Hydrologic and Geomorphic Processes

An understanding of the fundamentals of hydromodification is facilitated by the use of a Conceptual Model, Figure 3-1 (Geosyntec 2002) which illustrates the linkages between watershed hydrologic and geomorphic processes. Consideration of both sets of processes is key to understanding and addressing hydromodification impacts.

3.3.1 Hydrologic Processes

Hydrologic processes refer to infiltration, runoff, interflow, groundwater and evapotranspiration. These components of the hydrologic cycle (Figure 3-2) are driven by the local precipitation and climate regime, and controlled by the local geology and physiography which determine soil and vegetation types. Infiltrated water is stored in the soil and slowly released to streams either as interflow (movement through the unsaturated zone), or groundwater flow. Water moves more quickly to streams as surface runoff when precipitation rates are higher than infiltration capacity (referred to as Hortonian overland flow or infiltration excess flow), or where soils are saturated (referred to as saturation excess overland flow). Hortonian overland flow is dominant in arid/semi-arid climates where storms are intense, soils are less permeable and vegetation is sparse. Saturation excess overland flow is dominant in humid climates with long duration light rains, well developed soils with organics, and forested landscapes. Saturation overland flow can occur in arid climates in topographic depressions and drainage swales. Evapotranspiration refers to the combination of evaporative losses from both land surfaces and from plant metabolic processes which may tap groundwater sources.

These processes are highly variable, both spatially and temporally. For example, overland flow or surface runoff generated by a storm event after a long dry period can differ greatly from that generated by the same storm following a wet period due to the difference in antecedent soil moisture. Characteristics such as slopes, soil infiltration capacity and rainfall regime, can differ greatly from one watershed to the next, especially between various climatic and physiographic regions. Therefore, characterization of the resulting streamflow hydrograph is complex; runoff and stream flow volumes, long-term cumulative durations, peaks, base flows and timing are all critical components of the hydrograph which vary naturally based on these hydrologic processes.

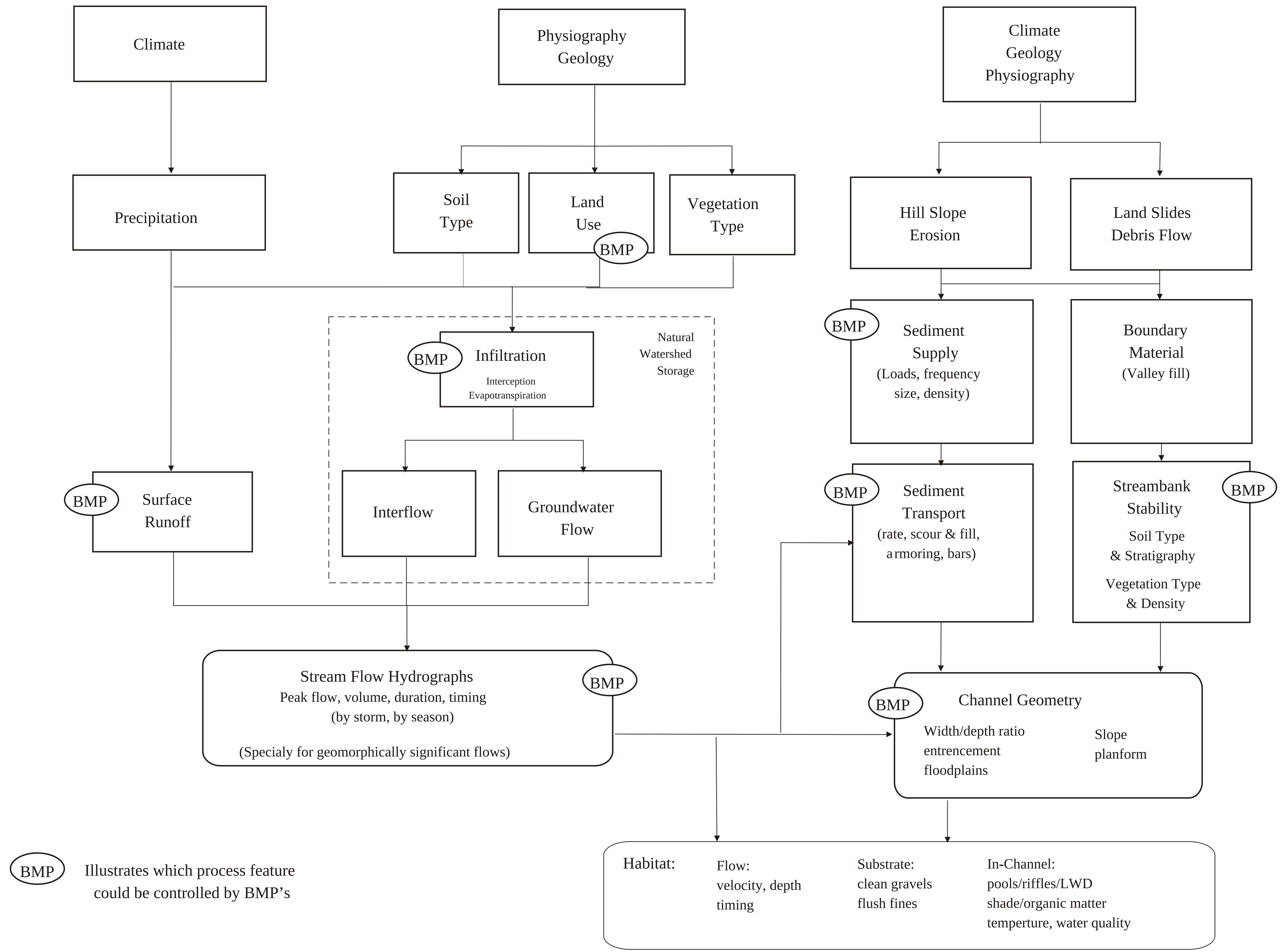

Figure 3-1. CONCEPTUAL MODEL ILLUSTRATING THE LINKAGES BETWEEN THE HYDROLOGIC AND GEOMORPHIC PROCESSES TO BE ADDRESSED IN HYDROMODIFICATION

Source: GeoSyntec Consultants, Walnut Creek, 2002

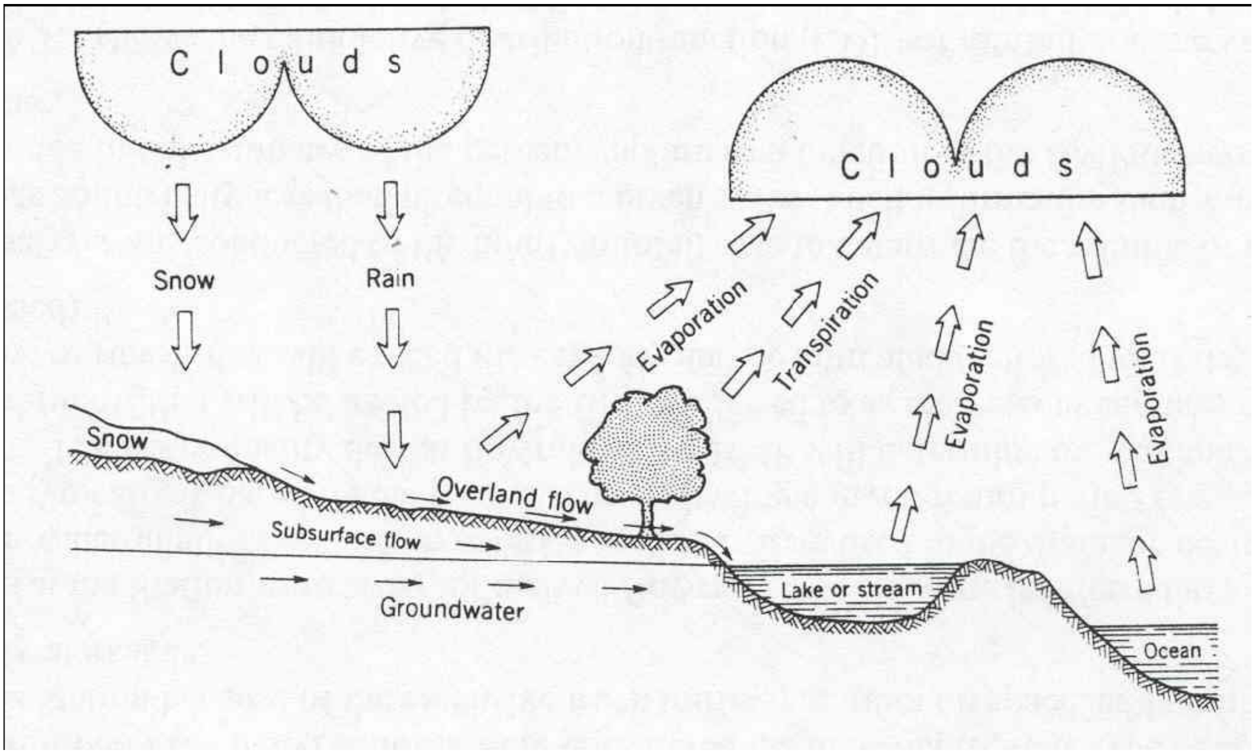

Figure 3-2. Schematic of the Hydrologic Cycle (Geosyntec 2002)

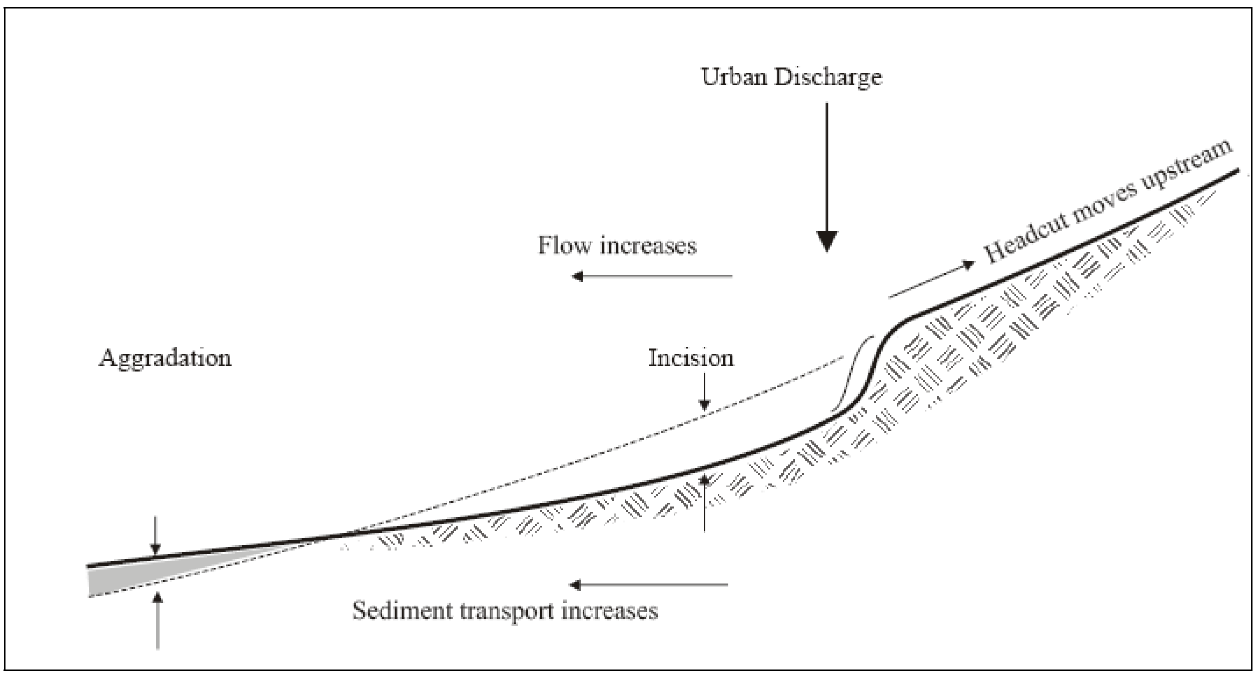

Figure 3-3. Example Changes in Longitudinal Profile (Slope) as a Result of Urban Discharges (Geosyntec 2002)

3.3.2 Geomorphic Processes

Geomorphic processes are those which contribute to stream channel morphology and characteristics, including sediment supply (hill slope erosion, land slides, debris flows) and transport (erosion and deposition, bar formation and destruction, downstream fining and armoring). This is often visualized as a continuum of landscape erosion, transport via channels, and deposition in bays or estuaries. Eroded sediments are transported and deposited along channel boundaries and on floodplains, and further eroded and re-worked as they move downstream. These processes, combined with stream bed and bank soil types and vegetation density, determine channel geometric features and form such as width/depth ratio, slope, planform and entrenchment. Sediment transport is driven by the stream flows; flows which create shear stresses high enough to initiate sediment transport within the channel are considered geomorphically-significant.

The combination of geomorphic processes and hydrologic processes determines channel stability as well as habitat quality, as discussed in the next sections.

3.4 Natural Channel Form and Stability

Lane's Principle (Lane 1955) is one of the fundamental relationships governing channel form. This relationship states that the product of sediment load and grain size is proportional to the product of discharge and channel slope. A balance exists between streamflow, slope, and sediment transport capacity. Where streamflow is increased, or sediment supply decreased, a decrease in slope is required to reestablish equilibrium; this is often manifest as channel incision (degradation) (Figure 3-3). In contrast, an increase in sediment supply will often be manifest as aggradation.

A stream is considered to be stable when its overall planform (meander pattern), cross-section and profile are maintained over time with no net degradation or aggradation within a range of variance. Natural streams are often in a state of dynamic equilibrium, where the channel exhibits stability over the long term, but is actively migrating laterally such that erosion of its outer banks is accompanied by sediment deposition and bar building on the inner banks. Natural channel systems can often withstand short-term disturbances without significant change. A large scale event, like a flood or landslide, can cause dramatic changes in channel form, but the channel will often re-established its pre-event planform, geometry and slope over time. However, a persistent alteration, like hydromodification, can cause the channel to begin an evolutionary change in morphology, leading to degradation and instability.

Channel response to changing inputs can be highly variable, ranging from as little as days for catastrophic floods, to decades for slower changes such as long term climate cycles. Random processes, response thresholds and feedback mechanisms may also play important roles in stream stability, potentially resulting in responses which are apparently disproportionate to the magnitude of change. For example, incremental increases in runoff in a slowly developing watershed may have only small impacts in a resistant streambed until a less resistant underlying soil layer is exposed, at which time erosion begins to accelerate. If this happens to coincide with a natural cycle of higher than average rainfall, an extreme response in channel morphology may result, despite little or no additional development occurring within that period.

3.4.1 Arid and Semi-Arid Stream Systems

Researchers who work with arid and semi-arid streams caution that these systems may differ significantly from those in humid regions; however, arid and semi-arid regions are under-represented in studies relating to human impacts and hydromodification. Most research focuses on perennial streams (those that flow constantly), with far fewer studies of intermittent or ephemeral streams (defined respectively as those which flow only seasonally, or only as a result of storm events).

Rainfall in semi-arid climates tends to be more episodic, with shorter duration storms of higher intensity than those in humid climates. Ephemeral streams in semi-arid regions are highly sensitive to human impacts and short term climate changes (Bull 1997). The combination of abundant sediment supply from hillslopes and infrequent large streamflow events creates disequilibrium as the deposition of channel fans causes the rise of local base level, and channel entrenchment causes the fall of local base level. These opposing base-level processes in adjacent reaches are maintained by self-enhancing feedback mechanisms. Riparian vegetation plays an important role in regulating sediment connectivity along the channel, but patterns and morphology of vegetation in dryland streams are more spatially variable compared to temperate and humid areas (Sandercock et al. 2007).

There can also be a high degree of spatial and temporal variability exhibited by semi-arid surface water-groundwater interactions (Newman et al. 2006), which affects biogeochemical characteristics and ecosystem dynamics. In gaining streams, groundwater drains into the channel, thereby supporting baseflow even under semi-arid conditions. Losing streams can be major recharge zones to alluvial aquifers, but the proportion of transmission losses accounted for by recharge versus riparian evapotranspiration is difficult to determine. These effluent and influent conditions can switch back and forth within the same reach over time.

3.4.2 High Sediment Load Stream Systems

For some braided stream systems with high sediment loads, channel responses may be dominated by episodic re-set events. The Santa Clara River in Los Angeles County is considered to be such a system, in which large events, occurring on the average approximately once every ten years, are believed to completely alter the form of the channel, serving as the dominant force in defining channel morphology and overwhelming the effects of smaller, more frequent flow events (Balance Hydrologics, 2005).

3.5 Riparian Ecology

Riparian corridors are the most complex, diverse and dynamic of all terrestrial habitats (Naiman et al. 1993). In proportion to their area within a watershed, riparian habitats are more biologically productive than uplands; higher levels of vegetation richness in riparian areas are especially pronounced in arid and semi-arid climates such as Southern California (NRC 2002). Riparian ecology is intimately linked with hydrologic and geomorphic processes. Spatial and temporal distributions of plant communities are tied to moisture availability and seasonality. The ability of vegetation to stabilize soils, trap sediments, and reduce flow velocities (Sandercock et al. 2007) can create a feedback process which promotes further vegetation establishment and enhancement of these stabilizing features. This can result in a strong influence on channel geometric features such as width (Anderson et al. 2004).

Riparian and aquatic fauna depend on vegetation communities and channel structures for refuge, spawning, nesting, rearing, and food supply. Critical morphological characteristics include the nature of the substrate, and the presence of pools, riffles, and shade. Flow characteristics such as depth, velocity, timing, temperature and clarity are tied to all aspects of faunal life cycles and provide triggers for many species to lay eggs, hatch or metamorphose. Flows also play a role in seed dispersal, distribution of organic matter, and oxygenation.

3.6 Development Alters Hydrologic and Geomorphic Processes

Land use changes have the potential to alter both hydrologic processes and geomorphic processes, thereby impacting channel stability, habitat, and aquatic biota, unless appropriate controls are implemented. Hydrologic processes are changed by the introduction of impervious surfaces, the connectivity of these surfaces, compaction of soil, removal of vegetation, and increase in drainage densities. The natural proportions of infiltration, runoff, and evapotranspiration are altered in such a way as to increase runoff volumes, frequency of runoff events, long-term cumulative duration of runoff and peak flows, as well as reduced times to peaks. Collectively, these changes are referred to as hydromodification (SCCWRP 2005b). Relative changes in runoff due to development are most pronounced for flows with a low return period (frequent flows). Base flows may either decrease due to reduced groundwater recharge, or increase due to the discharge of imported water such as dry weather irrigation. Dry weather flows in urbanized areas may be substantial; for example, average dry weather runoff in the Ballona Creek watershed has been estimated at approximately 180 cubic meters / square kilometer per day (Stein and Ackerman 2007). Water temperature may also increase as a larger percentage of precipitation in urban areas reaches streams as overland flow, rather than as interflow (Nelson and Palmer 2007).

For purposes of this report, changes to geomorphic processes, as well as hydrologic processes, are addressed under the term hydromodification. Development directly affects geomorphic processes in a number of ways, most importantly (for purposes of this discussion) by reducing sediment supply to streams through the introduction of impervious surfaces, and by changing bank resistance by removal or alteration of riparian vegetation. Combined with hydrologic changes, the result can be a radically altered balance between sediment supply and transport, the fundamental determinant of channel geometry and stability.

The USEPA (2007) defines hydromodification in a broader sense within the context of non-point sources pollution, and identifies three categories of hydromodification activities: (1) channelization and channel modification, (2) dams, and (3) streambank and shoreline erosion. However, neither the definition nor the guidance document was found to be helpful for purposes of addressing new development and re-development issues due to a lack of clarity in separating cause from effect and the focus on managing impacts rather than underlying causes.

While the introduction of urban pollutants into stormwater runoff is not specifically categorized under the term hydromodification, an increase in surface runoff will facilitate the discharge of these pollutants into receiving waterbodies. Later in this report, we discuss the relationship between hydromodification management and water quality improvements.

3.7 Development Linked to Stream Impacts

There are numerous studies linking urbanization to stream impacts, with particular focus on changes to channel morphology and changes to the integrity of aquatic biota. Two key publications were recently issued which included extensive literature reviews and a synthesis of findings on these topics: "Impacts of Impervious Cover on Aquatic Systems" by The Center for Watershed Protection (CWP 2003), and "Physical Effects of Wet Weather Flows on Aquatic Habitats: Present Knowledge and Research Needs" published by Water Environment Research Foundation (Roesner and Bledsoe 2003). There are important differences in how the two documents interpret and weigh the evidence and these are discussed later in this paper under the section on Impervious Cover; however, there is broad agreement regarding the fundamental findings from the reviewed literature, which are summarized here.

In an attempt to simplify the complex and inter-related hydrologic, geomorphic and biological processes at work, this summary categorizes these impacts in terms of channel morphology, habitat, biota, and water chemistry.

3.7.1 Impacts to Channel Morphology

Impacts to channel morphology are manifested as channel enlargement (either widening, downcutting, or both), increased local sediment yield from the eroding reach, changes in bed substrate conditions, decreased bank stability, and overall simplification of stream habitat features such as pools and riffles. These changes are mechanistically linked to the long-term increase in volumes, durations, and frequencies of the entire range of sediment transporting flows and the resulting increase in work performed on the channel boundary. This has important implications for management strategies, as discussed later in this report, and is a significant departure from the focus on peak flow or volume increases associated with individual design-storm or discrete events.

Reductions in sediment delivery from the watershed due to development may exacerbate instability when combined with increased runoff (Bledsoe 2002). Changes in one channel reach may propagate upstream in the form of a headcut, or downstream in the form of increased or decreased sediment delivery. Damages may extend beyond the stream channel itself to adjacent property, infrastructure, and utilities; in the latter case, this may create significant threats to water quality.

3.7.2 Impacts to Habitat

Impacts to stream habitat can occur due to multiple, interrelated mechanisms. Channel erosion and bank instability may result in the loss of associated riparian vegetation, potentially initiating a positive feedback response in which erosion is accelerated. Habitat changes are not just a result of morphological impacts, but can also result directly from changes in streamflow regime. For example, increases or decreases in baseflow or changes to the seasonal availability of water will directly determine the extent and type of riparian vegetation capable of thriving in that environment. White and Greer (2006) found an expansion of willow-dominated vegetation in a San Diego County creek over 34 years of watershed urbanization, which they attribute to increased flows from impervious surfaces and increased dry-season runoff of imported landscape irrigation water. Furthermore, an increase in the availability of water in a naturally intermittent or ephemeral system may allow invasive vegetation to become established and out-compete native plants.

3.7.3 Impacts to Stream Biota

Increased pollutant loads in urban areas makes it more challenging to discern the contribution of hydrologic changes versus water quality changes with respect to impacts on faunal communities such as fish, amphibians, and invertebrates. However, there are numerous studies which identify mechanistic links between hydromodification and biotic condition, either mediated by morphological and/or habitat changes, or due directly to altered flow regime. The simplification of channel morphology eliminates suitable substrate for macroinvertebrates and fish, as does the filling of gravel beds with fine sediments from eroding banks. Excess erosion can eliminate predator refuges in overhanging banks and reduce canopy shade which maintains cool water temperatures. Vegetation changes can have cascading effects on indigenous fauna which require native plants for food or nesting. For example, faunal community changes in urban streams in the Santa Monica Mountains were associated with increased water depths and flow; this conversion to more permanent systems may have enhanced invasion by exotic species thereby negatively affecting diversity and abundance of native amphibians (Riley et al. 2005).

Poff et al. (1997) emphasized the importance of the natural flow regime and its natural variability as critical to ecosystem function and native biodiversity; they cite numerous studies showing how the magnitude and frequency of high and low flows regulate numerous ecological processes, and the impacts of changed flow regimes on these processes. Chadwick et al. (2006) concluded that alteration of streamflow was one of the primary determinants of changes in leaf litter breakdown rates in urbanized headwater streams in the southeastern US. Konrad and Booth (2005) identified four hydrologic changes resulting from urban development that are potentially significant to stream ecosystems: increased frequency of high flows, redistribution of water from baseflow to stormflows, increased daily variation in streamflow, and reduction in low flow. They caution that ecological benefits of improving habitat and water quality may be tempered by persistent effects of altered streamflow and that hydrologic effects of urban development must be addressed for restoration of urban streams.

3.7.4 Impacts to Water Chemistry

As mentioned above, the introduction of pollutants from urban land uses is not explicitly included under the term hydromodification, but the two issues are related through the alteration of surface runoff and infiltration processes. Aside from urban pollutants, however, water chemistry can be impacted directly due to accelerated channel erosion. Increases in suspended sediment and turbidity decreases available sunlight and has adverse impacts on the growth of aquatic plants and plankton.

Temperature increases may also cause direct impacts to biota. As part of a study of urban streams in Maryland, Nelson and Palmer (2007) found that the upper temperature range for growth of freshwater fish species was often exceeded, especially at sites characterized by low discharge and high impervious surfaces.

3.7.5 Impacts to Beneficial Uses

The impacts discussed above may result in a reduction in the ability of the receiving water to support designated beneficial uses, such as: coldwater (COLD) or warm water (WARM) aquatic life habitat; waters that support rare, threatened, or endangered species and associated habitat (RARE); or high quality aquatic habitats suitable for reproduction and early development of fish (SPWN).

3.7.6 Pre-Urban Impacts

It is also important to recognize that channel instability may be present in areas not yet affected by urban development. Natural causes include high rates of tectonism, as well as climate cycles and threshold effects as discussed earlier.

Land use conversion from open space to agriculture or livestock grazing can have significant impacts on streams through the same mechanisms discussed above, including removal of natural vegetation, soil compaction, changes in sediment supply to stream channels, and direct modification of riparian buffers. An important component of hydromodification management is an assessment of watershed and stream channel condition and historic land uses in order to understand the baseline conditions; this is further discussed as part of management options below.

3.8 Local Influences on Development Impacts

It is important to note that the studies discussed above have found a wide variation in the degree of impacts, and in some cases even the direction of response may differ (for example, bed substrates may exhibit increased embeddedness or conversely, may coarsen). This applies to all categories of impacts, and is also true of the underlying alterations to hydrologic and geomorphic processes.

Climate, rainfall, geology, stream type, and many other local factors will influence the extent to which development alters hydrologic and geomorphic processes. For example, where soils have high infiltration capacity, the conversion of open space to impervious surfaces will cause greater increases in runoff and stream flows compared to a development on low infiltration soils. As a result, the instream effects can be much more dramatic. The significance of the observed impacts will also depend on the stream's physiographic context and spatial and temporal patterns of urban development (Konrad and Booth 2005), as well as the spatial and temporal scale of the study.

For Southern California streams, the threshold of response is estimated to be approximately three to five percent total imperviousness (for catchments less than five square miles) (SCCWRP 2005a, 2005b), as compared to seven to ten percent for other portions of the US. Geosyntec determined from field evidence that channel instabilities were evident when the percent imperviousness was between six percent and nine percent for study sites within the south San Francisco Bay area (SCVURPPP 2005). Large scale studies of hydrologic responses to urbanization (Chin 2006; Poff et al. 2006) also highlighted the regional variation in these responses and reinforced the need to understand local watershed and channel characteristics when managing hydromodification impacts. Gregory (2006) emphasized the contrasting response to human impacts in humid versus arid channel systems. Even within a single region, climate variability and basin physiographic characteristics can affect hydrologic responses to urbanization (Chang 2007).

Attributes of the development project itself will also influence the extent of impacts. For example, Beighley et al. (2003) predicted through modeling a Southern California watershed that as urbanization progresses upslope from the coastal plain, effects will be compounded by orographic rainfall and the spatial distribution of development, thereby having a greater relative impact on peak discharges and runoff volumes than past development. Colosimo and Wilcock (2007) performed a thirteen year study of channel geometry on 19 stream reaches in an urbanizing watershed in Maryland and found variation in channel response to urbanization and percent imperviousness, which the authors attribute to the multitude of additional factors involved such as position of stream reach within the basin, presence of herbaceous vegetation, presence of eroding upstream reaches acting as sediment sources, channel constrictions, or grade control structures.

3.9 Impervious Cover as a Metric

As mentioned earlier, there are important differences in conclusions between the Center for Watershed Protection (CWP 2003) report and the Water Environment Research Foundation (WERF) report (Roesner and Bledsoe 2003). As its name indicates, the CWP report focuses on the impacts of impervious cover (IC), building on the impervious cover model (ICM) previously introduced for general watershed planning purposes (Schueler 1994 and CWP 1998). This model predicts a decline in most stream quality indicators when watershed IC exceeds ten percent and severe degradation beyond 25 percent. The 2003 report re-examines the ICM in light of new data, addressing issues of statistical variation and regional differences, and noting that it is not certain if the ICM accurately predicts biological indicators in arid and semi-arid climates. The report also raises the critical question of the influence of watershed treatment practices and discusses studies aimed at answering this question. While it acknowledges that the generation of stormwater ponds evaluated in these studies were not adequately designed to prevent channel erosion or to protect habitat (see discussion below on peak flow control), and while it also identifies further studies to answer this question as one of three critical research directions, the CWP conclusions are generally negative regarding the potential for watershed practices to mitigate for IC.

In an interesting contrast to these conclusions, the WERF report emphasizes the limitations of current attempts to link stream impacts to gross measures of development such as total imperviousness, observing that these measures provide little meaningful information to understand key processes and to create practical strategies for mitigation. Roesner and Bledsoe contend that flow controls in urban drainage systems have strong influence on runoff hydrology, but this fact is not recognized in studies that attempt to relate stream impacts to gross imperviousness only. They stress that predictive models of reach-scale habitat changes must account for the connectivity and conveyance of the drainage system and relevant stormwater controls.

While some studies continue to use impervious cover as a metric for stream health impacts (Schiff and Benoit 2007), others have found statistically significant relationships between landscape patterns and stream biotic integrity, suggesting that patterns of urban development matter to aquatic ecosystems (Alberti et al. 2006). Several researchers highlight the difference between total impervious area, which they argue need not be specifically limited, and effective impervious area, which is the more meaningful metric with respect to hydromodification control (Walsh et al. 2005; Walsh, Fletcher, and Ladson 2005). This supports the idea that it is the drainage design which is most important, rather than specific limits on impervious area. Studies by Booth et al. (2004) demonstrate that impervious area alone is a flawed surrogate of river health.

The following section discusses recent developments in site design which have the potential to reduce hydromodification and which therefore have implications for prediction and management of impacts. This is followed by a discussion of appropriate metrics for prediction and control in light of these design approaches.

3.10 Changing Approaches to Development Design

New approaches, including incorporation of best management practices (BMPs) both on site and instream, and the use of watershed protection and low impact development (LID) strategies, are changing the nature of developments with respect to the characteristics that cause hydromodification. These new approaches, when applied through quantitative analyses based on continuous long-term simulations, have the potential to significantly reduce those changes to hydrologic processes that took place through traditional development practices.

3.10.1 Water Quality BMPs

Structural BMPs designed for water quality treatment are now a common component of new developments and re-development projects, in accordance with MS4 Permit requirements. Capture requirements for volume-based water quality treatment structures (e.g., extended detention basins, wetponds, or wetlands) can typically be on the order of the 85^{th} percentile storm event, or 80 percent of the average annual runoff volume. Some structural BMPs have the capacity to infiltrate a significant portion of captured volumes; Strecker et al. (2004) summarized data for BMPs which showed that biofilters and dry extended detention basins provide an average of approximately 40% and 30% reduction, respectively, in the volume of captured runoff. While the resultant infiltrated volumes alone are not sufficient for hydromodification control, there clearly can be synergies between water quality treatment and hydromodification management efforts.

3.10.2 Hydromodification Control BMPs

In an early attempt to manage channel erosion, local regulations limited increases in peak flows associated with development projects. Peak flow control basins were ultimately found to be inadequate due to their failure to address the full range of geomorphically significantly flows and lack of consideration for receiving water geomorphology in their sizing criteria (MacRae 1996; Roesner et al. 2001). In many cases, they were found to cause more harm than no controls at all by increasing the duration of erosive in-channel flows.

However, recent improved understanding has lead to the design of basins to maintain the full flow duration profile of sediment-transporting flows (Palhegyi and Bicknell 2004; Palhegyi et al. 2005). Currently, such basins have been designed or planned for several large development projects in California to address California Environmental Quality Act (CEQA) or local hydromodification control regulatory requirements. Under CEQA, a change to a project site's runoff regime would be considered to create hydrologic conditions of concern if the change could have a significant impact on downstream natural channels and habitat integrity. Flow duration control basins can combine water quality benefits with hydromodification mitigation, and can be applied at multiple scales, from an individual project scale to a regional level, to address both proposed and existing flows. Further discussion regarding quantitative metrics for flow duration control design is provided in the next section.

3.10.3 Watershed Protection Strategies

The Center for Watershed Protection outlines an approach which apples eight tools to protect or restore aquatic resources, among which is land use planning. Although large lot zoning has been a widely used planning technique to attempt to mitigate development impacts and may be effective for very large lot sizes (5 to 20 acres), this approach can actually contribute to regional sprawl and increase the total amount of imperviousness created for each dwelling unit due to associated road networks (Schueler and Holland 2000; Stone 2004). Recent modeling studies show urban cluster design to be one of the most effective at reducing runoff volume (Brander et al. 2004).

3.10.4 Low Impact Development / Distributed Infiltration

Low impact development is a site design strategy whereby stormwater is controlled at the source through distributed controls with the goal of maintaining or replicating the pre-development hydrologic regime. USEPA (2000) summarized a literature review on the application of LID in new development and existing urban areas, as well as studies of LID projects which provide evidence of effectiveness in reducing stormwater runoff volumes. The report found that LID offers both economic and environmental benefits, but may still necessitate structural BMPs in conjunction with LID in order to achieve watershed objectives; Williams and Wise (2006) also concluded, based on modeling studies, that LID would require augmentation by basins for very large events. LID appropriateness depends on site conditions such as soil permeability, slope and water table depth, in addition to spatial limitations.

Similarly, McCuen (2003) suggests an objective of replacing the natural storage volume that is lost during development with a storage volume that is hydrologically equivalent in terms of its magnitude and spatial and temporal distribution. An increasing number of studies focusing on monitoring or modeling runoff from various distributed infiltration systems are finding the potential for significant reductions in runoff volumes (Carter and Rasmussen 2006; Sullivan et al. 2006; Horner et al. 2004; Villarreal and Bengtsson 2004), increased lag times (Hood et al. 2007), increased groundwater recharge (Horner 2006), and an overall water balance closer to pre-development conditions (Holman-Dodds et al. 2003). However, there may be limitations on the extent to which distributed infiltration systems can be implemented in highly urban areas or re-development projects. Davis (2005) cautions that forced incorporation of LID infiltration practices could encourage urban sprawl with potentially greater ultimate environmental impact.

3.10.5 Development Design Conclusions

Recent incorporation of structural BMPs and changes in site design practices mean that gross measures of imperviousness are insufficient for either predicting or controlling impacts from these developments. The extent to which impervious surfaces are "disconnected" (drained to pervious surfaces, rather than directly to stormwater system piping) will affect the extent to which hydrologic processes are altered. For example, for the Alameda Countywide Clean Water Program, Geosyntec estimated that the amount of pervious surface required to effectively disconnect impervious areas would range between 18 and 23 percent of the impervious area draining to it, depending on soil type. This assumed that the pervious surface area had an equivalent infiltration rate as the catchment area before development and 12 inches of total storage depth (surface and porosity). Holz (2003) noted that Prince Georges County, MD, currently uses 7 percent as a presumptive standard (meaning that, at this level, no calculations are required to justify the design); however, he suggested that in the Puget Sound, WA area, a 2:1 ratio of bioretention facility to impervious area (200%) be established as the presumptive standard.

However, the potential for variation in the ratio of impervious-to-pervious area for "disconnected" surfaces means that metrics such as "effective impervious" or "connected impervious," although an improvement over gross impervious area, alone are not sufficient. Additional metrics that characterize more fundamental processes associated with response of watersheds to development are needed to better quantify hydrologic alteration, as well as to incorporate geomorphic factors to predict impacts, as discussed in the next section.

3.11 New Metrics to Explain, Predict, and Manage Impacts

As approaches to new and re-development site design evolve, and as there is an increasing understanding of the mechanisms which link development to stream degradation, new metrics have been developed with the aim of explaining, predicting, and/or managing hydromodification impacts.

3.11.1 Quantifying Hydrologic Alteration

Efforts have been made to develop new measurements which reflect those characteristics of stream flow which are directly related to channel instability. Hydrologic metrics that reflect chronic altered streamflows provide a direct mechanistic link between changes associated with urban development and declines in stream biological condition (Booth et al. 2004). This work has also further highlighted the need to address underlying hydrologic changes in addition to instream stabilization in order for restoration efforts to be effective. For example, Booth (2005) found strong correlations of stream biotic health with a measure of the flashiness of the hydrograph (Tq-mean = the fraction of a year daily mean discharge exceeds annual mean discharge), concluding that sustainable stream restoration must address catchment processes at their relevant scales including rehabilitating upland hydrology (e.g., stormwater re-infiltration or LID). Konrad et al. (2005) used three streamflow metrics that integrate storm-scale effects of urban development over annual to decadal timescales to study hydrologic effects of urbanization on gravel-bed stream channel form and stability. The authors concluded that urban stream flow patterns are likely to lead to increased frequency and extent of streambed disturbance even after transient adjustments of the channel.

The above metrics are focused on highlighting fundamental hydrologic alternations and predicting stream impacts. Relationships between channel conditions and other measures have also been studied, including landscape-scale metrics (McBride and Booth 2005), a ratio of applied shear to critical shear stress (Donigian and Love 2005), and a ratio of peak discharge to precipitation (Beighley and Moglen 2002), with varying levels of predictive success. However, these measures have not been linked to specific site designs, nor have they been proposed as a means to establish design standards for new developments. Toward these ends, a long-term characterization of runoff can be developed through the use of flow duration curves, which show the amount of time for which a given flow rate is equaled or exceeded. The following sub-section describes how this measure of hydrologic alteration can be combined with local geomorphic conditions to quantify the probability of physical impacts to the stream channel and to set standards for site design.

3.11.2 Quantifying Impact Probability

For a specific reach of stream, the flow rate at which bank erosion and/or sediment transport is initiated can be determined through the use of hydraulic modeling given the channel geometry and boundary characteristics (material characteristics, particle size, and associated critical shear stresses) or through field measurement of transport. The extent to which a development project increases the long-term duration of flows above this critical flow for bank erosion and/or sediment transport is a quantifiable estimate of the potential for geomorphic impacts (Palhegyi et al. 2003; Palhegyi and Bicknell 2004; Palhegyi et al. 2007).

Palhegyi and Bicknell (2004) present an Erosion Potential (Ep) index which was developed and used as a metric to compare the sediment transport / work capacity of pre- versus post-development flows. This approach is based on the use of long-term, continuous simulation of the entire range of sediment-transporting flows; the Ep metric is a time-integrated ratio of work done on the channel (or sediment transported in the channel) by post-development flows compared to pre-development flows. A value greater than one predicts an increase in work done by post-development flows over that in the pre-development condition. Traditional development with no controls could commonly result in Ep values as high as 10, 20, or even 40, indicating dramatic increases over pre-development conditions.

To test and validate the methodology, Geosyntec compared field evaluations of channel stability/instability to Ep values computed for existing versus pre-urban conditions; results showed a strong capability of the Ep methodology to predict stream impacts, as more than 80 percent of the model predictions were found to agree with the field evidence. This metric is rooted in a mechanistic understanding of how flow changes affect geomorphic processes, and is correlated to observed stream impacts. Furthermore, Ep can be directly applied in the design of management strategies (Palhegyi et al. 2005) for on-site hydromodification control, as well as for instream designs (Palhegyi and Rathfelder 2007).

Ep can also be used to evaluate alternative control standards by estimating the likelihood of channel instability. Palhegyi, et al. (2005) compared various flow control designs based on peak flow matching, hydrograph matching (including peak and volume, but for discrete events), and flow duration control, using Ep as a measure of likelihood of channel instability; this study found that only flow duration control achieves the desired range of Ep values. Other modeling studies have used a comparison of flow duration (Nehrke and Roesner 2004) or Ep (Rohrer and Roesner 2006) to evaluate various controls; results showed the inadequacy of discrete event-based approaches as they fail to consider the full range of geomorphically-significant flows, and the accumulated affects of these flows over time (i.e., long-term cumulative duration).

3.11.3 Long-term Continuous Modeling

While the specific application of flow duration control and Ep analysis to the design of control structures is still relatively new, there is widespread acknowledgement of the importance of the fundamental components, specifically the use of long-term, continuous simulations using the full range of geomorphically significant flows, and a number of studies have incorporated or recommended this approach (Palhegyi, et al. 2003, 2005, and 2007; Fan and Li 2004; SCCWRP 2005a; Harris and Adams 2006). A recently developed suite of analysis tools for fluvial systems, GeoTools (Bledsoe et al. 2007) supports the calculation of Ep and other metrics, given flow time series and basic geomorphic data, potentially making this approach more accessible.

3.11.4 Quantifying Sediment Supply Changes

A further development in metrics addresses the issue of sediment supply reduction occurring as a result of open space development. The current understanding of sediment transport in stream channels supports the use of a capacity-supply ratio (CSR) (Soar and Thorne 2001) as the basis for accounting for reduced sediment supply in flow control and channel restoration designs. CSR is calculated as the bed material load transported through the restored reach by the natural sequence of flow events over an extended time period divided by the bed-material load transported into the restored reach. This approach states that maintaining or restoring sediment continuity through the protected or restored reach requires an assessment of the sediment budget as determined by the magnitude and frequency of all sediment-transporting flows over the long-term.

To address changes in sediment supply delivered to the receiving channel, the CSR supports a refinement to the Ep methodology through modification of the “target value.” The target value of the Ep metric, for purposes of designing a flow duration control basin or a channel restoration, is commonly set at one (1.0) to represent the equivalence of pre-development and post-development sediment transport capacity. However, as discussed earlier, since sediment supply reduction has the same effect as increased runoff, the sediment transport capacity of post-development flows would need to be reduced even further, below the pre-development condition.. By reducing the target Ep value, sediment supply changes can be quantitatively accounted for in flow duration control basin or instream design standards (Palhegyi and Rathfelder 2007), although this approach is still fairly new and may need future refinement.

3.11.5 Quantifying Water Balance Changes

A final metric or quantitative approach which is becoming more common is the use of a water balance (or water budget) approach to evaluating changes between pre- and post-development conditions (Dow and DeWalle 2000; Holman-Dodds et al. 2003; Villarreal and Bengtsson 2004). While it does not characterize flow changes at the same level of detail, the water balance approach examines additional components of the hydrologic regime not addressed by a flow duration analysis or an Ep calculation, including seasonality of flows (of high importance for riparian ecology), and changes in groundwater recharge and evapotranspiration (of concern for integrated water resources and climate change planning).

3.11.6 Assessment Techniques

Due to the important role that local watershed conditions and pre-development stream stability play in determining development impacts, a quantitative assessment is a key component of a hydromodification management program. A component of this assessment process is the application of a classification system based on type (e.g., meandering, braided), substrate (e.g., bedrock, gravel, sand), channel geometric features and relationship to floodplain (Rosgen 1996; Montgomery and Buffington 1993). While the present level of such classification systems are well suited to description and communication, they are not currently appropriate for prediction of future channel changes (Juracek and Fitzpatrick 2003; Simon et al. 2007).

3.12 Summary and Implications for Managing Hydromodification

Channel stability and riparian ecology are functions of continuous, long-term hydrologic and geomorphic processes, which can be altered by development. The extent of these alterations is strongly affected by regional climate and local watershed characteristics, as well as the nature of the land use changes and associated drainage design. Resulting impacts to stream systems can be wide-ranging, extensive in magnitude, and long-lasting.

Early approaches to hydromodification control were unsuccessful, as they addressed only one aspect of hydrologic change (peak flow) and were not integrated into broader planning strategies.

The traditional metric of impervious cover used to correlate land use changes with stream impacts is also limited, in that it does not account for local conditions or site design attributes.

The current scientific understanding of hydromodification recognizes the need to address the full range of hydrologic and geomorphic processes and their complex interactions with stream ecology. Combined with evolving approaches to site design, this has necessitated the development of process-based, time-integrated metrics for prediction and control, as well as highlighted the need for a more comprehensive approach at the watershed planning level. The following are the major conclusions and specific recommendations for hydromodification management.

3.12.1 Overall Approach

- Hydromodification is best addressed with a suite of strategies including site design, onsite controls, regional controls, instream controls, and restoration of degraded stream systems.
- Hydromodification control strategies should be integrated with other watershed-level planning elements including clustered development, integrated land use planning, and stream restoration efforts.
- Local variations in critical watershed and climate characteristics such as precipitation, slope, geometry, bed and bank materials, and vegetation require region-specific management approaches which take these elements into account when setting standards.
- A baseline assessment is critical to understanding existing conditions, previous impacts, and future development plans for the watershed, in order to choose the most appropriate management strategy.
- Hydro-geomorphic modeling provides the best approach to develop our understanding of the complex inter-relationships between watershed and stream processes and provides our best chance at identifying successful management strategies.
- Hydrologic modeling should be based on continuous simulations, over long-term (20 to 30 year minimum for good statistical distributions) periods.
- Models must also consider the effects of sediment supply reduction and the compounding impacts this creates when combined with increased flows.

3.12.2 Implications for Site Design / LID

- LID principles should be incorporated wherever possible, as they have the potential to provide the closest reproduction of natural hydrologic processes due to the distributed nature of the infiltration approach. However, it is unlikely that LID alone will be able to fully address hydromodification in all cases.
- Furthermore, Davis (2005) warns that “from a regional development perspective, incorporating LID should not encourage urban sprawl. A forced over-implementation of infiltration practices could propel the development beyond its initial boundaries and result in more land being consumed. The cumulative impact may be greater than that of

traditional approaches if more undeveloped land is used and more roadway infrastructure is created to connect the sprawl development. LID practices should be carefully integrated into all development densities without forcing density reduction. High-density LID represents a formidable challenge."

3.12.3 Implications for On-site or Regional Structural Controls

- The Erosion Potential (Ep) metric is currently the best metric available for designing flow controls (as well as instream controls) with the objective of eliminating, minimizing, or managing direct physical impacts to stream systems. It is a time-integrated metric based on long-term continuous modeling, which quantifies the alteration of both the hydrologic and geomorphic processes that contribute to stream instability.
- However, because changes to the flow regime can have direct impacts on riparian ecosystems beyond their effects on channel stability, as well as impacts on groundwater recharge and local evapotranspiration, an Ep-based standard may not completely mitigate for hydromodification impacts.
- A water balance analysis that addresses seasonality or other life cycle factors has potential to identify additional hydrologic changes which may impact riparian ecosystems. While a water balance is an established calculation with a long history of use for multiple purposes, it has not been developed into a system for quantitatively evaluating, predicting, or controlling for development impacts to riparian ecosystems. (See below for a further discussion under future challenges.)

3.12.4 Implications for Instream Channel Controls / Restoration Design

- Instream hydromodification controls and channel restoration designs must be based on geomorphic principles integrated with long-term analytical analysis of work and/or transport of sediments to be successful.
- Estimates of effective discharge for purposes of stream channel restoration design should be derived from the hydrologic regime representing the developed conditions which the restored channel will experience (Doyle et al. 2007).
- However, Sudduth and Meyer (2006) note that while bioengineered bank stabilization can have positive effects on habitat and macroinvertebrates, it cannot completely mitigate impacts of urbanization. Similarly, Roesner and Bledsoe (2003) caution that reach-scale stabilization of streams does not imply a return of comparable habitat quality and complexity. Walsh et al (2007) also concluded that low-impact catchment drainage design was more important than riparian re-vegetation with respect to indicators of macroinvertebrate health. These findings are consistent with the above discussion regarding direct impacts of altered flow regimes on stream biota.

3.12.5 Implications for the Proposed Approach in the PGCP

With respect to the proposed requirements for matching total volume of runoff between pre- and post-project conditions:

- Managing total volume of runoff is an essential, but ultimately insufficient, control requirement when applied to new and re-development projects (especially when the volume requirement is associated with discrete design storm events)
- Runoff volume is only one of many hydrologic aspects altered by land use changes, and is not mechanistically equivalent to a long-term flow duration series.

With respect to the proposed requirements for not increasing the lag time between pre- and post-project conditions:

- Decrease in runoff travel time is characteristic of urban hydrology; however, it is possible to show the same or even longer travel time for a project, while still increasing the erosivity of runoff. The one article within the literature review that suggested using travel time as part of a control standard (McCuen 2003) allowed for flexibility such that if storage was provided prior to discharge to the stream channel, then travel time upgradient was not a concern.

With respect to the proposed requirements for distributing non-structural and structural controls within all drainage areas serving a first order stream or larger (projects of 50 acres or more) in order to preserve drainage patterns:

- The requirement for distributed controls, while supporting the objectives of LID approaches, does not allow for the many local and project-specific considerations which may make the choice of regional or instream controls more appropriate and protective.
- This requirement is contrary to the many recommendations for addressing hydromodification management with a suite of solutions to accommodate a range of site and watershed conditions and objectives.

With respect to the proposed requirements for preserving all first order drainage divides (projects greater than 2 acres):

- Management of first order streams is discussed in one paper (McCuen, 2003); the author believes these systems have the ability to provide greater hydrologic storage if incorporated into the development plan than if replaced with pipe systems. However, no recommendation was found in this or any other reviewed publication to prohibit alterations to drainage divides at this scale.

3.12.6 Future Challenges and Research Needs

A number of challenges remain related to managing hydromodification impacts from new and re-development. The most important among these include:

- Quantifying the effects of various LID components, particularly the use of small, distributed systems, will require improvements in current hydrologic modeling capacity (Potter 2006).

- The need to retain the increased stormwater runoff on site as much as possible requires infiltration as a primary management strategy. Historically, infiltration in class “C” and “D” soil types has been discouraged for water quality control. Today, however, managing hydromodification requires infiltration in all soil types and thus more research is needed on how best to design infiltration into class “C” and “D” soils.

- There is a need for long-term monitoring of projects which have implemented hydromodification control practices in order to assess the effectiveness of these practices. This monitoring should include the collection of continuous streamflow data to validate predictions and provide calibration data for future modeling work.

- There is a need to understand and reduce the uncertainty in modeling and the selection of values for key variables. For example, an emerging method for identifying the most representative critical shear stress for bank materials is through the use of a jet tester to measure shear stresses in situ (Simon et al. 2002).

- Improved understanding is needed regarding high sediment load streams to determine the extent to which “re-set” events dominate these system and methodologies to quantify thresholds of change.

- Efforts should move beyond stream stabilization to fully address ecological issues as well as integrated water resources planning. Metric development related to stream biota should consider the life cycles of sensitive species and be coordinated with biologists and other work related to Environmentally Sensitive Areas.

- A water balance analysis may offer a further basis for comparison of pre- and post-development conditions by providing complementary information to the flow duration / Ep calculations; however, this approach needs further development to be useful as a control standard.

4. REGULATORY REVIEW – PROGRAMMATIC FINDINGS

4.1 Introduction

Regulations exist in a number of states to control hydromodification impacts associated with development and re-development activities; recently issued and draft revised MS4 Permits throughout Southern California also contain similar requirements. However, these regulations vary widely in terms of the approaches taken and the specific control requirements mandated. Geosyntec reviewed a number of existing and proposed hydromodification regulations and implementation plans within California and nationwide and created a framework which provides a structure to facilitate understanding and comparison of these programs.

The first part of this section defines the elements in the framework and discusses the varying approaches to each element, based on review of existing and proposed regulations. Throughout this discussion, the most technically sound approach within each element is identified (these recommendations are then compiled and summarized in Section 5 of this report). The second part of this section provides a brief overview of a representative selection of existing and proposed regulations and a table summarizing their key attributes.

4.2 Program Framework

The majority of hydromodification regulations contain the following major elements: a development trigger, a stream susceptibility trigger, a set of general site design requirements, a numeric standard for on-site controls, and a methodology for performing site-specific analyses or developing a regionally-applicable model. Two additional elements that are not usually included, but should be integral components of all programs, are numeric standards for instream controls and monitoring requirements. All of these elements are represented in Figure 4-1 below.

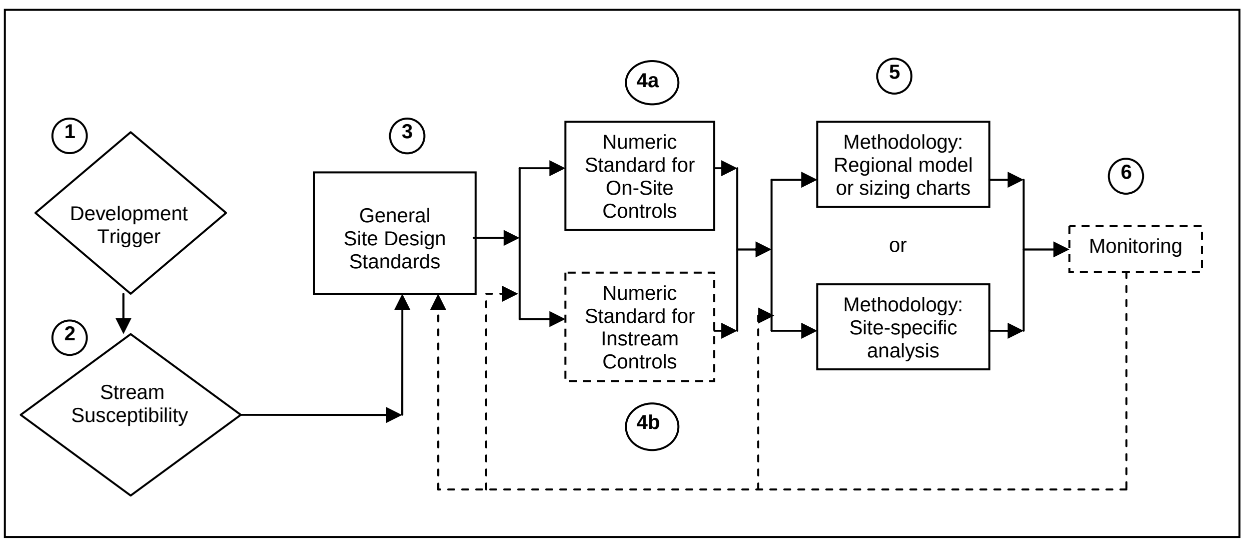

Figure 4-1. Major Elements of a Hydromodification Management Program

4.2.1 Development Trigger

The development trigger is generally a size threshold above which projects are required to comply with the numeric hydromodification control standard. Most regulations already contain thresholds for new developments and re-development projects to which water quality and construction activity regulations apply. These thresholds are commonly based on project land use type in conjunction with size, for example: 20 units or more of single family residential housing, or industrial/commercial projects with two acres or more of connected impervious surface. Thresholds can also be expressed by project size alone; for example, projects that construct 10,000 square feet or more of new impervious area. Triggers for hydromodification control standards may be the same as these existing thresholds, or may be established as a smaller subset.

The primary concern in setting an adequate development trigger is related to the cumulative impact of small projects that do not meet the regulatory trigger. The development trigger should be low enough to prevent cumulative impacts at the watershed scale, while allowing for smaller projects, such as single family homes, to proceed without difficult or infeasible control standards to implement. Many hydromodification programs include additional site design BMP / LID requirements that apply to all projects to address the potential cumulative hydromodification impacts of small projects. Watershed-level HMPs should account for the issue of cumulative impacts from exempt projects and develop regional strategies to address it.

Care must be taken when applying hydromodification control requirements to infill projects in highly urbanized areas, as this could potentially encourage urban sprawl if developers are forced to choose larger tracts of land with more open space to accommodate flow control structures. This trend would conflict with goals for protecting open spaces and maintaining habitat continuity. Where streams in highly urbanized areas are already degraded or channelized, resources may be better spent on stream restoration and/or regional flow control facilities, rather than full control of incremental flow increases which may not be detectible within a highly impacted existing condition. Approaches which claim to be able to provide hydromodification control in dense urban areas through the sole use of minimally-sized BMPs or LID techniques should be viewed skeptically. These approaches are likely to be found inadequate when carefully monitored. Ideally, hydromodification control triggers (and stream susceptibility) should be addressed at the watershed level in a watershed-based HMP, where multiple environmental protection objectives can be addressed and balanced if conflicts are identified.

4.2.2 Stream Susceptibility Trigger

The identification of streams that are (or are not) susceptible to hydromodification impacts allows control requirements to be applied appropriately and cost effectively. Regional efforts are currently underway through the SCCWRP Hydromodification Study to develop a mapping and classification system for streams to determine their susceptibility to hydromodification impacts to channel stability and morphology. Susceptibility will be evaluated based on both current properties and conditions of the stream and future increases in impervious cover. The relative susceptibility of different stream types will be classified based on the erodibility of different channel boundary materials, floodplain connectivity, geologic controls, and other factors. Such a system will help managers prioritize streams for protection and management, although it is not clear to what extent it will consider susceptibility of aquatic biota.

Hydromodification control requirements should not apply to new development and redevelopment projects where the project discharges stormwater runoff into creeks or storm drains where the potential for erosion, or other impacts to beneficial uses, is minimal or nonexistent. Such situations may include discharges into creeks that are concrete-lined or significantly hardened (e.g., with rip-rap, etc.), storm drains discharging directly to the ocean, lake, or other waterbody that is not susceptible to erosion, and construction of infill projects in highly developed watersheds where the potential for single-project and/or cumulative impacts is minimal. Hydromodification control requirements should also not apply to redevelopment projects that do not increase impervious surfaces, or that reduce impervious surfaces, as these projects would not cause hydrologic impacts. There are a number of stream systems where degradation is already occurring and where having the few remaining development projects implement significant hydromodification controls would not solve the existing hydromodification problem. An allowance for the use of geomorphically-referenced stream stabilization techniques or regional hydromodification controls should be considered in these cases.

4.2.3 General Site Design Standards

Some programs include general standards for site design which are related to hydromodification control, including requirements for LID implementation and limits on percent imperviousness. Currently, requirements for LID implementation are generally most appropriate when focused on development of design manuals, guidance documents, and educational outreach by the MS4 Permittees; additional options include requirements for projects to document attempts to maximize infiltration and reduce impervious surfaces as part of the site design. Numeric limits on percent impervious surfaces are inappropriate for reasons discussed in Section 3 of this report.

4.2.4 Numeric Control Standard

For projects that meet the development trigger and that discharge to susceptible watercourses, the numeric control standard establishes the basis for comparing existing and proposed conditions and for determining flow control requirements. In order to understand the differences among the wide variety of numeric standards currently proposed or in place, four components of a complete hydromodification control standard are illustrated in Figure 4-2 below. The recommended method for each component is highlighted in green. These components generally apply to on-site controls; instream numeric control standards are discussed at the end of this sub-section.

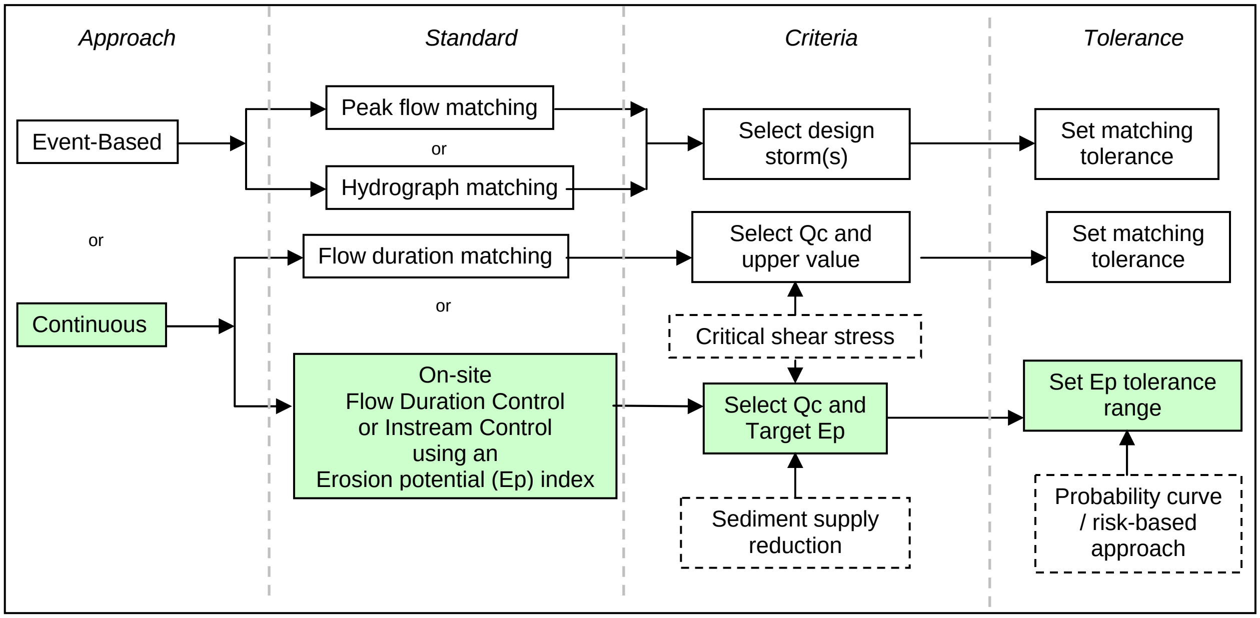

Figure 4-2. Four Components of a Hydromodification Numeric Control Standard

4.2.4.1 Approach

The hydromodification control standard can be based on controlling a discrete event (or series of discrete events) or a continuous series of flows. The current scientific literature supports the use of the continuous approach, as this approach captures the full range of precipitation variation and antecedent moisture conditions that will influence runoff and control measure sizing. Project runoff modeling should be performed using a long term rainfall record of 25 to 30 years or more (ideally in order to capture the effects of wet and dry sequences), in conjunction with a model capable of continuous simulation such as HEC-HMS, SWMM, or HSPF.

4.2.4.2 Standard

The standard refers to the hydrologic aspect(s) that are to be compared and matched between the pre- and post-development condition.

For event-based approaches, the standard is either a peak flow or full hydrograph matching requirement. Problems with peak flow matching have been well described in the literature; by extending the duration of erosive flows, this control strategy can actually increase downstream channel erosion rather than prevent it. Full matching of the hydrograph (peak, volume, and duration) provides some improvement over peak matching, but as mentioned above, event-based controls do not account for the full range of precipitation events and timing, and are not shown to be protective.

For continuous approaches, the standard can be set to require that project runoff flow durations be matched for a continuous range of flow events, or can specify the use of an instream Ep index. The Ep index is the ratio between post- and pre-development sediment transport capacity in the receiving stream channel, calculated based on critical shear stress and sediment transport equations. An Ep of one represents equal transport capacities before and after development, whereas an Ep value greater than one indicates an increase in sediment transport capacity and potential for channel erosion in the post-developed condition. The Ep index has several advantages described further below, including allowing sediment supply reductions to be accounted for (see next paragraph on "Criteria"), allowing the use of a risk-based approach to setting tolerances (see paragraph below on "Tolerances"), and being applicable to both on-site and instream control options (see discussion at the end of this sub-section).

4.2.4.3 Criteria

The criteria are the specific design storm(s) (for event-based approaches) or specific range of flows (for continuous approaches) that are to be matched in the pre- and post-development condition.

For event-based approaches, the criteria may be a single storm or a series of individual storms (e.g. the 2-year, 5-year and 10-year events).

For continuous approaches, the entire range of flows is considered. The lower end of the range is assumed to correspond to the critical flow, Qc, which initiates sediment transport. The critical flow is a function of the channel slope and geometry, as well as of the channel critical shear stress, which in turn is a function of sediment size, degree of consolidation, and vegetative cover. Due to its nature, the critical flow should be determined based on site-specific (for large projects) or locally-developed (for smaller projects) data, and can be identified as a percentage of the two year return flow (e.g., 20% of Q2). A critical flow should always be identified, as opposed to a criteria that encompasses all flows starting at zero. In the latter case, the ability to release stored volumes at a flow rate below the sediment transport threshold would be lost, reducing BMP design flexibility and unnecessarily increasing size and cost.

Where the standard is set for peak and duration matching, the upper end of the criteria defines the presumed limit of the critical range of erosive flows. This should be specified as no less than the ten year return flow (Q10). This value was determined as part of Geosyntec's work on the Santa Clara Valley HMP (Geosyntec 2002) in which it was determined that 95 percent of the total sediment load is transported by flows less than the 10 year peak flow. Where the standard is based on an Ep index, however, there is no need to specify an upper value, as the index will incorporate the entire range of flows (starting at Qc).

An additional advantage of using an Ep index is that it allows for consideration of the reduced sediment supply associated with development. Sediment supply reduction can cause similar impacts to receiving channels as increased flows. The target Ep value, which would normally be set at one (with a tolerance value as discussed below), would instead be reduced in proportion to the reduction in supply, such that long-term sediment transport is fully balanced.

4.2.4.4 Tolerance

Tolerance refers to the deviation permitted when attempting to match the pre- and post-development conditions according to the standard and criteria established. A tolerance is justified due to practical considerations associated with BMP design and construction. Only the Ep index method has an associated data set (developed using California streams) which quantifies the risk of channel instability as a function of deviation from the target value.

4.2.4.5 Numeric Standards for Instream Controls

Where onsite controls are infeasible, grade-control structures, incorporated as part of a “geomorphically-referenced” channel design (SCCWRP 2005a), can reduce channel slopes to maintain stability. The first step in such a design process is the selection of the equilibrium slope. The Ep index provides a basis for determining the post-development channel slope required to match pre-development sediment transport capacity. Geosyntec is unaware of other approaches for channel slope selection which address long-term changes in sediment transport capacity across the entire range of geomorphically significant flows. Therefore, the Ep index is uniquely capable of establishing a hydromodification control criteria for projects where instream controls are determined to be appropriate.

4.2.5 Analysis Methodology

The fourth element in a Hydromodification Control program is the analysis methodology. Two methodologies are presented here: 1) regional models or sizing charts, or 2) site-specific analysis.

Simplified implementation tools, such as hydromodification control BMP design manuals, nomographs, or sizing criteria that relate percent impervious area and soil type (infiltration rates) to BMP volume and land area requirements are feasible, workable, and technically-acceptable implementation tools for large and small projects. The tools would typically be derived from continuous simulation modeling, using watershed-specific rain gauge records and soil types. Ideally, the model would be calibrated using local, undeveloped and gauged watershed data. Each development project would then be required to use the following procedure: first, determine the physical sensitivity of the downstream system. This step could be accomplished via mapping prepared by the MS4 Co-Permittees, or by the project proponent for large projects. Then, if needed based on downstream sensitivity, hydromodification controls would be sized using the simplified implementation tool based on the percent imperviousness of the proposed project. Finally, the project proponent would provide the indicated storage and infiltration volume and area, either in the form of a single BMP, in smaller BMPs distributed throughout the project, or some combination thereof.

The advantages to using the regional model/sizing chart methodology include that the nomographs would be a watershed-based, regionally-calibrated tool that would be easy to access and use by project proponents. This tool would also ensure consistency at the watershed scale. Development of this tool would require time and resources by the MS4 Permittees, or potentially by a proponent of a large, watershed-scale project, in order to be developed prior to use. The tool would provide sizing for project-based or regional controls only, and could not be used for instream hydromodification control measures.

An alternative analysis methodology is project specific analysis conducted by proponents of large projects. Options for site specific analysis and/or agency-approved modification of regional model assumptions should always be provided for projects that can justify these variations and have the capability to perform the analyses. A size threshold for significant projects could be established for which a site specific analysis would be required or allowed. Project specific analysis would also be required for projects that propose instream hydromodification control measures.

4.2.6 Monitoring

The final component of a Hydromodification Control program is monitoring for the effectiveness of the HMP or project-based hydromodification controls. The current lack of hydromodification control BMP effectiveness data is hampering efforts to establish effective standards; therefore, flow monitoring should be required, both at the project-level (at BMP discharge points) and at the sub-watershed or watershed level, in order to further the understanding of hydromodification control.

4.3 Program Comparison

Programs from the following states and municipalities were reviewed and compared in terms of the key elements described above:

a) Western Washington
b) Maryland
c) Ontario, Canada
d) California
   i) San Francisco Bay Area
   ii) San Diego County
   iii) Ventura County
   iv) South Orange County
   v) Los Angeles County
   vi) San Bernardino County

Programs from outside California were selected for inclusion in this program comparison based on their maturity and level of development. The three agencies represented have been addressing hydromodification controls comprehensively since at least 2000 and have published program revisions at least once since that time. While these programs do not necessarily align with the recommendations of this report in every aspect, they are important models in terms of technical perspectives, implementation strategies, and lessons learned from their initial regulatory approaches. These programs were also included in the initial Geosyntec (2002) literature review and informed the development of the Santa Clara Valley HMP.

Programs and regulations within California were selected to represent a range of implementation stages and approaches to hydromodification control. All draft MS4 Permits in Southern California were included in order to assist with the review and comment process.

The following is a brief description of each program. Table 4-1 provides a summary of how the key elements are addressed in each program, and includes publication titles and dates where additional details can be found.

4.3.1 Washington State Department of Ecology – Western Washington

The Washington State Department of Ecology's Stormwater Management Manual for Western Washington (WDOE 2005) contains a hydromodification control standard that is meant to control the increase in flow duration. The standard is based on the assumption that the flow that initiates transport of channel sediment in Western Washington can be generally estimated by the one-half of the 2-year flow. The standard requires maintaining the durations of flows at their predevelopment levels for all flows greater than one-half of the 2-year peak flow up to the 50-year peak flow. The predevelopment peak flow rates for the 2-year and 10-year runoff events are also intended to be maintained when applying this control standard.

The manual prescribes the use of a continuous hydrologic model for the development project hydrologic analysis rather than an event model. Event models were used in the previous version of the manual, but were found to be ineffective.

The Department of Ecology developed a continuous simulation hydrologic model based on the EPA's HSPF (Hydrologic Simulation Program-Fortran) for use in compliance with the Western Washington Manual's hydromodification control standard. This model (The Western Washington Hydrology Model, or WWHM) has been developed based on continuous simulation using long-term (43 to 50 years) precipitation data. The WWHM is provided free-of-charge to the public and is technically-supported by the Department of Ecology.

The hydromodification (flow control) standard is as follows:

> *Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. In addition, the developed peak discharge rates shall not exceed the pre-developed peak discharge rates for 2-, 10-, and 50-year return periods.*

Unless reasonable, historic, site-specific information is provided to the contrary, the applicant shall use the historic vegetation map in the Ecology Hydrology Model to determine the pre-developed condition.

This standard requirement is waived for sites that will reliably infiltrate all the runoff from impervious surfaces and converted pervious surfaces.

Western Washington Alternative Requirement:
An alternative requirement may be established through application of watershed-scale hydrological modeling and supporting field observations. Possible reasons for an alternative flow control requirement include:

- *Establishment of a stream–specific threshold of significant bedload movement other than the assumed 50% of the 2-year peak flow;*

- *Zoning and Land Clearing Ordinance restrictions that, in combination with an alternative flow control standard, maintain or reduce the naturally occurring erosive forces on the stream channel; or*

- *A duration control standard is not necessary for protection, maintenance, or restoration of designated beneficial uses or Clean Water Act compliance."*

4.3.2 Maryland State Department of the Environment

The Maryland Stormwater Design Manual presents a unified approach for sizing runoff controls to treat runoff, maintain groundwater recharge, reduce channel erosion, prevent overbank flooding, and pass extreme floods. This approach includes three volumetric criteria that are designed to meet pollutant removal goals, maintain groundwater recharge, and reduce channel erosion, as well as peak flow criteria to prevent overbank flooding and pass extreme floods. An important feature of the three volumetric criteria is the correspondence with natural hydrologic processes. Explicitly, the recharge criterion is designed to promote groundwater recharge and interflow. Likewise, the rationale for the channel erosion criterion is that runoff will be stored and released in such a gradual manner that critical erosive velocities during bankfull and near bankfull events will seldom be exceeded in downstream channels. The water quality storage volume also provides management at a critical level (⅓ bankfull elevation) within stream channels. When considered together, these three volumetric criteria aim to mimic natural recharge and channel forming processes.

The volumetric criteria are as follows:

The Water Quality Volume is the storage needed to capture and treat the runoff from 90% of the average annual rainfall. In numerical terms, it is equivalent to an inch of rainfall multiplied by the volumetric runoff coefficient (Rv) and site area. The specific rainfall depth to be used depends on whether the site is located in the Eastern or Western rainfall zone of Maryland.

The criteria for maintaining recharge is based on the average annual recharge rate of the hydrologic soil group(s) present at a site as determined from USDA, NRCS Soil Surveys. More specifically, each specific recharge factor is based on the USDA average annual recharge volume per soil type divided by the annual rainfall in Maryland (42 inches per year) and multiplied by 90%. This keeps the recharge calculation consistent with the WQv methodology.

To protect channels from erosion, 24 hour extended detention of the one-year, 24 hour storm event shall be provided. In Use III and IV watersheds, only 12 hours of extended detention shall be provided. The requirement to protect channels from erosion does not apply to direct discharges to tidal water or Maryland's Eastern Shore unless specified by an appropriate review authority on a case by case basis. Local governments may wish to use alternative methods to provide equivalent stream channel protection such as the Distributed Runoff Control method or bankfull capacity/duration criteria (MacRae, 1993).

4.3.3 Ontario Ministry of the Environment, Canada

The Stormwater Management Planning and Design Manual of the Ontario Canada Ministry of the Environment (MOE 2003) promotes the use of watershed and subwatershed planning as the most desirable approach for establishing project stormwater requirements. Standards in subwatershed plans are based on a series of technical studies that establish existing environmental conditions together with the key form, function and linkages of the natural resources in the subwatershed.

In the absence of a subwatershed plan, the manual presents a preferred Detailed Design Approach that establishes controls based on an assessment of stream stability using an erosion potential criteria and an analysis of alternative control measures. If the development project is small relative to the total tributary area of the receiving channel or if the receiving channel is low risk with no habitat value, a simplified approach may be used for the design of stormwater controls.

The Instream Erosion Criteria for the Simplified Design Approach is given as:

The change in instream erosion potential cannot exceed that change which is equivalent to a 10% paving of the basin without implementation of Stormwater Management measures for the control of erosion potential.

The Simplified Design Approach makes use of nomographs to determine detention pond storage volume based on the total amount of directly connected impervious area, the amount of volumetric source control provided through site design techniques, and SCS Hydrologic Soils Group. Separate curves are provided for Soils Groups A to B and C to D. These nomographs were developed through geomorphic assessments carried out on over 40 streams in Ontario, British Columbia, Texas, and Vermont.

Having determined the storage volume required to control instream erosion potential, the next step is to determine the hydraulic performance of the outlet control structure for the detention facility. The Ontario Manual presents a method called the Distributed Runoff Control (DRC) approach. The intent of the DRC approach is to control stream erosion potential for the range of flows exceeding the critical flow with the highest level of control focused on flows in the mid-bankfull range.

4.3.4 State of California

Within California, a number of MS4 Permits contain hydromodification control requirements. MS4 Permits are National Pollutant Discharge Elimination System (NPDES) General Permits issued by the Regional Water Quality Control Boards to county and city municipalities. Phase I covers medium (serving between 100,000 and 250,000 people) and large (serving 250,000 people) municipalities. Most of these permits are issued to a group of co-permittees encompassing an entire metropolitan area. Phase II provides coverage for smaller municipalities, including non-traditional Small MS4s, which are governmental facilities such as military bases, public campuses, and prison and hospital complexes.

A component of the Phase I MS4 Permit establishes standards for new development and re-development projects; in the permits discussed below, this includes requirements for hydromodification control. In the case of the San Francisco Bay Area, these requirements have already been implemented through the development of local Hydromodification Management Plans (HMPs). Two representative HMPs from the Bay Area are discussed. In Southern California, hydromodification regulations exist in a variety of stages: interim standards and less comprehensive requirement are already established and implemented in some counties; more comprehensive standards are either still in draft form, or just adopted and awaiting implementation.

4.3.4.1 San Francisco Bay Area Hydromodification Management Plans

- *Santa Clara Valley HMP*

  The Santa Clara Valley HMP was finalized in April 2005. The program was developed following a comprehensive literature review to assess the state of scientific knowledge regarding the causes of hydromodification and the impacts to stream stability. The numeric control standard is the Erosion Potential (Ep) Index, with a criteria of Ep = 1.0, meaning that post-project sediment transport capacity should equal the pre-project capacity. Numeric controls are applicable to projects which create 1 acre of more of impervious surface over the project site, with exemptions for certain types of redevelopment projects. There is also an exemption for discharges to streams where potential for erosion is minimal such as concrete or hardened channels.

- *Contra Costa County HMP*

The Contra Costa HMP was finalized in May 2005. Projects must demonstrate compliance with the standard by any of the following methods:

1. Show there will be no increase in directly connected impervious area.

2. Use Integrated Management Practices (IMPs) that meet Program design requirements to control all runoff from new impervious areas.

3. Model and compare post-project to pre-project runoff peaks and durations.

4. Show projected increases in runoff peaks and/or durations will not accelerate erosion of receiving stream reaches.

Sizing factors for IMPs, such as planter boxes or vegetated swales, were developed using HSPF and a 35-year record of local hourly rainfall data. The criterion was matching peaks and flow durations from 50% of the 2-year flow up to the 10-year flow.

4.3.4.2 San Diego MS4 Permit

The final revision of the San Diego Permit was adopted on January 24, 2007 by the San Diego RWQCB. Copermittees are required to collaborate to develop and implement a HMP to manage increases in runoff discharge rates and durations from Priority Development Projects, where such increased rates and durations are likely to cause increased erosion of channel bed and banks, sediment pollutant generation, or other impacts to beneficial uses and stream habitat due to increased erosive force. The HMP shall include a number of components, including among others: a literature review; an in-channel standard to maintain the pre-project erosion and deposition characteristics as necessary to maintain or improve stability; a range of runoff flows for which post-project runoff flow rates and durations shall not exceed pre-project runoff flow rates and durations, such that the lower boundary of the range corresponds with the channel flow that produces the critical shear stress that initiates bed movement or that erodes the toe of the banks; criteria for selection and design of management practices; a description of pre- and post-project monitoring to assess effectiveness.

The permit requirements do not apply to projects discharging into channels or storm drains where the pre-existing conditions result in minimal potential for erosion or other impacts to beneficial uses. Criteria for identification of such situations is required to be included as part of the HMP.

4.3.4.3 Ventura County MS4 Permit

The second draft revision of the Ventura County Permit was issued on August 28, 20007 by the Los Angeles RWQCB. It contains interim and final hydromodification control standards; interim standards for projects of 50 acres or more, and final standards are based on an Erosion Potential (Ep) equal to 1, “unless an alternative value can be shown to be protective of the natural drainage system from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat.” The Permittees are required to develop watershed-specific Hydromodification Control Plans (HCPs) that address a range of issues including stream classifications, flow rate and duration control methods, sub-watershed mitigation strategies, and stream restoration measures. The HCP shall also identify the allowable low critical flow which initiates sediment transport, the range of flows and goodness of fit criteria for flow duration control methods, and monitoring and effectiveness assessment, among other elements.

The draft Ventura Permit also includes two other requirements which are related to hydromodification management:

- The Permittees are required to develop a Low Impact Development (LID) Technical Guidance for use by land planners and developers, and to facilitate implementation of LID through a training program.

- The Permittees must require all new and re-development projects to reduce "effective impervious area" (EIA) to less than 5 percent of the total project area. "Ineffective" is defined as draining into a vegetated surface or infiltration trench, or being collected and stored for re-use, but no quantitative criteria are specified.

4.3.4.4 South Orange County MS4 Permit

The draft revision to the South Orange County Permit was issued on February 9, 2007. The permit contains requirements for each Copermittee, as part of its local SUSMP, to develop and apply requirements to Priority Development Projects so that runoff discharge rates, durations and velocities are controlled to maintain or reduce downstream erosion conditions and protect stream habitat. These requirements must include an evaluation of the condition of receiving waters, and an evaluation of the proposed post-construction hydrology and hydraulics in order to assess the effects on receiving waters. Factors for proposed discharges must include changes in volumes, frequency of erosive discharges, durations of erosive discharges and patterns of flow variability.

Interim requirements for projects greater than 20 acres include disconnection of impervious areas using on-site or off-site storm water reuse, evapotranspiration, and/or infiltration for small precipitation events, based on site soil and groundwater limits. Furthermore, runoff must be controlled through one of two methods:

1. Hydrograph matching for a range of return periods from 1 year to 10 years, or

2. Matching flows and durations for a continuous range of return periods from 10% of the 2-yr to the 10-yr

Where stream channels are adjacent to, or are to be modified as part of the development, buffer zones and setbacks for channel movement must be established. Where instream controls are necessary, geomorphically-referenced channel design techniques must be used.

4.3.4.5 Los Angeles County MS4 Permit

The Los Angeles County Permit (issued December 13, 2001) includes a requirement for projects to maximize the percentage of pervious surfaces to allow percolation of storm water into the ground and minimize the quantity of storm water directed to impervious surfaces and the MS4. It furthermore requires that the permittees control post-development peak storm water runoff discharge rates, velocities, and duration in natural drainage systems to prevent accelerated stream erosion and to protect stream habitat.

The Principal Permittee (Los Angeles County Department of Public Works, LACDPW) issued the following Interim Peak Flow Runoff Criteria on January 31, 2005:

> *Post-development runoff from a 2-year, 24-hour storm shall not exceed the pre-development peak flow rate, burned, from a 2-year, 24-hour storm when the pre-development peak flow equals or exceeds five cubic feet per second.*

The Los Angeles RWQCB issued a memo on December 15, 2006 to clarify the provisions of the MS4 Permit with respect to Development Planning. This included a statement that a flow control criteria should be developed for downstream channel protection which takes into consideration flow volume, duration and frequency, to maintain the pre-development distribution of instream flows above the critical flow for streambed erosion, thus preserving the pre-development capacity to transport sediment, while not accelerating down stream erosion. The memo suggests that an appropriate criteria might be set to match discharge rates and durations from 10 percent of the 2-yr, 24-hr flow up to the 10-yr, 24-hr flow.

It is expected that this MS4 Permit will be reissued in 2008.

4.3.4.6 San Bernardino County MS4 Permit

The San Bernardino County Permit was issued on April 26, 2002. It contains requirements for the Permittees to "minimize changes in hydrology," "require incorporation of controls...to mitigate any projected increases in...flows", and to "ensure that post-development runoff rates and velocities from a site do not adversely impact downstream erosion, stream habitat., minimize the quantity of storm water directed to impermeable surfaces and the MS4s; maximize the percentage of permeable surfaces to allow more percolation of storm water into the ground."

The San Bernardino County Stormwater Program issued a Model Water Quality Management Plan Guidance (most recently revised on June 9, 2005) to establish criteria to meet the MS4 Permit requirements. The Guidance uses the following standards:

1. *The project does not create a HCOC [hydrologic condition of concern] if all downstream conveyance channels that will receive runoff from the project are engineered, hardened (concrete, riprap or other), and regularly maintained to ensure design flow capacity, and no sensitive stream habitat areas will be affected.*

2. *The project does not create a HCOC if runoff rates, volumes, velocities, and flow duration for the post-development condition do not exceed those of the pre-development condition for 1-year, 2-year, and 5-year frequency storm events.*

4.3.5 Program Comparison Summary and Conclusions

Additional details regarding each of the programs described above are summarized in a comparison table (Table 4-1) at the end of this section. Based upon this program review and comparison, the following are the key conclusions regarding existing and proposed programs:

- There is wide variation across all program elements for controlling hydromodification impacts of new development and redevelopment.

- Not all standards in California are based on the most current scientific understanding as described in this report; therefore, susceptible streams in these jurisdictions are at risk from the impacts of uncontrolled or insufficiently controlled hydromodification.

- The lack of consistency among programs may create additional costs to the building industry for compliance.

- There is a need to include monitoring and data collection requirements in the regulations to verify control effectiveness and to allow for adaptive management / improvement feedback.

Despite the variation among programs, however, all regulations reviewed applied at the development planning stage. A more detailed discussion regarding why post-construction hydromod control standards are inappropriate within the PGCP is contained in the next section.

A COMPARISON OF HYDROMODIFICATION CONTROL PROGRAMS

Program			Development Trigger	Stream Susceptibility Exemptions	General Requirements	Numeric Control Standard					In-stream Control Standard	Analysis Methodology			Additional Notes
Agency	Publication	Date				Approach	Standard	Criteria	Considers Sediment Supply?	Tolerance		Regional Model / Sizing Charts	Baseline Assumptions	Site Specific Analysis	
Western Washington / Washington State Dept of Ecology	(i) Phase I Municipal SW Permit - Appx 1, (ii) Stormwater Management Manual for Western Washington	(i) Feb 16, 2007, (ii) 2005	Developments adding 10,000 sq-ft or more of impervious surfaces, or converting 3/4 acre or more of native veg to landscaped areas, or causing 0.1 cfs increase in the 100yr flood frequency	Flow control generally not required for discharges to Flow Control Exempt Surface Waters listed in Appx I-E of the Stormwater Management Manual	Natural drainage patterns shall be maintained, and discharges from the project site shall occur at the natural location, to the maximum extent practicable. The Permittee must require On-site Stormwater Management BMPs to infiltrate, disperse, and retain stormwater runoff onsite to the maximum extent feasible without causing flooding or erosion impacts. Roof Downspout Control BMPs shall be required.	Continuous	Flow durations	Match from critical low flow of 50% of Q2, up to Q50	No	No exceedance from 0.5Q2 to Q2; exceedance no more than 10% of time above Q2	Not specified	Western WA Hydrology Model (HSPF)	Pre-development condition (assumed to be forested land cover in most cases)	Allowed; generally requires HSPF, but SWMM or equivalent model may be used in some cases	
Maryland / Department of the Environment	(i) Regulations: COMAR 26.17.02 (ii) Stormwater Design Manual, (iii) Model Stormwater Ordinance	(i) Oct 2, 2000 (ii) Oct 2000, (iii) July 2000 & Suppl 2007	Developments distrubing over 5,000 sq-ft of land area (with some exemptions, inlcuding sites for which the 1-yr post-development discharge is less than 2 cfs)	Channel protection storage volume (Cpv) requirement generally does not apply to direct discharges to tidal water or Maryland's Eastern Shore	Requires site design to promote infiltration and maintain pre-development gw recharge rates. All redevelopment projects shall reduce existing site impervious areas by at least 20% or, if infeasible, provide qualitative control for at least 20% of the site's impervious area.	Event based	Peak flow	Channel Protection Volume = 24-hr extended-detention of the post-developed 1-yr design storm. Also, match 10-yr peak. (Regs also require a Recharge Volume (Rev) to mimic existing rates of gw recharge - this standard may contribute to hydromod control)	No	Not specified	Not specified	Sizing criteria specified in the Stormwater Design Manual which describes required computations. Based on TR-55 peak flow equations.	"Natural conditions of the site"	Not specified	
Ontario, Canada / Ministry of the Environment	Stormwater Management Planning and Design Manual	2003	A development trigger is not mentioned. Appears to apply to all projects	No exemptions stated, but approaches differ based on risk category of stream		Continuous	Erosion Potential Index	The change in in-stream erosion potential cannot exceed that change which is equivalent to a 10% paving of the basin without implementation of Stormwater Management measures for the control of erosion potential. (Appx C)	No	Not specified	Where deemed necessary, must use natural channel design	A "Simplified Design Approach" is provided for sites less than 20 hectares (appx 50 acres) if watershed is >25 sq-km or if receiving channel is low risk with no habitat value	Not specified	Yes, a "Detailed Design Approach" is preferred if data is available to complete the specified assessment steps	Based on MacRae 1996. The intent for the control of erosion potential is the preservation or enhancement of a "stable", sustainable fluvial system and its associated habitat, aesthetic value, educational and recreational potential while accomodating development needs.
Santa Clara Valley, CA / SF Bay RWQCB	(i) MS4 Permit 01-024, Order 01-119; (ii) SCVURPPP HMP Final Report	(i) Feb / Oct 2001; (ii) April 21, 2005	Projects which create 1-acre or more of impervious surface over the entire project site. Exemption for redevelopment projects in watersheds 90% or more built out, with 65% or more impervious surface.	Yes, does not apply to streams where potential for erosion is minimal such as concrete or hardened channels	Not specified	Continuous	Erosion Potential Index or Flow Duration Control	Ep = 1.0. Match flow rates and durations from a critical low flow of 10% of Q2	No	"Goodness of fit" standard for flow duration control: no more than a 10% exceedance over no more than 10% of the curve from 0.1Q2 up to Q10.	Yes, allowed - must meet same Ep criteria	The Bay Area Hydrology Model (in development) for FDC sizing	Pre-project condition.	Allowed	
Contra Costa County, CA / SF Bay RWQCB	(i) MS4 Permit R2-2003-002; (ii) Contra Costa County HMP	May 15, 2005	Any development which will increase directly connected impervious area	Yes, does not apply to streams where potential for erosion is minimal such as concrete or hardened channels ("Low Risk" category), or in some cases of "Medium Risk" category channels following a detailed analysis.	None specified	Continuous	Peaks and flow durations	Match from 50% of Q2, up to Q10.	No	"Goodness of fit" standard: No exceedance from 0.5Q2 to Q2; up to a 10% exceedance allowed for a 1-yr band within the Q2-Q10 range	Instream control / channel restoration is an option	HSPF-based sizing factors provided for a variety of "Integrated Management Practices"	Pre-project condition. Infiltration rate for A/B soils = 0.30 in/hr, and for C/D soils = 0.03 in/hr.	Allowed; shall use continuous model such as HSPF with at least 30 yrs rainfall record; guidance provided on data sources and parameter values	
Los Angeles County, CA / Los Angeles RWQCB	(i) MS4 Permit CAS004001, Order No. 01-182; (ii) LA County DPW Interim Standard	(1) Dec 13, 2001; (ii) Jan 31, 2005	Applies to all Planning Priority Development projects and Redevelopment projects in listed categories which meet redevelopment thresholds.	Only applies to areas tributary to natural drainage systems in Malibu Creek, Topanga Canyon Creek, Upper Los Angeles River, Upper San Gabriel River, Santa Clara River, and LA County coastal streams	MS4 Permit requires Permittees to develop numerical criteria for peak flow control - this has been established through the LACDPW Interim Peak Flow Criteria. The MS4 Permit also requires all projects to maximize pervious surfaces to allow percolation of storm water; furthermore, single-family hillside homes shall conserve natural areas, protect slopes and channels, divert roof runoff and surface flow to vegetated areas before discharge unless it would result in slope instability.	Event based	Peak flow	Match existing 2-yr, 24-hr burned, when the pre-development flow equals or exceeds 5 cfs.	No	Not specified	Not specified	Not developed	LA County manuals provide soil infiltration rates and %imp by land use type	LA County Modified Rational Method	
San Bernardino County, CA / Santa Ana RWQCB	(i) MS4 Permit CAS618036, Order No. R8-2002-0012; (ii) SB County Model WQMP Guidance	(i) April 26, 2002; (ii) June 9, 2005	Applies to listed new development categories and redevelopments within these categories which add or create 5,000 or more sq-ft of impervious surfaces on an already developed site.	Controls not required if all downstream conveyance channels that receive runoff are engineered, hardened and regularly maintained and no sensitive stream habitat areas will be affected.	Requires permittees to "minimize changes in hydrology," "require incorporation of controls...to mitigate any projected increases in...flows", and to "ensure that post-development runoff rates and velocities from a site do not adversely impact downstream erosion, stream habitat., minimize the quantity of storm water directed to impermeable surfaces and the MS4s; maximize the percentage of permeable surfaces to allow more percolation of storm water into the ground."	Event-based (from County Model WQMP Guidance; MS4 Permit does not specify)	Hydrograph matching (rates, volumes velocities and flow duration)	Match 1-yr, 2-yr, and 5-yr storms	Recognizes potential impact of sediment supply reduction, and requires reduction calculations using USLE, but not clear how changes are factored quantitatively into site design criteria.	Not specified	Not specified	Not developed	Not specified	Sites from 0-10 acres use Small Area Runoff Hydrograph method; greater than 10-ac used Unit Hydrograph Method (SB County Hydrology Manual, 1986)	
Ventura County, CA / Los Angeles RWQCB	DRAFT MS4 Permit CAS004002, Order No. 07-xxx	FIRST DRAFT issued Dec 27, 2006; SECOND DRAFT issued Aug 28, 2007	Event-based Interim Standard applies to projects < 50-ac, which meet the definition of new or re-development	Control measures are to protect "natural drainage systems which include unlined or unimproved (not engineered) creeks, streams, rivers and their tributaries...located in the following watersheds: Ventura River, Santa Clara River, Calleguas Creek and miscellaneous Ventura Coastal. Requires permittees to participate in the SMC Hydromod Control Study which includes establishment of a stream classification system.	All new and re-development must have % "effective impervious area" </=5% and implement LID principles into project design	Event based	Hydrograph matching	2-yr, 24-hr	No	Peak flow and volume to match within 1%	Not specified	Not developed	Not specified	Not specified	
			Continuous (Ep-based) Interim Standard applies to projects >/= 50-ac, and Final Standard applies to all projects which meet the definition of new or re-development			Continuous	Erosion Potential Index	Ep = 1. Match discharge rates and durations from the critical low flow (TBD) up to the pre-development 10-yr peak flow (or equivalent alternative criteria). Ep = Wpost/Wpre; use shear stress eqn to calculate W	No	Not specified - to be developed as part of watershed-specific Hydromodification Control Plans (HMPs)	Not specified - may be developed as part of watershed-specific (HMPs)	Not specified - may be developed as part of watershed-specific (HMPs)	Not specified - may be developed as part of watershed-specific (HMPs)	Allowed	

Program			Development Trigger	Stream Susceptibility Exemptions	General Requirements	Numeric Control Standard					In-stream Control Standard	Analysis Methodology			Additional Notes
Agency	**Publication**	**Date**				**Approach**	**Standard**	**Criteria**	**Considers Sediment Supply?**	**Tolerance**		**Regional Model / Sizing Charts**	**Baseline Assumptions**	**Site Specific Analysis**	
South Orange County, CA / San Diego RWQCB	DRAFT MS4 Permit CAS0108740, Revised Tentative Order No. R9-2007-0002	DRAFT issued July 6, 2007	Applies to all Priority Development Projects, which are defined as new projects which fall under listed categories or locations, and those redevelopment projects that create, add or replace at least 5,000 sq-ft of imperivous surfaces on an already developed site that fall into those same categories or locations. This is the same set of projects to which all other Development Planning Component requirements apply.	Directs Permittees to develop a waiver strategy where total impervious cover on a site is increased by less than 5% in new developments and decreases by at least 10% in re-developments, or in cases where receiving waters are severely degraded, concrete-lined, or underground storm drains directly to bays or the ocean.	Requires site design measures for hydromodification and preference for on-site controls over in-stream controls in situations where beneficial uses have not been adversely affected by hydromodification. Interim requirements for >20-acre sites include disconnecting impervious areas using stormwater reuse, evap, and/or infiltration for small precip events	Interim approach for >20-acres: 1) Series of single events, or 2) Continuous	1) Hydrograph matching or, 2) Matching flows and durations	1) Hydrograph matching for a range of return periods from 1-yr to 10-yrs, or 2) Continuous range of return periods from 10% of the 2-year to 10-yrs based on long-term records	No	1) Closely mimic, or 2) Post-project flow duration curve must not deviate above the pre-project flow duration curve by more than 10% and must not deviate above the pre-project flow duration curve over more than 10% of the length of the curve.	Where in-stream controls are necessary, use geomorphically-referenced channel design techniques.	Allowed - A local implimentation tool based on flow duration control, derived from continuous simulation modeling, in the form of nomographs relating %imp area and soil type to BMP volume and land area requirements.	Not specified	A site specific critical flow may be substituted for the lower return period (10% of the 2-yr flow) if available	
San Diego County, CA / San Diego RWQCB	MS4 Permit CAS0108758, Tentative Order No. R9-2007-0001	Jan 24, 2007	Applies to all Priority Development Projects, which are defined as new projects which fall under listed categories or locations, and those redevelopment projects that create, add or replace at least 5,000 sq-ft of imperivous surfaces on an already developed site that fall into those same categories or locations. This is the same set of projects to which all other Development Planning Component requirements apply.	Requirements do not apply where the pre-existing channel or storm drain conditions result in minimal potential for erosion or other impacts to beneficial uses, usch as concrete lined channels, etc.	Not specified, but directs Permittees to inlude (in the HMP) other performance criteria (numeric or otherwise) for Priority Development Projects as necessary to prevent urban runoff from increasing erosion or other impacts to beneficial uses and stream habitat.	Continuous	Flow rates and durations	Post-project flow rates and durations shall not exceed pre-project for a range of runoff flows identified such that the lower boundary of the range corresponds with the critical channel flow that initiates channel bed movement or that erodes the toe of the channel banks. The range may differ by watershed, channel or reach.	No	Not specified	Allows HMP to include in-stream control measures, but bans use of "non-naturally occuring hardscape materials such as concrete, riprap, gabions, etc."	Not specified in MS4 Permit	Pre-project conditions	Not specified in MS4 Permit	Interim range of runoff flow rates to be matched must be developed for projects disturbing 50 acres or more. HMP must include description of pre- and post-project monitoring and other program evaluations to assess effectiveness of HMP implementation.
General Contruction Permit / California SWRCB	Preliminary DRAFT NPDES Construction General Permit CAR000002, Order No. 2007-XX-DWQ	DRAFT issued March 2, 2007	All new development and redevelopment Disturbed project area >2-ac Disturbed project area >50-ac	Not specified	No others specified	Not clear	Not clear	Post-devel volume must approximate pre-project volume for areas covered with impervious surfaces Preserve drainage divides for all drainage areas serving a 1st order stream or larger, and no reduction in time of concentration Preserve drainage patterns by distributing controls within all drainage areas serving 1st order streams and larger, and no reduction in Tc	No	Not specified	Not specified	Not developed	Pre-project condition	Demonstrate compliance by submitting Attachment G worksheet with the Notice of Termination	

5. POST DEVELOPMENT HYDROMODIFICATION REGULATION

Hydromodification impacts are of concern when the physical characteristics of receiving water drainages make them susceptible to destabilization and/or to degradation of riparian habitat. Accordingly, additional hydromodification regulatory guidance/management for new development and redevelopment projects may be appropriate where comprehensive, technically sound programs are not already in place. However, mandating the incorporation of hydromodification control measures into already planned, entitled, and environmentally reviewed, approved, and permitted projects via the Construction General Permit is inefficient and inappropriate. However, utilizing the existing authorities identified below, the State and Regional Boards can successfully address post-construction hydromodification impacts at the appropriate time—during the development planning process—and at the local level.

5.1 Recommended Regulatory Authorities

This section summarizes the Post-Construction Hydromodification Regulation Policy Paper prepared for the CBIA by Nossaman Guthner Knox Elliott LLP and Geosyntec Consultants (provided in Appendix C).

The PGCP seeks to regulate hydromodification at the time of obtaining a grading permit. This is too late in the land use/development planning, entitlement and environmental review process to meaningfully and cost-effectively address hydromodification control. Technical literature and policy studies summarized in Section 3 of this report conclude that to effectively address hydromodification, regulatory and management strategies must be developed for, and integrated into, the project planning, design, and environmental review and approval phases of development. "One-size fits-all" statewide rules regarding hydromodification control will effectively preclude the evaluation of local physical characteristics that is critical in determining the potential for adverse hydromodification impacts on beneficial uses and for identifying appropriate management approaches.

The State Board should rely upon local approaches to hydromodification control. Such approaches may include (but are not limited to) regulation through existing locally managed water quality programs such as: Phase I and Phase II MS4 Permit stormwater programs, provision of hydromodification control standards in basin plan updates conducted under Section 303 (e) of the CWA, consideration and identification of hydromodification control measures in Section 303 (d) listings/ Total Maximum Daily Load (TMDL) development and planning, and CWA Section 401 certification review. Effective alternative approaches to hydromodification control might also include Regional Board participation in land use decision-making processes such as California Environmental Quality Act (CEQA) review of local agency decisions or participation in local government land use plan approvals.

These existing local programs are a technically superior approach for achieving feasible hydromodification control at the most reasonable cost. Local programs better account for watershed specific physical characteristics and hydrologic and geomorphic considerations, and local understanding of a particular watershed (and the potential stressors on beneficial uses) is paramount to the establishment of effective hydromodification controls. A hydromodification strategy that might be effective in the wet and heavily wooded climate of northwestern California may adversely impact beneficial uses in the dry washes of the Mojave Desert. Rather than implement a "one-size-fits-all" approach, the State Board should consider directing Regional Boards to utilize the mechanisms discussed below to address potential impairment from post-development hydromodification at the local level.

5.1.1 Nonpoint Source Management Plans

Nonpoint Source (NPS) management plans are an appropriate tool for addressing hydromodification impacts. Volume II of the California NPS Program Plan, Sections 5.0-5.1 (SWRCB 2000) lists extensive authorities of Regional Boards and other state/local agencies to control hydromodification impacts. The *Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program*, Section IV (SWRCB 2004) (NPS Implementation and Enforcement Policy) also lists existing actions/programs of the Regional Boards to address hydromodification concerns in urban areas. Rather than using the Construction General Permit, the better mechanism for addressing hydromodification control is for the State Board to amend the NPS Program Plan or NPS Implementation and Enforcement policy to direct Regional Boards to utilize existing regulatory authorities to implement strategies and BMPs for addressing post-construction hydromodification impacts utilizing existing regulatory and planning authority at the local level.

5.1.2 Hydromodification Control Via Phase I and Phase II MS4 NPDES Permit Stormwater Programs

The State Board's MS4 Stormwater program provides a comprehensive platform for Regional Board regulation of hydromodification impacts associated with post-development stormwater and runoff discharges via storm drain systems in the urbanized or semi-urbanized areas of the State. Because either a Phase I or Phase II MS4 permit is required by federal regulations for all MS4s in urbanized areas serving 10,000 people or more, and a conditional waiver can be required for urbanized areas characterized by a sufficiently dense population of 1,000 persons or more, most urban or urbanizing areas of the state are currently (or can readily be made) subject to a Phase I or Phase II MS4 permit or conditional waiver. Under Porter-Cologne, the Regional Boards have the discretion to incorporate hydromodification control standards into MS4 Permits and several Regional Boards have done exactly that (see Section 4 of this report). With additional guidance from the State Board, all Regional Boards can be directed to address hydromodification control not only in Phase I MS4 permits, but in Phase II MS4 permits and NPDES Permit Conditional Waivers as well. Incorporation of hydromodification control requirements in Phase I and Phase II MS4 permits statewide will assure regulation of all urban and urbanizing areas, which are the primary areas where adverse hydromodification impacts are of environmental concern.

Small MS4s that were not originally listed by the EPA as regulated under the Phase II stormwater program may still be regulated by states (at the state's discretion) where designation is undertaken pursuant to 40 CFR §§ 123.35(b)(3),(b)(4) or is based upon a petition filed under 40 CFR § 122.26(f). Based on this EPA guidance, the State Board has taken the position that

MS4s not otherwise listed may be designated if they: have a high population density; have high growth or growth potential; are a significant contributor of pollutants to an interconnected MS4 or to waters of the U.S.; or they discharge to sensitive water bodies. Given these broad criteria for MS4 permit coverage, the existing MS4 permit stormwater program, when considered in its entirety, provides sufficient authority to impose hydromodification control requirements on the vast majority of urbanizing areas, as well as particularly sensitive watersheds within otherwise rural areas. Conversely, most areas that are not within the reach of the MS4 program's jurisdiction will be comprised of lands subject to rural land use or zoning designations, or land management plans for state and federal lands (up to 50% of the landmass of California). These existing programs effectively limit the potential for the type of development and urbanization that could result in hydromodification.

5.1.3 Hydromodification Control Via Basin Planning Process

While hydromodification control via the MS4 Permit program would only apply to urbanizing areas that are currently subject to MS4 regulation (and those areas that are designated in the future), the State Board can also direct Regional Boards to tackle the issue of hydromodification directly during the basin planning process. California's process for implementing local and regional controls to control point and non-point sources of pollution could be made more robust by State Board direction to the Regional Boards to address hydromodification control. Basin planning and the triennial review process, which forces a "fresh look" at each Basin Plan every three years—throughout the entire state—can provide a useful mechanism for Regional Boards to implement post-development hydromodification control strategies. Such strategies could be implemented in urban and non-urban watersheds alike—on a watershed specific basis— after consideration of local factors that impact feasibility, effectiveness, and cost of available control measures. As noted in the Board's NPS Program Plan, once implementation strategies (such as for hydromodification) are incorporated in Basin Plans, the Regional Boards have a variety of regulatory and non-regulatory tools (voluntary and / or mandatory BMPs) at their disposal to ensure that receiving water beneficial uses are protected.

5.1.4 Hydromodification Control Via TMDLs

Section 303(d) of the CWA requires the State Board (and through it, the Regional Boards) to list watershed segments that have beneficial uses that are impaired because they do not (and are not anticipated to) meet pertinent water quality objectives (due to point and/or nonpoint source pollution). The Regional Boards then investigate the cause of impairment and ascertain total maximum daily load (TMDL) targets that will ensure attainment of standards and protection of beneficial uses. They then develop TMDLs for pollutants causing impairment and incorporate those TMDLs, along with required implementation measures and any necessary implementation schedules, into local basin plans.

The 303(d) listing process and TMDL development and implementation plans are good opportunities to address post-development hydromodification impacts because these processes can be targeted to local conditions and specific reaches where hydromodification-related impairment of beneficial uses is of concern. In the 303(d) context, implementation measures can be developed and recommended to address post-construction hydromodification controls. Upon TMDL development, Regional Boards can enforce hydromodification control (if pertinent to the impairing pollutant) by incorporating hydromodification BMPs on a watershed or site specific basis into the Basin Plan. In addition, regulated stakeholders may be willing to voluntarily implement post-construction hydromodification controls through memoranda of agreement if such implementation will facilitate delisting of an impaired water (or result in future credit in the TMDL if delisting is not successful). Using this regulatory tool, the areas of the state that most need post-construction modification management plans (impaired watersheds) will get them in an enforceable manner that accounts for the uniqueness of each watershed.

5.1.5 CWA Section 401 Certifications

Under Section 401 of the federal Clean Water Act (CWA), Regional Boards ensure that federally-permitted activities, such as permits issued by the Army Corps of Engineers under Section 404 of the CWA, are adequately protective of beneficial uses and pertinent water quality objectives. Where a construction project is likely to result in the addition of fill to jurisdictional waters, Regional Boards have the ability to condition their certification of the required Army Corps of Engineers Section 404 permit for implementation of appropriate post-development hydromodification BMPs. Again, utilizing a targeted and locally sensitive process such as a 401 certification—that considers site specific conditions in receiving waters—allows project proponents to tailor their post-construction footprint in such a way as to ensure compliance with all water quality objectives at the most reasonable cost.

5.1.6 California Environmental Quality Act (CEQA)

The California Environmental Quality Act (CEQA) is triggered by discretionary approval by a public agency of a project that has the potential to cause a significant effect on the environment. Because CEQA is triggered whenever a lead agency is required to exercise discretion with respect to approval of a private project, the vast majority of projects that would require coverage under the Construction General Permit would also trigger CEQA review by the local government charged with review and approval of the development project.

CEQA puts the Regional Boards (and concerned stakeholders) on notice that a project with potential water quality impacts is in the planning and design stage. The Regional Boards have the ability, and can be directed by the State Board, to exercise their authority to comment on proposed developments and recommend project design features, site specific best management practices, and other mitigation measures for post-development hydromodification impacts. The CEQA lead agency may only disregard the recommendations of the Regional Boards pertaining to environmental mitigation upon findings (based on substantial evidence in the record) that both (i) recommended hydromodification control measures (or alternative control measures) are not feasible; and (ii) any significant but unavoidable adverse hydromodification effects resulting from the failure to incorporate project design features and mitigation measures are outweighed by economic, social, legal, technological or other compelling benefits of the proposed project. Thus CEQA accomplishes the same goals as the PGCP, but at an appropriate point in project planning, design, and approval process. CEQA provides Regional Boards notice of projects with potential hydromodification impacts, and provides a site-specific mechanism for the Regional Boards to mandate the implementation of appropriate post-development hydromodification controls.

5.1.7 Land Use Approvals

To the limited extent that development projects may be outside of the reach of MS4 permit stormwater programs, but still of sufficient scope so as to trigger potential significant adverse hydromodification impacts, such projects will, in many cases, not only require CEQA review, but will also require adoption or amendment of a local government's general plan, specific plan, or both. Adoption or amendment of a general or specific plan provides yet another opportunity for Regional Boards to impose hydromodification standards at the local level—either by requesting project specific requirements from the local government at the approval hearing, or by seeking a programmatic amendment of one or more of the elements of the general or specific plan to mandate post-construction hydromodification controls.

As part of the general planning process, local governments are required to notify Regional Boards that a particular project is under consideration. Any amendments to the Conservation Element that impact water resources must be developed in coordination with all local agencies that deal with water in that community. Thus, Regional Boards throughout the state (in rural and urban areas) will receive notice of development projects of sufficient scope to raise hydromodification control concerns, and local governments will be required to strongly consider the guidance provided by the Regional Boards before a project requiring general plan amendment can move forward.

Regional Boards will have similar opportunities to provide input and seek hydromodification controls in the context of specific plan amendments—which may be triggered for smaller projects that do not require amendment of a general plan. A specific plan is a tool for the systematic implementation of the general plan. It effectively establishes a link between implementing policies of the general plan and the individual development proposals in a defined area. The specific plan must be consistent with the policies detailed in the general plan. Thus, where a Regional Board has had hydromodification controls incorporated into one of the elements of a general plan, a developer will not be able to obtain a specific plan amendment unless it can demonstrate that the proposed project is consistent with the controls established in the general plan.

In addition to authority to provide guidance to local agencies on general plans and specific plans, Regional Boards have authority, to the extent required by promulgated Regional Board regulations, to require local agencies to provide notice to the Regional Board whenever application for approval of a tentative subdivision map is filed. Thus, even when the approving local government does not circulate a document for review in accordance with CEQA, a Regional Board has the authority to require notice of virtually any development within the region subdividing land into four or more lots. As with general and specific plans, Regional Boards may then provide guidance to local agencies regarding project design features, BMPs, and other hydromodification mitigation measures that may be appropriate based on project and local conditions, and local agencies are required to consider and give due deference to the State Agency comments.

5.2 Recommended MS4 Standards

This section recommends two alternative standards for hydromodification management which integrate the findings and discussion of the previous sections. The first alternative is presented as permit language for inclusion in an MS4 Permit; this would ensure the most technically defensible approach is being applied throughout all Phase I and Phase II urban areas in California. This standard could also be applied to large projects that fall outside of the MS4 Permit areas through the 401 certification, CEQA, or land use approval mechanisms listed above.

The second alternative applies to small projects that lie outside of Phase I and Phase II areas. In these cases, where project proponents and municipalities have far fewer resources for program development, a standard based on implementation of specific LID measures is recommended until such time that a more quantitative methodology is developed that can be readily implemented in these areas.

5.2.1 Alternative 1

The following proposed permit language could be used to establish a technically-based, consistent approach to hydromodification control in MS4 Permit areas:

X. Requirements for Hydromodification Control

Each Permittee shall ensure that its local (*insert local new development/redevelopment planning document name here*) includes effective hydromodification control requirements for Priority Development Projects (*as defined in the MS4 Permit*) such that local hydrologic conditions of concern are identified and addressed. Hydromodification control measures shall be required to prevent changes to downstream channels that would adversely affect physical structure, biologic condition, or water quality and to protect downstream beneficial uses.

As part of its (*insert local new development/redevelopment planning document name here*), each Permittee shall apply requirements to Priority Development Projects such that runoff discharge rates, durations, and velocities are controlled to maintain (or reduce) downstream erosion conditions and to protect downstream habitat.

(1) Assessment of Downstream Erosion and Waivers

(a) Each Permittee shall require evaluation of the adjacent and downstream conditions of receiving waters (i.e., waters of the U.S. and State) when evaluating Priority Development Projects. Factors to evaluate shall include the designated beneficial uses of the receiving waters, type of channel receiving discharges, the stage of channel adjustment/alteration, channel slope, composition of bed and bank materials, underlying geology, watershed position (e.g., stream order and location), and connections between the streams and adjacent floodplains.

Permittees may summarize the results of this evaluation in the form of channel susceptibility mapping that is provided to the Priority Development Project proponent.

(b) Onsite hydromodification control waivers: Copermittees may develop a strategy for waiving hydromodification requirements for onsite hydromodification controls (not LID/site design BMPs) in situations where assessments of downstream channel conditions and proposed discharge hydrology clearly indicate that adverse hydromodification effects to present and future beneficial uses are unlikely. The waivers must be based on the following determinations:

(i) Watershed-specific waivers: Waivers may be implemented for new development and redevelopment projects within a watershed where a watershed management plan or study has been prepared that establishes thresholds for project waiver based on watershed-specific factors. The watershed plan or study shall establish when potential for substantial hydromodification impacts is not present based on appropriate assessment and evaluation of relevant factors, including: runoff characteristics, soils conditions, watershed conditions, channel conditions, and proposed levels of development within the watershed. The plan or study may also indicated systems where, due to current hydromodification impacts, the best course of action is to address hydromodification with instream restoration techniques.

(ii) Redevelopment project waivers: Waivers may be implemented where redevelopment projects do not increase the potential for hydromodification impacts over the existing site conditions, by both no increase in impervious area and no decrease in the infiltration capacity of pervious areas.

(iii) Degraded stream channel condition: Waivers may be implemented in situations where the receiving system is concrete-lined or significantly hardened (e.g., with rip-rap, sackcrete, etc.) downstream to their outfall in bays or the ocean; or the project would discharge into underground storm drains discharging directly to bays or the ocean.

(iv) Modified channel conditions: Conditional waivers for onsite controls may be implemented in situations where receiving waters are currently degraded (unstable due to irrevocable changes to its form). In this situation, conditional waivers shall include requirements for contribution to regional controls or instream measures designed to improve the beneficial uses adversely affected by hydromodification. The regional controls or instream measures must be implemented within the same watershed as the Priority Development Project.

(c) The requirements in sections X(2) and (3) below do not apply to Priority Development Projects that meet the waiver requirements in subsection (b) above.

(2) Implement Hydromodification Management Strategy

Each Permittee must implement, or require implementation of, a suite of hydromodification control measures by each Priority Development Project.

(a) The suite of hydromodification control measures may include LID/site design measures, onsite controls, regional controls, and/or instream controls. Regional controls shall be implemented prior to discharge of project runoff to the receiving stream channel.

(b) LID/site design measures for hydromodification must be implemented on all Priority Development Projects where feasible.

(c) Preference must be given to onsite or regional controls over instream controls in situations where, in the pre-project condition, beneficial uses within the receiving channel have not been adversely affected by hydromodification.

(d) Implementation of instream controls must not adversely affect beneficial uses or result in sustained degradation of water quality of waters of the U.S./State.

(3) Hydromodification Control Standard

(a) Each Permittee must develop a quantitative standard which governs the design of on-site, regional, and instream hydromodification controls, based on the use of an Erosion Potential Index, as follows:

(i) The standard shall maintain the pre-project sediment transport capacity (erosion potential) in the receiving channel to within an identified tolerance based on local or regional data.

(ii) The standard shall be based on a continuous simulation of the long-term, local rainfall record, with guidance provided on acceptable hydrologic models and assumptions (e.g. infiltration rates by soil type).

(iii) The standard shall identify the minimum flow required to initiate sediment transport (or contain a methodology by which to do so), which will serve as the lower boundary of the range of flows for which post-project runoff flows and durations shall not exceed pre-project flows and durations.

(iv) The standard shall quantitatively account for the reduction in sediment supply associated with the proposed project.

(v) The standard shall specify the method by which control design will be verified and effectiveness will be assessed. This shall include pre- and post-project instream flow monitoring at a regional scale and for projects exceeding a designated acreage.

(b) The standard shall also include a methodology and criteria for the comparison of the pre- and post-development water balance, for projects exceeding (*insert designated acreage*) and at a watershed scale as part of land use permitting, to assess changes in timing and seasonality of flow and groundwater recharge.

5.2.2 Alternative 2

This alternative applies to small projects that lie outside of MS4 Permit areas. In these cases, where project proponents and municipalities have far fewer resources to address hydromodification impacts through development of a technically-based local hydromodification control standard, but where projects should have sufficient land area to fully implement LID measures, a standard based on implementation of specific LID measures is recommended until such time that a more quantitative methodology is developed that can be readily implemented.

X. Requirements for Hydromodification Control

New Development and Significant Redevelopment projects shall integrate Low Impact Development (LID) strategies into project design to infiltrate, disperse, and retain runoff onsite to the extent feasible and appropriate. One or a combination of the following LID strategies shall be implemented for each project unless shown to be infeasible or inappropriate given applicable goals and constraints:

(1) Construct streets, sidewalks, and parking lot aisles to the minimum widths specified in the land use code and in compliance with regulations for the Americans with Disabilities Act and safety requirements for fire and emergency vehicle access.

(2) Use vegetated or infiltration-based treatment control and/or hydromodification control BMPs (may satisfy by drainage to regional or sub-regional BMPs) located either on-site or off-site.

(3) Direct runoff from impervious areas (roadways, roofs, sidewalks, walkways, trails, and patios) into adjacent landscaping where site groundwater elevations, soils conditions and permeability and geotechnical constraints allow, and/or to vegetated or infiltration-based treatment control and/or hydromodification control BMPs located either on-site or off-site.

(4) Construct trails with open-jointed paving materials, granular materials, or other pervious materials, in compliance with regulations for the Americans with Disabilities Act and safety requirements for fire and emergency vehicle access.

(5) Use native and/or non-native/non-invasive, climate-appropriate landscaping vegetation that requires less watering and chemical application.

(6) Minimize impervious surfaces in landscape design.

(7) Use efficient irrigation technologies for landscape watering.

6. EXAMPLE PROJECT - RECOMMENDED VERSUS. PGCP STANDARDS

In order to illustrate the difference between the PGCP proposed standards and the recommended alternative described in Section 5, an example project site was selected as a basis for comparison. Flow controls were designed for the site based on each of the two standards, and a comparison of effectiveness was made between the two approaches. Below is a brief summary of this study; a detailed report is provided in Appendix B.

The example project site was a 716 acre catchment within the Thompson Creek sub-watershed in San Jose, CA, which discharges to a natural, stable creek. Runoff was modeled under two scenarios: an undeveloped condition, and a developed condition in which a mix of residential, commercial and park land uses resulted in an average of 44 percent impervious area.

In the developed condition, runoff was routed through end-of-pipe detention basins sized using two flow control strategies (an uncontrolled condition was also modeled). The first strategy corresponded to the PGCP requirements to match runoff volume and time of concentration. Because the PGCP does not state the flow event(s) to which the criteria apply, but State Board workshop discussions indicted the intent to use a discrete event, three flow options were tested under this scenario: the 2-year, 10-year, and 50-year events. The second strategy corresponded to the recommended alternative, in which flow duration was controlled across the range of geomorphically-significant flow events (those flows which cause most of the sediment transport within the channel), such that the pre-development frequency distribution of hourly runoff, as well as total runoff volume, was maintained. The captured volume is infiltrated and/or released at less than the critical flow for sediment transport.

Continuous hydrologic simulation modeling was performed using HEC-HMS, based on 50 years of rainfall data. Runoff was converted to flow depth and resulting shear stresses were estimated based on a surveyed cross-section of the receiving channel and standard hydraulic calculations. The total work performed on the channel boundary was calculated over the period of simulation, based on critical shear stress values corresponding to sampled median grain sizes in the channel. Because results can vary based on local topography and sediment size, three different combinations of slopes and median sediment sizes were tested to represent a range of possible conditions.

Effectiveness was evaluated based on the calculated change in sediment transport capacity (the erosion potential, or Ep) in the receiving stream between pre- and post-developed conditions with flow controls. Geosyntec has developed a relationship between Ep and field observations of stream stability, from which the probability of channel instabilities can be estimated (Figure 6.1). This probability, or risk, can be considered in terms of the number of streams that are predicted to become unstable out of the total number of streams to which the control strategy is applied. For example, a control strategy corresponding to a 40% probability means that 4 out of 10 streams are likely to become unstable with the controls in place.

Results show that runoff controls sized to meet the discrete event volume and time of concentration criteria (proposed PGCP standards) do not reproduce the pre-existing flow duration curve and have significantly higher total runoff volumes over the long-term. As a result, the Ep calculations show significant increases in sediment transport capacity. Control approaches based on a 2-year or 10-yr discrete event provided almost no improvement over the uncontrolled development scenario, and would be virtually certain to result in stream channel instabilities. Even the 50-yr discrete event design resulted in, at best, a 72% probability of instability for the channel conditions modeled.

In contrast, the flow duration control design maintained the pre-urban distribution of instream flows and as a result maintained the pre-urban capacity to transport sediment. Computed Ep values corresponded to a 5-12% risk of instability which is equivalent to the background probability.

In conclusion, an objective of maintaining the instream erosion potential requires an approach to controlling urban runoff that only flow duration control can accomplish. The PGCP strategy must be considered ineffective, and using this approach on a large scale would not likely protect the beneficial uses of streams from the effects of hydromodification.

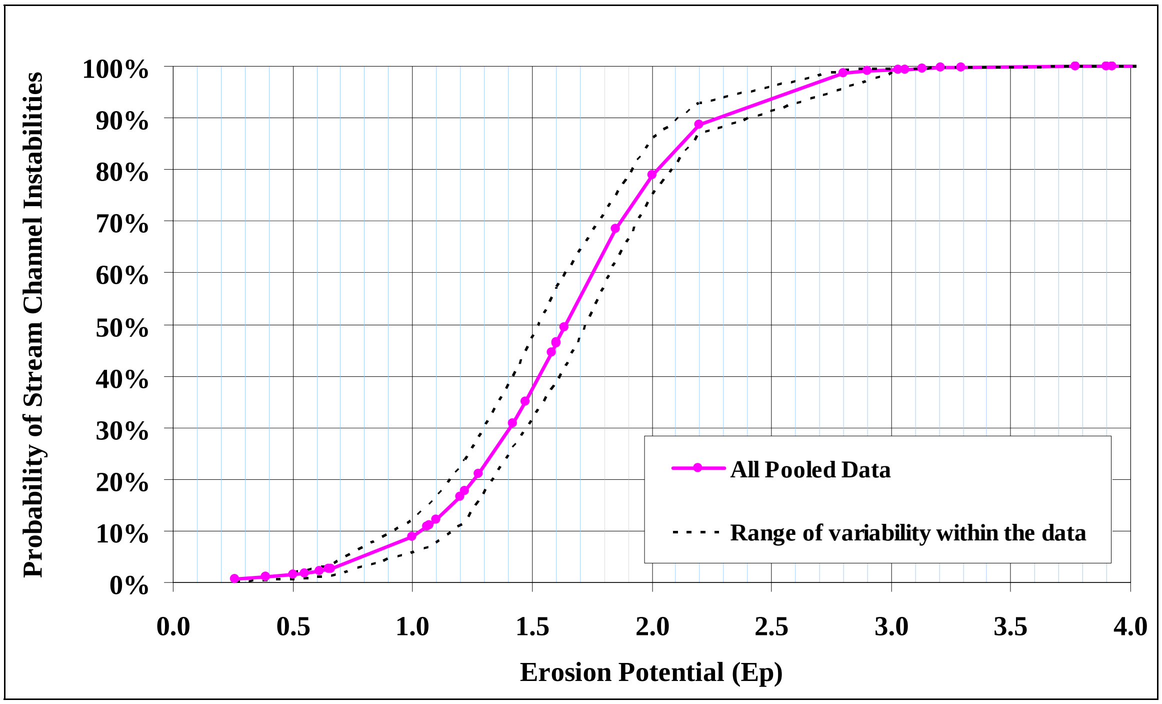

Figure 6-1. Probability of Stream Channel Instability for Bay Area Streams

7. SUMMARY / CONCLUSIONS

Hydromodification is best addressed with a suite of control strategies and should be integrated with other watershed-level planning elements including clustered development, integrated land use planning and stream restoration efforts. Solutions must be flexible to adapt to a wide variety of local conditions. While LID principles should be incorporated wherever feasible, it is unlikely that LID alone will be able to fully address hydromodification in most cases. Forced over-implementation of infiltration requirements may become counter-productive by encouraging urban sprawl.

The current scientific understanding of hydromodification recognizes the need to address the full range and variability of hydrologic and geomorphic processes and their complex interactions with stream ecology. Long-term, continuous hydro-geomorphic modeling provides the best approach to develop our understanding of the complex inter-relationships between watershed and stream processes.

Control standards must be based on metrics that reflect the truly relevant characteristics of the hydrologic and geomorphic processes which affect stream stability and beneficial uses. Standards based on discrete events or on limited aspects of the hydrologic regime such as time of concentration, such as those proposed in the PGCP, are insufficient to prevent stream degradation and essentially equivalent to no controls at all. Similarly, gross measures of development such as impervious area, or metrics based on "effective" impervious area in the absence of a quantitative definition of "ineffective," fail to quantify those processes which contribute to hydromodification impacts and would therefore result in high levels of variability in site design and uncertain outcomes with respect to stream protection.

The most technically sound approach to managing direct physical impacts to stream systems is one based on the evaluation of the post-project long-term sediment transport capacity compared to the pre-project capacity. The Erosion Potential (Ep) metric is a well-developed tool based on this approach that can be used as a standard for designing on-site, regional, or instream flow controls with the objective of eliminating or managing direct physical impacts to stream systems. It is a time-integrated metric based on long-term continuous modeling, which quantifies the alteration of both the hydrologic and geomorphic processes that contribute to stream instability.

However, because changes to the flow regime can have direct impacts on riparian ecosystems beyond their effects on channel stability, as well as impacts on groundwater recharge and local evapotranspiration, compliance with the Ep metric may not completely mitigate for hydromodification impacts. A water balance analysis that addresses seasonality or other life cycle factors has potential to identify additional hydrologic changes which may impact riparian ecosystems. Further development of this approach should be encouraged and potential applications at regional scales and for major project planning should be explored. The development of additional metrics to quantify biotic impacts and establish control standards should be encouraged.

Additional challenges remain, including quantifying the effects of LID through hydrologic modeling, designing infiltration systems for class "C" and "D" soils, assessing model validity and effectiveness through long-term monitoring and continuous streamflow data, and understanding and reducing uncertainty in models and the selection of values for key variables.

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9. APPENDICES

A – Annotated Bibliography From the Literature Review

B – Example Project Study

C – Post-Construction Hydromodification Regulation Policy Paper prepared for the CBIA by Nossaman Guthner Knox Elliott LLP and Geosyntec Consultants, August 27, 2007

D – Attachment G of the PGCP - New and Re-development Performance Standard Worksheet

APPENDIX A

Annotated Bibliography From the Literature Review

	Article Citation	Year	Notes
1	Alberti, M., Booth, D., Hill, K., Coburn, B., Avolio, C., Coe, S., and Spirandelli, D., (2006). The Impact of Urban Patterns on Aquatic Ecosystems: An Empirical Analysis in Puget Lowland Sub-basins. *Landscape and Urban Planning* , 80, 345-361.	2006	Found statistically significant relationships between landscape patterns (both amount and configuration of impervious area and forest land) and biotic integrity of streams in the Puget Sound area, suggesting that patterns of urban development matter to aquatic ecosystems.
2	Anderson, R.J., Bledsoe, B.P., and Hession, W.C., (2004). Width of Streams and Rivers in Response to Vegetation, Bank Material, and Other Factors. *Journal of the American Water Resources Association* , October, 1159-1172.	2004	Meta-analysis of data from over 1,100 locations shows that vegetation effects on natural channel width is scale dependent. For watershed greater than 10-100 sq-km, widths are narrower in channels with thick woody bank vegetation than in grass lined or non-forested banks. The converse is true in smaller streams. Not clear how many study locations were in arid / semi-arid or Mediterranean climate areas.
3	AQUA TERRA Consultants, (2004). Urbanization and Channel Stability Assessment in the Arroyo Simi Watershed of Ventura County, CA. Final Report. Prepared for Ventura County Waterhsed Protection Division, Ventura, CA.	2004	Same as Donigian and Love, 2005.
4	Beighley, R.E., and Moglen, G.E. (2002). Trend Assessment in Rainfall-Runoff Behavior in Urbanizing Watersheds, *Journal of Hydrologic Engineering* , Jan/Feb 2002, 27-34.	2002	Looks at two hydrologic time series to identify non-stationarity in streamflow due to urbanization. Finds that a peak discharge-precipitation ratio is a strong predictor in that it correlates well with quantitative measures of urbanization. This metric allows for identification of trends from urbanization even with a strong climate signal in the flow data, and also where these trends are not evident in the annual maximum time series.
5	Beighley, R.E., Melack, J.M., and Dunne, T. (2003). Impacts of California's Climatic Regimes and Coastal Land Use Change on Streamflow Characteristics, *Journal of the American Water Resources Association* , Dec 2003, 1419-1433	2003	Used HEC-HMS to model Atascadero Creek near Santa Barbara, CA, over a period of urbanization. Three land use scenarios were modeled - from 1929, 1998, and projected in 2050. Results of changes on the annual and 14-yr period distributions of streamflow, peak discharge and annual runoff were analyzed. As urbanization progresses upslope from the coastal plain, effects will be compounded by orographic rainfall and the spatial distribution of development (not clearly explained), thereby having a greater relative impact on peak discharges and runoff volumes than past development. Urbanization also resulted in a less variable rainfall/runoff response because it disproportionately increases runoff from small versus large floods. There was high inter-annual variability in streamflow due to El Nino / La Nina effects.
6	Bledsoe, B.P., Brown, M.C., and Raff, D.A., (2007). Geotools: A Toolkit for Fluvial System Analysis. *Journal of the American Water Resources Association* , 43(3), 757-772.	2007	Presents a suite of analytical tools which accepts input flow records and basic geomorphic data, and calculates a numerous hydrologic, hydraulic and geomorphic descriptors including erosion potential.
7	Bledsoe, Brian P., (2002). Stream Erosion Potential and Stormwater Management Strategies. *Journal of Water Resources Planning and Management* , 128(6), 451-455.	2002	Reduction in sediment delivery to streams, in conjunction with increased runoff, may exacerbate channel instability. "Stream type and mode of sediment transport are...very important considerations in predicting the response of a stream to various land-use and stormwater management scenarios." This paper also involved modeling of a basin designed to match the cumulative sediment transport potential for the 2-year flow event, however, the results with respect to Ep are quite varied depending on assumptions of channel material and sediment transport equation used.
8	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.	2005	Draws on past and ongoing studies to assess prevalence and importance of hydrologic alteration in urban catchments, and evaluates the nature and outcome of common enhancement approaches in urban streams. Uses Tq-mean (the fraction of a year daily mean discharge exceeds annual mean discharge) as a reflection of the flashiness of the hydrograph. Concludes that sustainable stream restoration must address catchment processes at their relevant scales including rehabilitating upland hydrology (e.g. stormwater reinfiltration or LID).

	Article Citation	**Year**	**Notes**
9	Booth, D.B., Karr, J.R., Schauman, S., Konrad, C.P., Morley, S.A., Larson, M.G., and Burges, S.J., (2004). Reviving Urban Streams: Land Use, Hydrology, Biology, and Human Behavior. *Journal of the American Water Resources Association* , October, 1351-1364.	2004	Used two hydrologic metrics, representing multi-year patterns of stormflow and baseflow, as surrogates for impervious area. At study sites in the Puget Sound area of Washington, correlated these hydrologic metrics with stream condition as measured by a benthic index of biological integrity. Results demonstrates that impervious area alone is a flawed surrogate of river health. Hydrologic metrics that reflect chronic altered streamflows provide a direct mechanistic link between changes associated with urban development and declines in stream biological condition.
10	Brander, K.E., Owne, K.E., and Potter, K.W., (2004). Modeled Impacts of Development Type on Runoff Volume and Infiltration Performance. *Journal of the American Water Resources Association* , 40(4), 961-969.	2004	Modeling results show reduced runoff from various types of LID types. "Urban cluster produced the smallest volume of runoff due to the large portion of land kept in natural condition."
11	Bull, W.B. (1997). Discontinuous ephemeral streams, *Geomorphology,* vol.19(3-4): 227-276.	1997	Ephemeral streams in semi-arid regions are inherently unstable and sensitive to human impacts and short term climate changes because hillslopes supply abundant sediment to infrequent large streamflow events. Disequilibrium is promoted by channel entrenchment that causes the fall of local base level and by deposition of channel fans that causes the rise of local base level. These opposing base-level processes in adjacent reaches are maintained by self-enhancing feedback mechanisms. (SEE ALSO Sandercock et al 2007, and Bullard 2006 - not yet added to table)
12	Carter, T.L, and Rasmussen, T.C., (2006). Hydrologic Behavior of Vegetated Roofs. *Journal of the American Water Resources Association* , 42(5), 1261-1274.	2006	Compares runoff from green roof versus black roof for one year of monitoring and uses data to estimate the green roof curve number at 86. One of the few papers with actual monitoring data versus just modeling different scenarios.
13	Center for Watershed Protection, 2003. Impacts of Impervious Cover on Aquatic Systems, Watershed Protection Research Monograph No. 1, March.	2003	Includes an extensive literature review on impervious cover impacts on hydrology, physical channel changes, water quality and biology. Reviews the Impervious Cover Model introduced by Schueler (1994) and the CWP (1998). Relationships between impervious cover and increased volumes and peaks are well established, but limited data to show how various watershed treatment / management practices can change this relationship.
14	Chadwick, M.A., Dobberfuhl, D.R., Benke, A.C., Huryn, A.D., Suberkropp, K., and Thiele, J.E., (2006). Urbanization Affects Stream Ecosystem Function by Altering Hydrology, Chemistry and Biotic Richness, Ecological Applications, Vol. 16(5), 1796-1807.	2006	Studied leaf litter breakdown in headwater streams in the southeastern US. Concluded that the effects of urbanization on stream discharge, biomass and richness of snails, and nutrients and metal concentrations were primary determinants of litter breakdown.
15	Chang, H.J., (2007). Comparative Streamflow Characteristics in Urbanizing Basins in the Portland Metropolitan Area, Oregon, USA. *Hydrological Processes* , 21(2), 211-222.	2007	Studies streamflow characteristics to assess changes in a variety of hydrologic metrics with urbanization. Demonstrated the importance of spatial and temporal scale, climate variability and watershed physiographic characteristics in the hydrologic impacts of urbanization
16	Chin, A., (2006). Urban Transformation of River Landscapes in a Global Context. *Geomorphology* , 79, 460-487.	2006	Compiles research from over 100 studies. "Embryonic research in arid environments…suggests variable river responses to urbanization that are characterized by rapid morphological change over short distances." "…several decades are likely needed for enlarging channels to stabilize and potentially reach a new equilibrium."
17	Chin, A., and Gregory, K.J., (2005). Managing urban river channel adjustments, *Geomorphology,* 69, 28-45.	2005	Based on a study of desert washes near Phoenix, AZ, where channels were impacted by road crossings. Presents a categorization system for level of impact, identification of potential hazards and possible management options.

	Article Citation	Year	Notes
18	Coleman, D., MacRae, C., and Stein, E.D., (2005). Effect of Increases in Peak Flows and Imperviousness on the Morphology of Southern California Streams. *A report from the Stormwater Monitoring Coalition, Southern California Coastal Water Research Project* , Technical Report #450, April 2005.	2005	The study objective was to establish a stream classification system for So. CA, to assess stream channel response to watershed change and to attempt to develop deterministic or predictive relationships between changes in impervious cover and channel enlargement. Estimated that threshold of channel response in So CA is approx 2-3% total impervious area compared to 7-10% in other regions of the US.
19	Colosimo, M.F., and Wilcock, P.R. (2007). Alluvial Sedimentation and Erosion in an Urbanizing Watershed, Gwynns Falls, Maryland., *Journal of the American Water Resources Association* , 43(2): 499-521	2007	Thirteen year study of channel geometry on 19 stream reaches in an urbanizing watershed in Maryland. Categorized channels as aggraded, early erosional, or late erosional. Found variation in channel response to urbanization and percent imperviousness, which the authors attribute to the multitude of additional factors involved such as position of stream reach within the basin, presence of herbaceous vegetation, presence of eroding upstream reaches acting as sediment sources, channel constrictions or grade control structures. However, they state that the aggradational stage will eventually give way to erosion in the long term.
20	Davis, Allen P., (2005). Green Engineering Principles Promote Low-Impact Development. *Environmental Science & Technology* , August 15, 338A-344A.	2005	Does not contain specific research findings, but provides overall perspective and opinion from the director of the Maryland Water Resources Research Center and professor of Civil and Env Engineering at U of Maryland. "From a regional development perspective, incorporating LID should not encourage urban sprawl. A forced overimplementation of infiltration practices could propel the development beyond its initial boundaries and result in more land being consumed. The cumulative impact may be greater than that of traditional approaches if more undeveloped land is used and more roadway infrastructure is created to connect the sprawl development. LID practices should be carefully integrated into all development densities without forcing density reduction. High-density LID represents a formidable challenge."
21	Donigian, A.S. and Love, J.T. (2005). The Use of Continuous Watershed Modeling to Address Issues of Urbanization and Channel Stability in Southern California. In *Proceedings of the Environmental and Water Resources Institute World Water and Environmental Resources Congress 2005: Impacts of Global Climate Change* , Walton, R. (Ed.), American Society of Civil Engineers, Anchorage, AK, May 15-19.	2005	Continuous HSPF modeling of the upper Calleguas Creek Watershed (So. CA) to assess alternative future land use conditions and mitigation alternatives to assess effectiveness in meeting peak flow control criteria. Uses a ratio of shear to critical shear stress. Concludes that their model results are incorrect because they predict too large a % of time of flows when unstable or bed movement conditions occur. Attribute incorrect results to choice of too small a critical shear value for the channel, although that value was based on the available data for bed particle size. States that findings from 2 years of stream observations do not reflect the predictions for unstable / bed movement conditions.
22	Dow, C.L., and DeWalle, D.R. (2000). Trends in evaporation and Bowen ratio on urbanizing watersheds in eastern United States, *Water Resources Research* , Vol. 36(7), 1835-1843.	2000	Long-term trend in annual evaporation and Bowen ratio were studied on 51 eastern US watershed with varying levels of urbanization over a 70-yr period. Estimated annual watershed evaporation as the difference between streamflow and precipitation. Using net radiation data and evaporation values, calculated Bowen ratios. Found significant decreases in evaporation and significant increases in sensible heating of the atmosphere with increased urban development.
23	Doyle, M.W., Shields, D., Boyd, K.F., Skidmore, P.B., and Dominick, D., (2007). Channel-Forming Discharge Selection in River Restoration Design, Journal of Hydraulic Engineering, 133(7), 831-837.	2007	Proposes a method for determining Qeff (effective flow) for purposes of river channel restoration design. Advocates the use of a cumulative sediment discharge curve to allow quantification of the channel's sediment budget for a given hydrologic regime as the preferred measure of channel forming discharge. Modeling using HEC-RAS performed for study sites in Wisconsin, but also draws on results from other studies throughout the US and Australia). Differences between Qbf (bankfull), Qri (return interval) and Qeff are high for streams which are unstable due to human impacts, supporting the need to use Qeff derived from the existing hydrologic regime.

	Article Citation	Year	Notes
24	Fan, C., and Li, J., (2004). A Modelling Analysis of Urban Stormwater Flow Regimes and their Implication for Stream Erosion. *Water Quality Research Journal of Canada* , 39(4), 356-361.	2004	Used SWMM to model ED Basins of different designs and looked at resulting flow durations compared to pre-urbanization. No new information, but one of many papers looking at flow duration from long-term continuous simulations, which supports this methodology.
25	GeoSyntec Consultants, (2002). Santa Clara Valley Urban Runoff Pollution Prevention Program Hydromodification Management Plan Literature Review.	2002	A comprehensive literature review which formed the basis of recommendations for a hydromodification management approach for the Santa Clara Valley. It is being added to and updated as part of this 2007 review.
26	Gregory, K.J., (2006). The Human Role in Changing River Channels. *Geomorphology* , 79, 172-191.	2006	There is a contrasting response to human impacts in humid and arid channel systems. Modeling is recommended for prediction of channel change in order to reduce uncertainty. Channel design involving geomorphology should be an integral part of restoration procedures.
27	Harris, J.A., and Adams, B.J., (2006). Probabilistic Assessment of Urban Runoff Erosion Potential. *Canadian Journal of Civil Engineering* , 33, 307-318.	2006	Derives a probability distribution which can be used in place of continuous simulation modeling to calculate Ep for planning or screening-level analyses.
28	Hinman, C., (2004). Washington State University-Pierce County Low Impact Development Pilot Project Monitoring. *2003 Georgia Basin/Puget Sound Research Conference Proceedings* , 31 Mar – 3 April 2003.	2004	Describes plans for pilot study of an LID residential development in the Puget Sound region.
29	Holman-Dodds, J.K., Bradley, A.A. and Potter, K.W., (2003). Evaluation of Hydrologic Benefits of Infiltration Based Urban Storm Water Management, *Journal of the American Water Resources Association,* Feb 2003	2003	Models 3 scenarios using SCS curve numbers and design storm events: predevelopment, high impact development, and low impact development. Looks at runoff depths, hydrographs and water balance. Shows that LID can contribute to reduction in runoff and improve water balance.
30	Holz, Thomas W., (2003). In the Absence of Standards, Low Impact Development Might Equate to High Impact Development. *2003 Georgia Basin/Puget Sound Research Conference Proceedings* , 31 Mar – 3 April 2003.	2003	This article appears to be advocating more prescriptive standards for BMP sizing to support the Puget Sound "LID 65 / 0" code. The author notes that Prince Georges County, MD does not have an LID standard for bioretention, but treats it as a "presumptive" standard BMP. But also says that the calculated ratio there for bioretention area to impervious area is about 7%. Suggests using 200% in order to meet the 65/0 code.
31	Hood, M.J., Clausen, J.C., and Warner, G.S., (2007). Comparison of Stormwater Lag Times for Low Impact and Traditional Residential Development, *Journal of the American Water Resources Association,* Aug 2007.	2007	Monitored three watersheds: 2 traditional and 1 LID. Found that lag times were greater in the LID watershed for small storms, short duration storms and storms with low antecedent soil moisture conditions.
32	Horner, R.R., Lim, H., and Burges, S.J., (2004). Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects: Summary of the 2000-2003 Water Years, University of Washington, *Department of Civil and Environmental Engineering, Water Resources Series Technical Report No. 181* , Oct 2004.	2004	Results of 3 water years (beginning Oct 1, 2000) of flow monitoring of two drainage projects in Seattle: Viewlands Cascade and the SEA Streets project. Shows ability of on-site design (SEA Streets) to greatly reduce storm water runoff.
33	Horner, Richard R., (2006). Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices ("LID") for the San Diego Region. *Source* , pp.	2006	The author models several development types based on common development projects in the City of San Marcos. The SCS curve number method was used to estimate runoff. Total site capacity which could be available for stormwater infiltration was taken from the Chralowicz (2001) study which posited various areas, depths and infiltration rates. Modeling results show that without stormwater management, development is likely to reduce groundwater recharge by half. The author believes that LID techniques are more capable of regaining this lost infiltration than conventional BMPs. The soils in the study area would be able to support infiltration of impervious area runoff; soil enhancement would improve this.

	Article Citation	Year	Notes
34	Juracek, K.E., and Fitzpatrick, F.A., (2003). Limitations and Implications of Stream Classification. *Journal of the American Water Resources Association* , June, 659-670.	2003	The use of stream classification systems should be limited to description and communication; they are too many uncertainties and limitations to apply them to inferring stream geomorphic processes or predicting future geomorphic response over a range of climate settings or physiographic regions.
35	Konrad, C.P., and Booth, D.B., 2005. Hydrologic Changes in Urban Streams and Their Ecological Significance, American Fisheries Society Symposium.	2005	Given the previous evidence that streamflow influences structure and composition of lotic communities, the authors identified 4 hydrologic changes resulting from urban development that are potentially significant to stream ecosystems: increased frequency of high flows, redistribution of water from baseflow to stormflows, increased daily variation in streamflow, and reduction in low flow. The significance of these changes depend on the stream's physiographic context and spatial and temporal patterns of urban development. Ecological benefits of improving habitat and water quality may be tempered by persistent effects of altered streamflow. Hydrologic effects of urban development must be addressed for restoration of urban streams.
36	Konrad, C.P., Booth, D.B., and Burges, S.J., (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(W07009), 1-15.	2005	Uses three streamflow metrics that integrate storm-scale effects of urban development over annual to decadal timescales to study hydrologic effects of urbanization on gravel-bed stream channel form and stability. Concluded that urban stream flow patterns are likely to lead to increased frequency and extent of streambed disturbance even after transient adjustments of the channel.
37	McBride, M., and Booth, D.B., (2005). Urban Impacts on Physical Stream Condition: Effects of Spatial Scale, Connectivity, and Longitudinal Trends. *Journal of the American Water Resources Association* , June, 565-580.	2005	The study assessed multiple reaches within four watersheds in the Puget Sound area using a rapid stream assessment and a multi-metric index to describe physical conditions. Two landscape metrics relating to quantity of intense and grassy urban land (one at a watershed scale and one at a local scale) and a measure of proximity of road crossing were found to best explain the reach conditions based on multiple regression analysis.
38	McCuen, Richard H., (2003). Smart Growth: Hydrologic Perspective. *Journal of Professional Issues in Engineering Education and Practice* , 129 (3), 151-154.	2003	Advocates "incorporating...first order streams into the development plan rather than eliminating them. The streams contribute greater hydrologic storage than….the pipe systems that replace them." Also suggests a smart growth principle "to replace the volume of natural storage lost during development with storage that is hydrologically equivalent in terms of its magnitude, spatial distribution, and temporal distribution." He also advocates a metric for surface runoff travel time, however, he allows flexibility and exceptions to this, for example if there is storage provided.
39	Nehrke, Seth M., and Roesner, Larry A., (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. *Water Resources Research* , 42(3), Art. No. W03S08.	2004	Based on modeling and flow duration comparisons, shows the inadequacy of various control scenarios (all appear to be peak flow control based)
40	Nelson, K.C., and Palmer, M.A. (2007). Stream temperature surges under urbanization and climate change: Data, models and responses, *Journal of the American Water Resources Association* , 43(2): 440-452	2007	Developed empirical relationships based on monitoring streams in Maryland, to predict temperature changes due to urbanization and climate change. Found that urbanization is more likely to impact stream temperature. While most measured temperatures in urbanized areas were below the critical thermal maxima (at which death is imminent), the upper temperature range for growth was exceeded, especially at sites characterized by low discharge and high impervious surfaces.

	Article Citation	Year	Notes
41	Newman, B.D., Vivoni, E.R., Groffman, A.R. (2006). Surface water-groundwater interactions in semiarid drainages of the American southwest, *Hydrological Processes* , Vol. 20, 3371-3394.	2006	Emphasizes the high degree of spatial and temporal variability exhibited by semi-arid surface water - groundwater interactions, which links to biogeochemical characteristics and ecosystem dynamics. In gaining streams, groundwater drains into the stream, thereby supporting baseflow even under semi-arid conditions. Losing streams can be major recharge zones to alluvial aquifers, but the proportion of transmission losses accounted for by recharge versus riparian evapotranspiration is still largely unknown. These effluent and influent conditions can switch back and forth within the same reach over time. States that it is critical to understand the importance and mode of lateral inputs to the stream and aquifer and whether effluent or influent conditions prevail. Other researchers have observed extended recession limbs on discharge hydrographs from semiarid catchments that are not easily explained by overland flow alone, and therefore the impact of subsurface runoff in semiarid drainages may be more important than has been traditionally assumed.
42	Palhegyi, G.E., Mangarella, P. Strecker, E., Bicknell, J., Sen, D., (2003). Developing Management Plans To Address Impacts From Urbanization On Stream Channel Integrity. World Water & Environmental Resources Congress, June 2003, Philadelphia, PA.	2003	Paper and powerpoint presention which gives results of the literature reviewed performed for the SCVURPPP; introduces the use of the Erosion Potential methodology, field work for Thompson Creek and associated probability curve.
43	Palhegyi, G.E., and Bicknell, J., (2004) Using Concepts of Work to Evaluate Hydromodification Impacts on Stream Channel Integrity and Effectiveness of Management Strategies. *World Water and Environmental Resources Congress, June 2003, Philadelphia, PA* .	2004	Summary of work done on the SCV HMP, in which an Erosion Potential (Ep) index was developed and used as a metric to compare the sediment transport / work capacity of pre- versus post-development flows. Field evaluations of channel stability were compared to Ep values computed for existing vs. pre-urban conditions; results showed a strong predictive capability of the Ep methodology.
44	Palhegyi, G.E., Potter, C., Dean, C., and Strecker, E., (2005) Evaluating the Effectiveness of Flow Controls at Protecting Streams from the Effects of Hydromodification in Urbanizing Watersheds. *AWRA Annual Water Resource Conference, Nov 7-9, 2005, Seattle, WA* .	2005	Compares various flow control designs based on peak flow matching, hydrograph matching, and flow duration control, using Ep as a measure of likelihood of channel instability. Finds that only flow duration control achieves the desired range of Ep values.
45	Palhegyi, G.E., P. Mangarella and E. Strecker. A Modeling Methodology to Assess and Manage the Effects of Hydromodification in Urban Streams. Urban Runoff Modeling: Intelligent Modeling to Improve Stormwater Management. Humboldt State University, July 22-27, 2007, Arcata, California.	2007	Presents the Erosion Potential modeling methodolgy, and provides example of results from several projects throughout Calif.
46	Palhegyi, G.E. and K. Rathfelder (2007) Applying the Erosion Potential Methodology to Natural Channel Design Procedures in Southern California. Presented at CASQA, Sept 2007, Orange County, Calif.	2007	Illustrates the use of the Erosion Potential Method for natural channel design, while meeting the Ep standard
47	Paul, M.J., and Meyer, J.L. (2001). Streams in the Urban Landscape, *Annual Review of Ecology and Systematics* , Vol 32, 333-365	2001	(Not included in the 2002 SCV lit review) A review article summarizing the impacts of urbanization on streams. Not included in bibliographies of the 2003 reports from CWP or WERF; however, conclusions and cited articles are similar.

	Article Citation	Year	Notes
48	Pitt, R., Chen, S-E, and Clark, S., (2002) Compacted Urban Soils Effects on Infiltration and Bioretention Stormwater Control Designs, *Proceedings of the 9th International Urban Drainage Conference, edited by E.W. Strecker and W.C. Huber,* Sept 8-13, 2002, Portland OR. Sponsored by the ASCE and the International Water Association.	2002	Summary of field measurements of soil infiltration rates, showing that compaction can have a significant effect on infiltration. The author recommends measuring soil compaction prior to selecting an infiltration rate for stormwater control modeling and design.
49	Poff, N.L., Bledsoe, B.P., and Cuhaciyan, C.O. (2006). Hydrologic variation with land use across the contiguous United States: Geomorphic and ecological consequences for stream ecosystems, *Geomorphology,* 79, 264-285.	2006	Highlights the regional variation in hydrologic response of streams to urbanization. But only included two urbanized watersheds in the Southwest Region, and that region included very little area in California.
50	Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., Stromberg, J.C., (1997). The Natural Flow Regime *BioScience* , vol. 47(11), 769-748.	1997	(not included in the 2002 SCV lit review) Review of the widespread human alteration of river flow and consequent changes in geomorphology and ecology. Emphasizes the importance of the natural flow regime and its natural variability which is critical to ecosystem function and native biodiversity. Cites studies showing how the magnitude and frequency of high and low flows regulate numerous ecological processes, and showing the impacts of changed flow regimes on these processes.
51	Potter, K.W., (2006). Small-Scale, Spatially Distributed Water Management Practices: Implications for Research in the Hydrologic Sciences.	2006	"The use of smaller, more distributed water management practices challenges the hydrological science community to improve its capacity for assessing and predicting hydrologic conditions and to make this capacity accessible to water resource practitioners."
52	Presler, H.H., (2006). Infiltration BMPs: Policies and Design Standards that Permit Detention Volume Reductions. *StormCon 2006 Conference Proceedings.*	2006	A review of four East-Coast state regulations to determine if allowance is made for infiltration practices in detention volume sizing criteria. In some cases this was allowed. Infiltration BMPs mitigate post-construction stormwater quantity but are unsuited for controlling the largest storm events.
53	Riley, S.P.D., Busteed, G.T., Kats, L.B., Vandergon, T.L., Lee, L.F.S., Dagit, R.G., Kerby, J.L., Fisher, R.N., and Sauvajot, R.M. (2005). Effects of Urbanization on the Distribution and Abundance of Amphibians and Invasive Species in Southern California Streams, *Conservation Biology* , 19(6) 2005.	2005	Studied 35 streams over 3 years in the Santa Monica Mountains. Found absence of some native amphibians and presence of exotic species in the more urbanized streams. Exotic crayfish affected the abundance of Pacific treefrogs. Macroinvertebrate communities were also less diverse and weighted toward tolerant species in urban streams. Faunal community changes in urban streams may be related to changes in physical stream habitat and increased water depth and flow leading to more permanent streams. This may enhance invasion by exotic species and negatively affect diversity and abundance of native amphibians.
54	Roesner, L.A., and Bledsoe, B.P., (2003). Physical Effects of Wet Weather Flows on Aquatic Habitats: Present Knowledge and Research Needs, Water Environment Research Foundation, 00-WSM-4.	2003	Includes an extensive literature review. Discusses change in the flow frequency curve with urbanization. Emphasizes that flow controls in urban drainage systems have strong influence on runoff hydrology, but this fact is not recognized in studies that attempt to relate stream impacts to gross imperviousness only. The result of changes in flow distribution are determined largely by the sediment transport capacity of the entire distribution of flows. Predictive models of reach-scale habitat changes must account for the connectivity and conveyance of the drainage system and relevant stormwater controls. An increase in the frequency and magnitude of disturbance from wet weather flows will disrupt habitat more often and favor "weedier" species. Cautions that while reach-scale stabilization of streams sometimes occurs within a few decades after land use changes, this does not imply a return of comparable habitat quality and complexity.

	Article Citation	Year	Notes
55	Roesner, L.A., Bledsoe, B.P., and Brashear, R.W., (2001). Are Best-Management-Practice Criteria Really Environmentally Friendly? *Journal of Water Resources Planning and Management*, May/June, 150-154.	2001	Makes the point that conventional designs have been detrimental because they have not considered the full range of flows which need to be managed and that sizing criteria have not incorporated receiving water geomorphology. (Not included in the original lit review)
56	Rohrer, C.A., and Roesner, L.A., (2006). Matching the Critical portion of the Flow Duration Curve to Minimise Changes in Modelled Excess Shear. *Water Science & Technology*, 54(6-7), 347-354.	2006	Modeling various control approaches and comparing the Ep results show inadequacy in these peak-flow based approaches. Results differ significantly depending on grain size distribution.
57	Sandercock, P.J., Hooke, J.M., and Mant, J.M. (2007). Vegetation in dryland river channels and its interaction with fluvial processes, Progress in Physical Geography, 31(2), 107-129.	2007	Discusses the role vegetation in channel processes and emphasizes the high spatial variability of riparian vegetation morphology and pattern compared to temperate and humid systems. Further research is required to better understand the role of vegetation in reducing connectivity of sediment delivery downstream.
58	Schiff, R., and Benoit, G., (2007). Effects of Impervious Cover at Multiple Spatial Scales on Coastal Watershed Streams. *Journal of the American Water Resources Association*, 43(3), 712-730.	2007	A study of urbanization impacts on streams in New Haven, Connecticut showed a critical level of 5% impervious cover above which stream health declined. Shows importance of maintaining riparian buffers.
59	Schueler, T.R. and Holland, H.K. (2000). The Tools of Watershed Protection, in *The Practice of Watershed Protection*, published by the Center for Watershed Protection, Ellicott City, MD.	2000	The Practice of Watershed Protection is a comprehensive text which compiles articles covering an extensive range of issues relating to watershed protection. Includes articles cited individually in the original SCV 2002 literature review.
60	Simon, A., G. Hanson and K. Cook. Non-Vertical Jet Testing of Cohesive Stream Bank Materials (2002). USDA-ARS, ASAE 2002 International Meeting, Paper No. 022119. Chicago, IL July $28^{th.}$	2002	Presents an in-situ method for determining the critical shear stress of stream bank boundary materials.
61	Simon, A., Doyle, M., Kondolf, M., Shields, F.D. Jr., Rhoads, B., and McPhillips, M. (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, Oct 2007, Vol 43(5), 1097-1107	2007	The paper "present a critical review, highlight inconsistencies and identify technical problems of Rosgen's 'natural channel design' approach to stream restoration." The authors conclude that the Rosgen classification system cannot be used to predict equilibrium morphologies or determine how to mitigate channel instability.
62	Soar, P.J., and Thorne, C.R. (2001). Channel Restoration Design for Meandering Rivers. US Army Corps of Engineers, Final Report, ERDC/CHL CR-01-1, September.	2001	Uses a Capacity-Supply Ratio as the basis for channel restoration design, which is calculated as the bed material load transported through the restored reach by the natural sequence of flow events over an extended time period divided by the bed-material load transported into the restored reach. Emphasizes that restoring sediment continuity through the restored reach requires an assessment of the sediment budget, which is determined by the magnitude and frequency of all sediment-transporting flows. Also notes that as a general rule for sand-bed rivers, it was found that the mean annual discharge and the bankfull discharge form lower and upper bounds respectively to the range of effective discharge, while the 2-yr recurrence interval is an upper bound to the range of bankfull discharge.
63	Stein, E.D. and Ackerman, D., (2007). Dry Weather Water Quality Loadings in Arid, Urban Watersheds of the Los Angeles Basin, California, USA, Journal of the American Water Resources Association, vol. 43(2):398-413	2007	Average dry weather runoff in the Ballona Creek watershed was determined to be 180 cu-m / sq-km per day.

	Article Citation	Year	Notes
64	Stein, E.D. and Zaleski, S., 2005. Managing Runoff to Protect Natural Streams: the Latest Developments on Investigation and Management of Hydromodification in California, SCCWRP Technical Report #475	2005	Good definition of hydromodification. Contains a different estimate of the %imp threshold for So CA streams (3-5%) compared to the Peak Flow Study (2-3%). Emphasizes that managing the effects of hydromod requires attention to more than peak runoff; the work or energy that affects physical and biological channel structure results from movement of water and sediment controlled by runoff volume, flow magnitude and duration, frequency of erosive events, timing of high flows and magnitude and duration of base flows. Changes in patterns of flow variability and increases in the frequency of high flows have been shown to have measurable effects on the community composition of stream biota. Hydrologic models should be based on long term (20-30 year) simulations. Hydromodification is best addressed with a suite of strategies including site design, onsite controls, regional controls, in-stream controls, and restoration of degraded stream systems. Includes discussion of Contra Costa HMP, Santa Clara Valley HMP and Newhall Ranch in-stream solutions.
65	Stone Jr., Brian, (2004). Paving Over Paradise: How Land Use Regulations Promote Residential Imperviousness. *Landscape and Urban Planning* , 69, 101-113.	2004	Demonstrated that in Madison, "lower density models of single family residential development are associated with a greater use of impervious materials than higher density models." Believes that this would hold true for any city in North America.
66	Strecker, E.W., Quigley, M.M., Urbonas, B., and Jones, J., 2004. Analyses of the Expanded EPA/ASCE International BMP Database and Potential Implications for BMP Design, In: Proceedings of the World Water and Environmenal Congress 2004, June 27 - July 1, 2004, Salt Lake City, UT. Edited by Sehlke, G., Hayes, D.F. and Stevens, D.K., ISBN 0-7844-0737-1, ASCE, Reston, VA.	2004	Summarizes volume reduction data for BMPs. Biofilters showed and average of about 40 % less runoff volume. Dry-extended detention systems show 30% less runoff volume.
67	Sudduth, E.B., and Meyer, J.L., (2006). Effects of Bioengineered Streambank Stabilization on Bank Habitat and Macroinvertebrates in Urban Streams. *Environmental Management* , 38(2), 218-226.	2006	Studied bank habitat and bank macro-invertebrates at bioengineered sites. Results suggest that bioengineered bank stabilization can have positive effects on habitat and macroinvertebrates but cannot completely mitigate impacts of urbanization.
68	Sullivan, J.F., Brocard, D.N., and Brandon, F., (2006). LID Techniques to Avoid the Impacts of Hydro-modification: A Case Study. *StormCon 2006 – Workshop B70 – 7/27/06.*	2006	Implementation of LID on a large water storage and distribution facility and modeling to compare pre and post construction runoff using HEC-1. Groundwater elevations and surface water flow data were collected for model calibration. Hydrologic modeling used SCS curve number methodology. Overall results were compared in terms of volumes and peaks for individual storm events. The authors conclude that the post development runoff is close to the pre-developed runoff and that the LID features were successfully implemented.
69	Taylor, Andre C., and Fletcher, Tim D., (2007). Nonstructural Urban Stormwater Quality Measures: Building a Knowledge Base to Improve Their Use. *Environmental Management* , 39(5), 663-677.	2007	An investigation and evaluation of use, performance and cost revealed four non-structural measures of greatest potential value, including: mandatory planning controls that promote LID and strategic urban stormwater management plans.
70	Trimble, S.W., 1997. Contribution of Stream Channel Erosion to Sediment Yield from an Urbanizing Watershed, Science, 278(5342), 1442-1444.	1997	(Not listed in original Lit Review) Study in San Diego Creek Watershed (Orange County) tracking stream channel enlargement throughout >15 years. Showed that large percentage of sediment delivery to Newport Bay was due to channel erosion.

	Article Citation	Year	Notes
71	Urbonas, B.R. (2003). Effectiveness of Urban Stormwater BMPs in Semi-Arid Climates, presented at the regional conference on: *Experience with Best Management Practices in Colorado* , April 2003	2003	Addresses common issues associated with BMP effectiveness. Makes the point that the infiltration emphasis of LID is no different than what is recommended in the Denver Flood Control District's design manual since 1994. Emphasizes that all BMPs need maintenance, but will perform properly when designed and maintained according to the standards. Discusses importance of micro-pools and trash racks in ED Basins. Also discusses why BMP effectiveness should be expressed in terms of effluent concentration and not percent removal.
72	US EPA Office of Water, 2000. Low Impact Development, A Literature Review, EPA-841-B-00-005, October.	2000	(Not listed in original Lit Review) Summarizes literature review on the application of LID in new development and existing urban areas, as well as studies of LID projects which provide evidence of effectiveness in retaining pre-development hydrology. Finds that LID offers both economic and environmental benefits, but may still necessitate structural BMPs in conjunction in order to achieve watershed objectives. Appropriateness depends on site conditions such as soil permeability, slope and water table depth, in addition to spatial limitations. Local regulations and codes may also be obstacles to reducing impervious cover. Uses curve number (CN), time of concentration (Tc) as metrics to quantify site hydrology.
73	US EPA Office of Water, 2007. National Management Measures to Control Nonpoint Source Pollution from Hydromodification, July.	2007	Addresses non-point sources. Defines hydromodification differently than we do, but states that it needs to be addressed comprehensively at a watershed-level.
74	Villarreal, E.L, and Bengtsson, ASDL, (2004). Inner City Stormwater Control Using a Combination of Best Management Practices. *Ecological Engineering* , 22(4-5), 279-298.	2004	Study of implementation of various infiltration BMPs and open stormwater systems for an inner city area in Sweden. Compared synthetic hydrographs for design storms as well as a water balance to compare pre and post-implementation hydrology. Found green roofs to be effective at reducing total runoff.
75	Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., Morgan, R.P.III, (2005). The Urban Stream Syndrome: Current Knowledge and the Search for a Cure. *Journal of the North American Benthological Society* , 24(3), 706-723.	2005	Studied 15 streams in Australia. Found that "total catchment imperviousness (TI) has commonly been used as an indicator…although the influence of TI on stream hydrographs varies substantially with permeability of pervious parts of the catchment (Booth et al 2004) and with how much of the impervious area drains directly to streams through pipes rather than draining to the surrounding pervious land (Walsh Fletcher Ladson 2005)" This supports the idea that specifically limiting impervious area is not necessary, what is important is the drainage design.
76	Walsh, C.J., Fletcher, T.D., and Ladson, A.R. (2005). 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(3), 690-705.	2005	"We propose that maintenance of a near-natural frequency of surface runoff should be the critical objective of stormwater management. Impervious surfaces for which this objective is achieved can be classified as unconnected and thus should have minimal impacts on receiving streams. This approach....differs markedly from commonly applied objectives for stream protection such as maximum limits to TI....We hypothesize that TI can potentially be maintained as long as EI [effective imperviousness] is reduced."
77	Walsh, C.J., Waller, K.A., Gehling, J., and Mac Nally, R. (2007). Riverine invertebrate assemblages are degraded more by catchment urbanization than by riparian deforestation, *Freshwater Biology* 52(3): 574-587.	2007	Study of Australian streams to determine the extent to which land use measures explained macroinvertebrate assemblage composition. Results show strongest correlation (negative) with proportion of catchment covered by impervious surfaces. Some influence from riparian forest cover, but small compared to %imp. Authors conclude that riparian revegetation is not as effective as using dispersed, low-impact drainage schemes throughout the catchment.
78	Weinstein, Neil, (2005). New Directions in Low Impact Development: Implications for Urban Redevelopment. *Proceedings of the 2005 Georgia Water Resources Conference* , 25-27 April 2005.	2005	General LID information

	Article Citation	Year	Notes
79	White, M.D., and Greer, K.A. (2006). The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Penasquitos Creek, California, *Landscape and Urban Planning,* 74, 125-138	2006	Studied changes to Los Penasquitos Creek in San Diego County over the 34 years of watershed urbanization. Looked at changes to the runoff regime and the riparian vegetation community. They found an expansion of willow-dominated vegetation which they attribute to increased flows from impervious surfaces and increased dry-season runoff of imported landscape irrigation water.
80	Williams, E.S, and Wise, W.R., (2006). Hydrologic Impacts of Alternative Approaches to Storm Water Management and Land Development. *Journal of the American Water Resources Association* , 42(2), 443-455.	2006	Modeled four development alternatives using HEC-HMS for two design storms and a continuous rainfall record: traditional development, cluster development, partial LID and full LID. Results show that LID resulted in a hydrologic response closer to natural conditions, especially if accompanied by a land preservation program, however, the LID designs modled were unable to meet the regulatory requirements for peak flow control and had to be augmented by basins for very large events.

APPENDIX B

Example Project Study

EXAMPLE PROJECT COMPARING RECOMMENDED HYDROMODIFICATION STANDARDS VS. GENERAL CONSTRUCTION PERMIT PROPOSED STANDARDS

Introduction

The California State Water Resources Board (SWRCB) recently issued a Preliminary Draft General Construction Permit (GCP) which contains requirements related to post-construction hydromodification control. Included within Section K, New Development and Re-development Storm Water Performance Standards, are the following two requirements:

> *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.*
>
> *For projects whose disturbed project area exceeds two acres, the discharger shall …ensure that* ***post-project time of concentration is equal to or greater than [pre-project] time of concentration****.*

The California Building Industry Association (CBIA) has hired Geosyntec Consultants to develop an example of a hydromodification project which meets the above stated GCP criteria and compare its effectiveness with Geosyntec's standard flow duration control approach.

To perform this comparison, we selected a catchment located within the Thompson Creek sub-watershed in San Jose, CA (Figure 1) which discharges to a natural and stable creek segment (Figure 2). We modeled runoff from the catchment under two scenarios: an undeveloped condition, and a developed condition (44% imperviousness) using two flow control strategies (Table 1). Effectiveness was evaluated based on the calculated change in sediment transport capacity in the receiving stream between pre- and post-developed conditions with flow controls.

Table 1. Summary of Flow Control Strategies Tested

❖ **GCP or Hydrograph Matching**	❖ **Flow Duration Matching**
➢ 2-Year Discrete Event ➢ 10-Year Discrete Event ➢ 50-Year Discrete Event	➢ Flow Duration Control

Methods

Geosyntec used an existing model setup consisting of 716 acres of undeveloped land with a stable receiving channel. The study catchment is part of the Thompson Creek sub-watershed, which drains 26 square miles, originates in the Diablo Mt. Range at an elevation of 2,300 feet, and flows northerly to its confluence with Lower Silver Creek at an elevation of approximately 125 feet.

The following presents the model assumptions and the standards used to evaluate effectiveness.

General Conditions

- Channel slopes generally range from 0.001 to 0.030 ft/ft.
- The channel bed is generally composed of medium to fine gravel with some sand. The sampled median grain size (D50) ranged from 3.2 to 10.2 millimeters. The average value assumed for critical shear stress is 0.14 lbs/sq-ft.
- Infiltration rates vary according to soil moisture and range from 0.15 to 0.25 inches/hour.
- Three separate channel conditions were evaluated with varying slope and bed material size so that we could test effectiveness under a range of conditions. The actual channel condition has a slope of 0.013 and a D50 of 4mm (Test 1). Slope was reduced to 0.004 in one case (Test 2) and the D50 was increased to 12mm in the other case (Test 3).
- HEC-HMS was used to run a continuous hydrologic simulation based on 50 years of rainfall data to produce a continuous flow record

Developed Condition Assumptions:

- Post-development land use consists of single family residential, commercial, and park; for an average value of 44% directly connected impervious area (DCIA) across the 716 acre catchment.
- End-of-pipe detention basins with a headwall and orifice outlet structures were sized for each of the flow control strategies. In these tests, other volume reduction BMPs were not addressed or accounted for. This analysis is focused on identifying and understanding the in-stream effects under various discharge strategies.

GCP Modeling Assumptions:

Because the GCP does not state the flow event(s) to which the criteria for volume and time of concentration apply, Geosyntec applied three different flow options under this scenario: the 2-year, 10-year, and 50-year hydrographs. Modeled runoff for this scenario was routed through three separate detention basin and outlet structures designed to mimic 2-year, 10-year, and 50-year hydrographs, respectively.

Flow Duration Control Modeling

Modeled runoff for this scenario was routed through a detention facility designed for flow duration control. This type of facility maintains the pre-development frequency distribution of hourly runoff as well as the total runoff volume. The captured volume is infiltrated and/or released at less than the critical flow for bed mobility (Qc). The flow duration method recognizes the need to manage the distribution of all flows, as opposed to assuming that a single design event captures all the relevant characteristics of hydromodification. In modeling for flow duration control, a detention basin and outlet structure is sized through an iterative process in order to recreate the pre-development flow duration curve.

Evaluation of Effectiveness

The probability of channel stability and the effectiveness of flow controls were evaluated using a measure of relative change in sediment transport between pre and post-development conditions, known as the Erosion Potential (Ep). First, estimates of the total sediment load transported were calculated for the two post-development conditions and compared to that of the pre-development condition, as follows:

1. Flows for each time step were converted to flow depths based on a surveyed cross sectional geometry of the receiving channel (Figure 3) and hydraulics using Manning's equation.
2. Effective shear stress was calculated by multiplying the unit weight of water by the flow depth and longitudinal slope.

$$\tau_i = \rho g d S$$

3. An expression for total work was derived by integrating the dimensionless form of the Meyer-Peter, Muller sediment transport equation, which is dependent on effective shear stress, over the time of record. .

$$W = \sum_{i=1}^{n} 8 \cdot \left(\tau_i^* - 0.047\right)^{1.5} \cdot \Delta t_i$$

$$\tau_i^* = \tau_i \Big/ \left((\rho_s - \rho) g D_{50}\right)$$

Where 0.047 is the shields constant, τ^*_i = dimensionless shields parameter, τ_i = applied hydraulic shear stress, Δt_i = duration of flows (hours), n = length of hourly flow record, ρ = density, g = gravity, $D50$ = median grain size for bed material, d = flow depth, and S = local channel slope.

The index under urbanized conditions is compared to the index under pre-urban conditions. The comparison, expressed as a ratio, is defined as the Erosion Potential (Ep). Ep was also calculated for the post-development scenario without any controls to provide a basis for comparison.

$$Ep = \frac{W_{post}}{W_{pre}}$$

Geosyntec has developed a relationship between Ep and field observations of stream stability, from which the probability of channel instabilities can be estimated (Figure 4). This probability, or risk, can be considered in terms of the number of streams that are predicted to become unstable out of the total number of streams to which the control strategy is applied. For example, a control strategy corresponding to a 40% probability means that 4 out of 10 streams are likely to become unstable even under management.

Results

GCP Design Results

A comparison of the runoff volumes between pre and post-development discreet hydrographs under the GCP scenarios (Table 2) shows the volumes are very closely matched, and therefore these designs would meet the GCP requirement in this respect. Likewise, a comparison of the hydrographs (Figures 5, 6, and 7) shows the timing of the peak flows are no shorter than in the pre-development condition, thereby fulfilling the time of concentration requirement.

Table 2. Calculated Runoff Volume and Percent Difference of Discrete Event Hydrographs

	Pre-Development Volume (ac-ft)	Post-Development with Hydrograph Matching Volume (ac-ft)	Difference (%)
2-Year Event	**20.5**	**20.6**	0.5
10-Year Event	**65.7**	**69.2**	5.3
50-Year Event	**112.0**	**113.3**	1.1

Though the detention facilities modeled to match discrete event hydrographs do fulfill the GCP requirements, they do not reproduce the pre-existing flow duration curve (Figure 8) or runoff volume (Table 3).

Flow Duration Control Design Results

A comparison of the flow duration curve for the detention basin outlet with that of the pre-development condition (Figure 9) shows a close match, confirming that the modeled detention facility was designed as intended. Additionally, the total outflow volume of the flow duration control basin is similar to the pre-development runoff volume, as shown in Table 3.

Table 3. Calculated Total Runoff Volume for 50 Year Continuous Flow Record

Scenario	Total Runoff Volume (ac-ft)	% Difference from Pre-Development
Pre-Development	549	-
Flow Duration Control Basin	609	11
2-Year Event Basin	1,825	232
10-Year Event Basin	1,321	141
50-Year Event Basin	969	77
Post-Development without Basin	14,655	2,569

Measure of Effectiveness

Table 4 lists the computed erosion potentials for the uncontrolled post-development scenario and the two flow control strategies, for each of the three test conditions. Table 5 lists the corresponding probabilities for channel instability based on Figure 4.

Table 4. Resulting Erosion Potential (Ep) for Tests Conducted

Flow Control Strategy	Ep - Test 1 Slope = 0.013 D50 = 4mm	Ep - Test 2 Slope = 0.004 D50 = 4mm	Ep - Test 3 Slope = 0.013 D50 = 12mm
Uncontrolled			
	27	26	24
GCP			
2-Year Discrete Event	3.3	4.0	4.1
10-Year Discrete Event	2.4	2.8	3.1
50-Year Discrete Event	1.9	2.3	2.6
Flow Duration Control			
Flow Duration Control	**1.1**	**0.8**	**0.9**

Table 5. Probabilities of Channel Instabilities for Tests Conducted

Flow Control Strategy	Probability Test 1 Slope = 0.013 D50 = 4mm	Probability Test 2 Slope = 0.004 D50 = 4mm	Probability Test 3 Slope = 0.013 D50 = 12mm
Uncontrolled			
	100 %	100 %	100 %
GCP			
2-Year Discrete Event	100 %	100 %	100 %
10-Year Discrete Event	94 %	99 %	100 %
50-Year Discrete Event	72 %	90 %	95 %
Flow Duration Control			
Flow Duration Control	**12 %**	**5 %**	**7 %**

Discussion

Analysis results show that the GCP control approach based on a 2-year or 10-yr discrete event provides almost no improvement over the uncontrolled development scenario, and is virtually certain to result in stream channel instabilities (Table 5). Even the 50-year discrete event design results in, at best, a 72% probability of channel instability for the channel conditions modeled. Table 3 above showed that although the discrete event runoff volume was matched, the long-term runoff volume was not. Figure 8 also illustrates the same thing, showing more hours of runoff contributing to the increased total runoff volume. The GCP strategy must be considered ineffective, and using this approach on a large scale would not likely protect the beneficial uses of streams from the effects of hydromodification.

Flow duration control maintains the pre-urban distribution of in-stream flows and as a result maintains the pre-urban capacity to transport sediment. This is reflected in Table 4, where the computed Ep ranges from 0.8 to 1.1. This corresponds to a 5-12% risk of instability which is equivalent to the background probability (Table 5). A management objective of maintaining the in-stream erosion potential requires a comprehensive approach to controlling urban runoff that only flow duration control can accomplish.

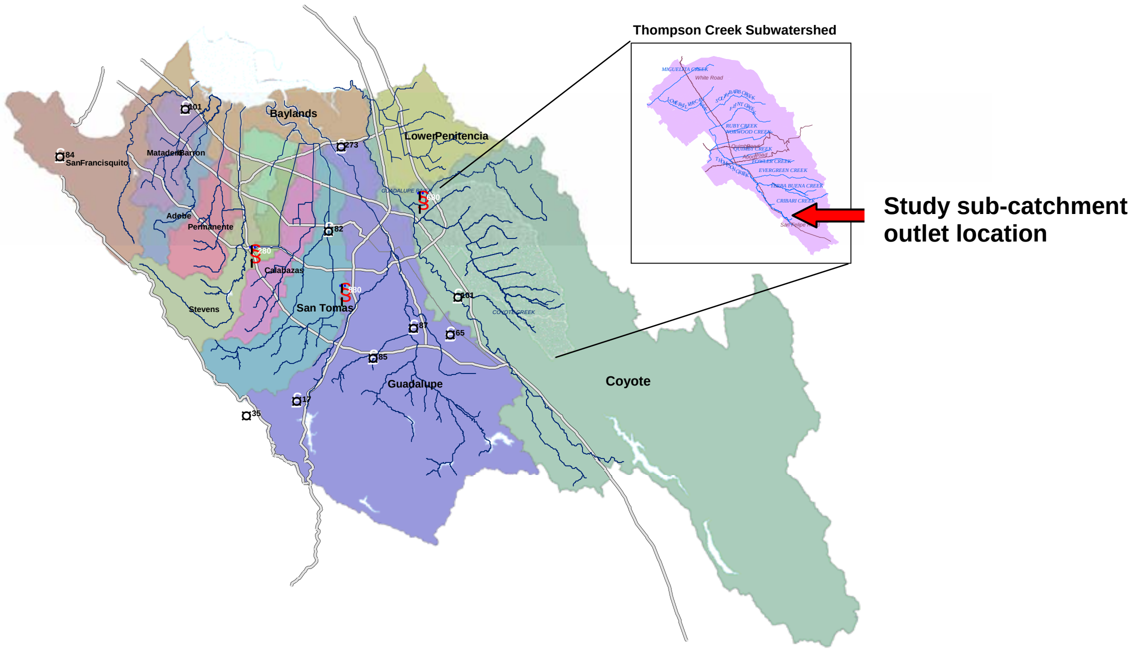

Figure 1. Location Map

Figure 2. Photograph of Receiving Channel

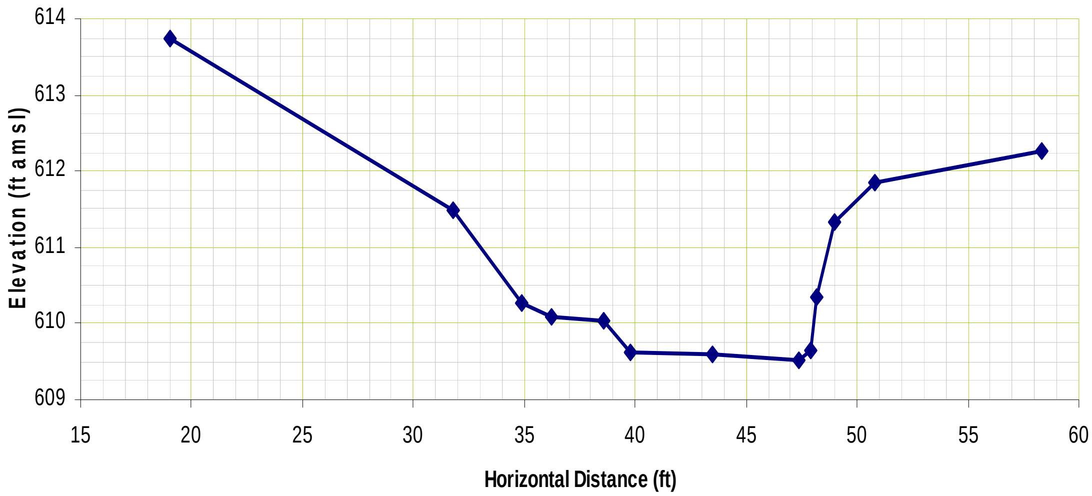

Figure 3. Cross Sectional Geometry of Receiving Channel

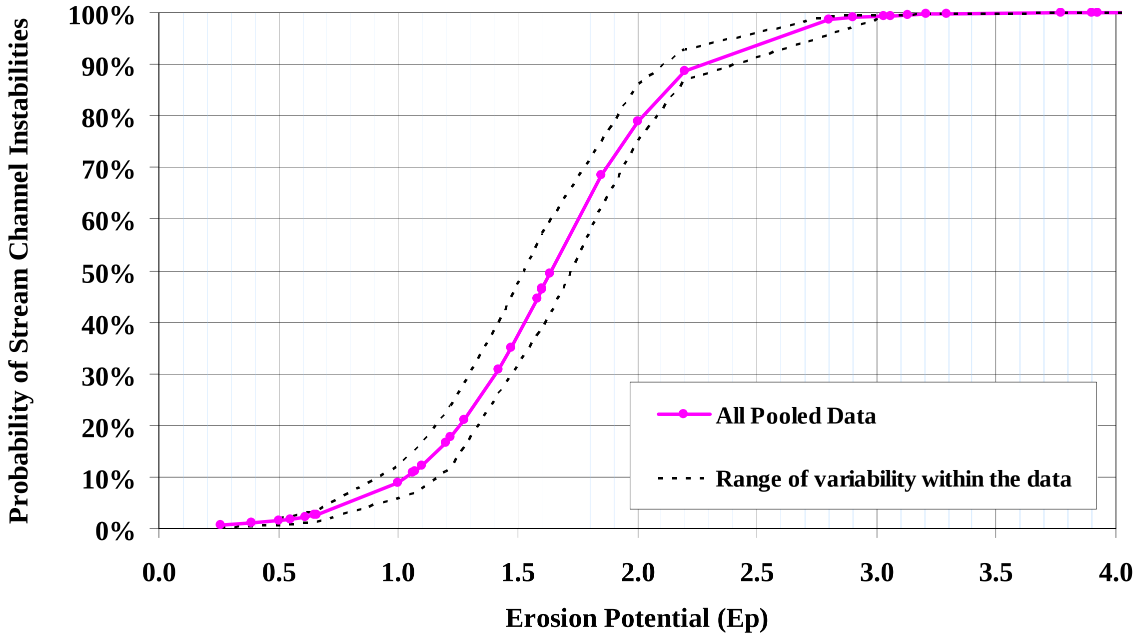

Figure 4. Probability of Stream Channel Instability for Bay Area Streams

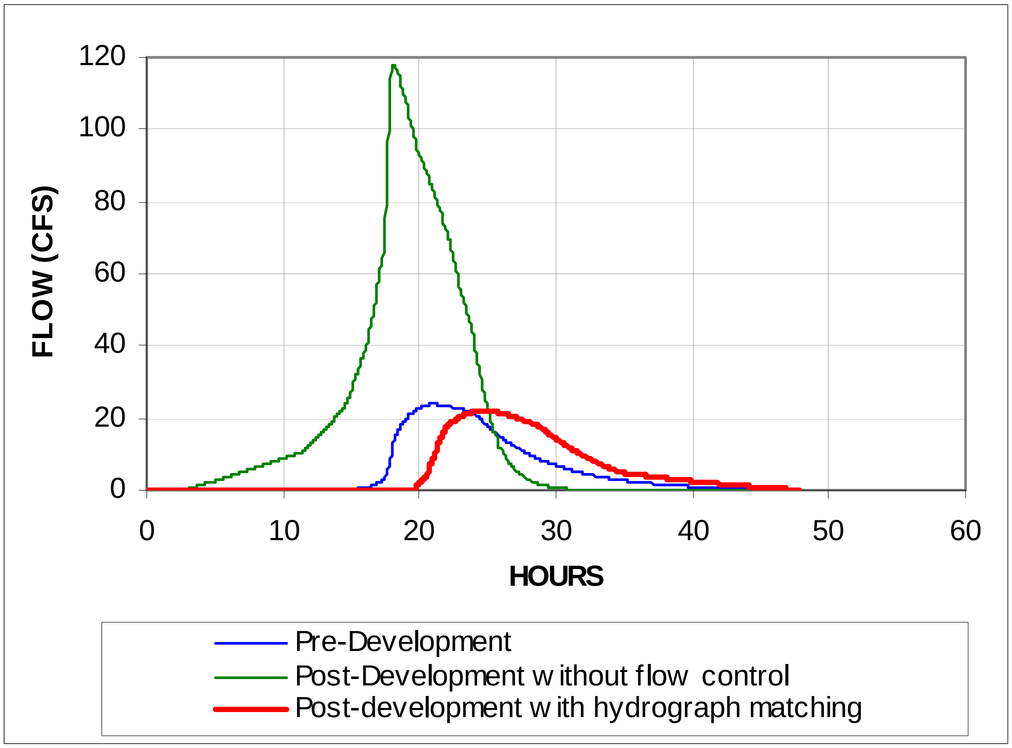

Figure 5. 2-Year Event Hydrograph

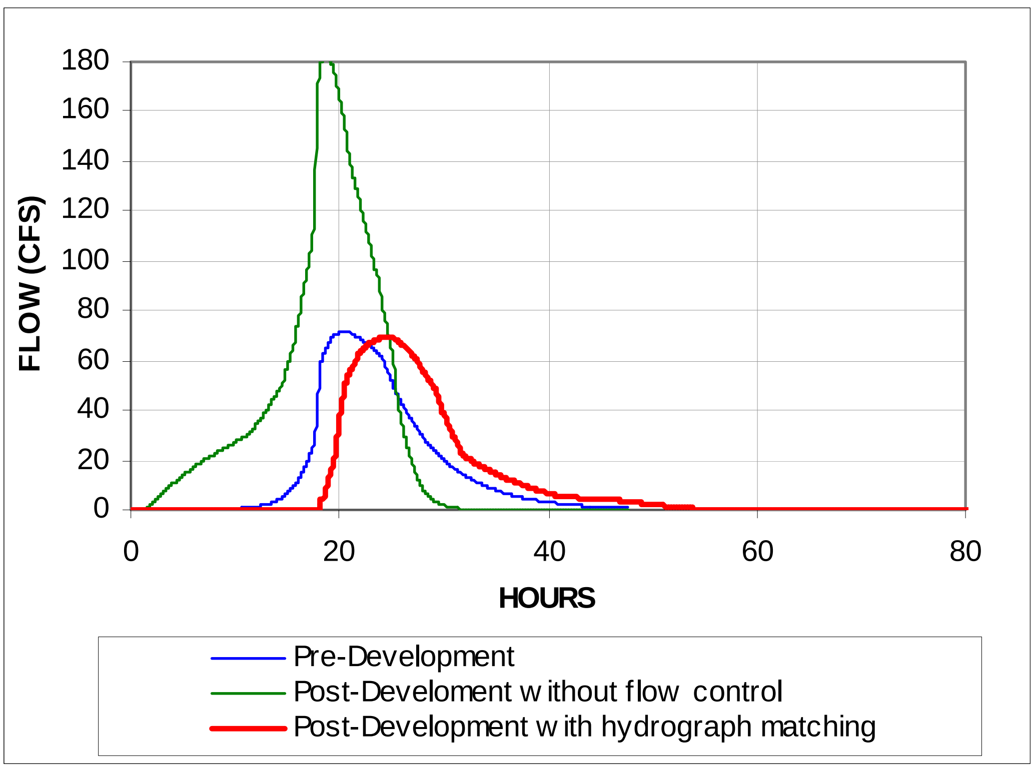

Figure 6. 10-Year Event Hydrograph

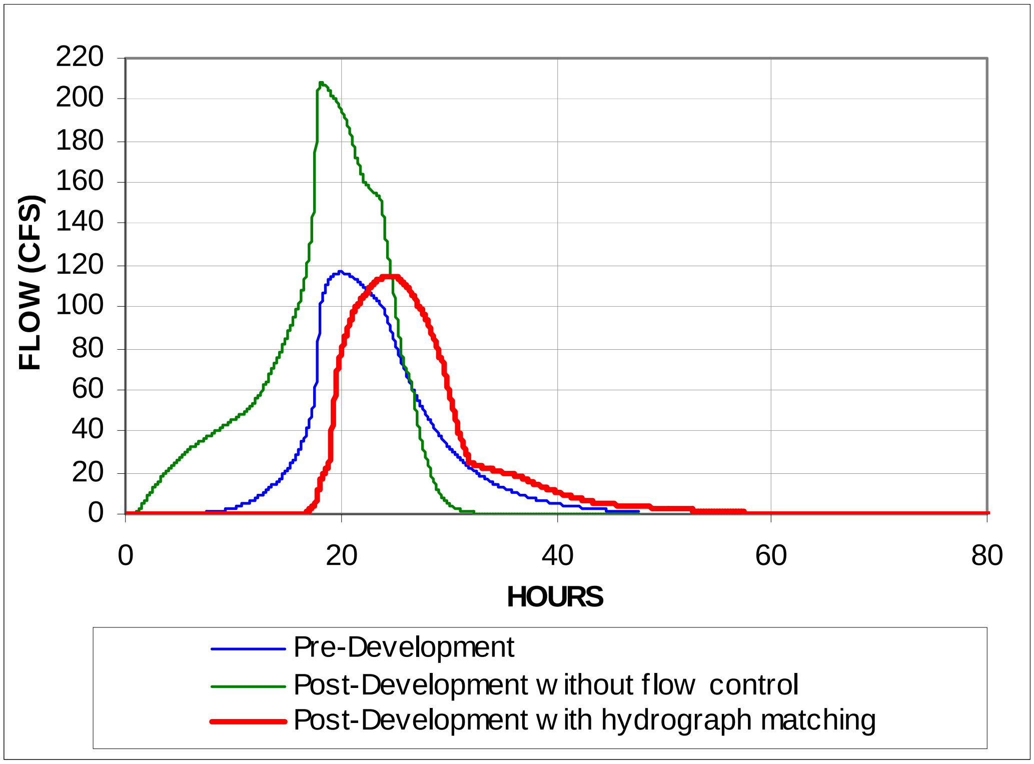

Figure 7. 50-Year Event Hydrograph

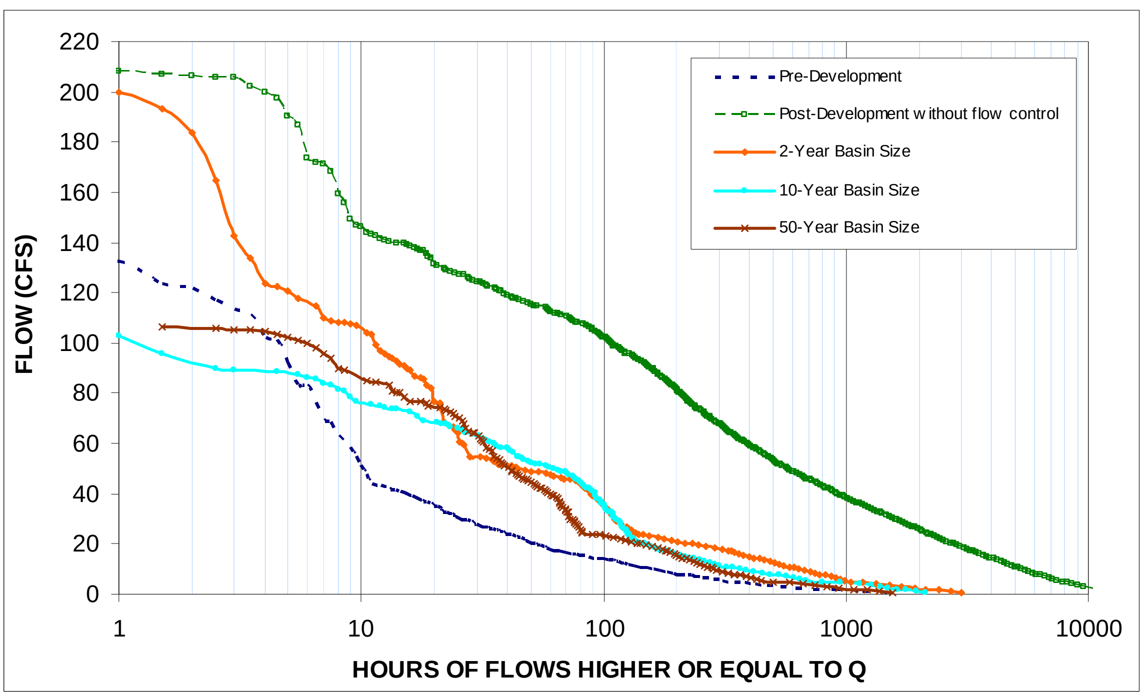

Figure 8. Flow Duration Curve Comparison for GCP Strategy

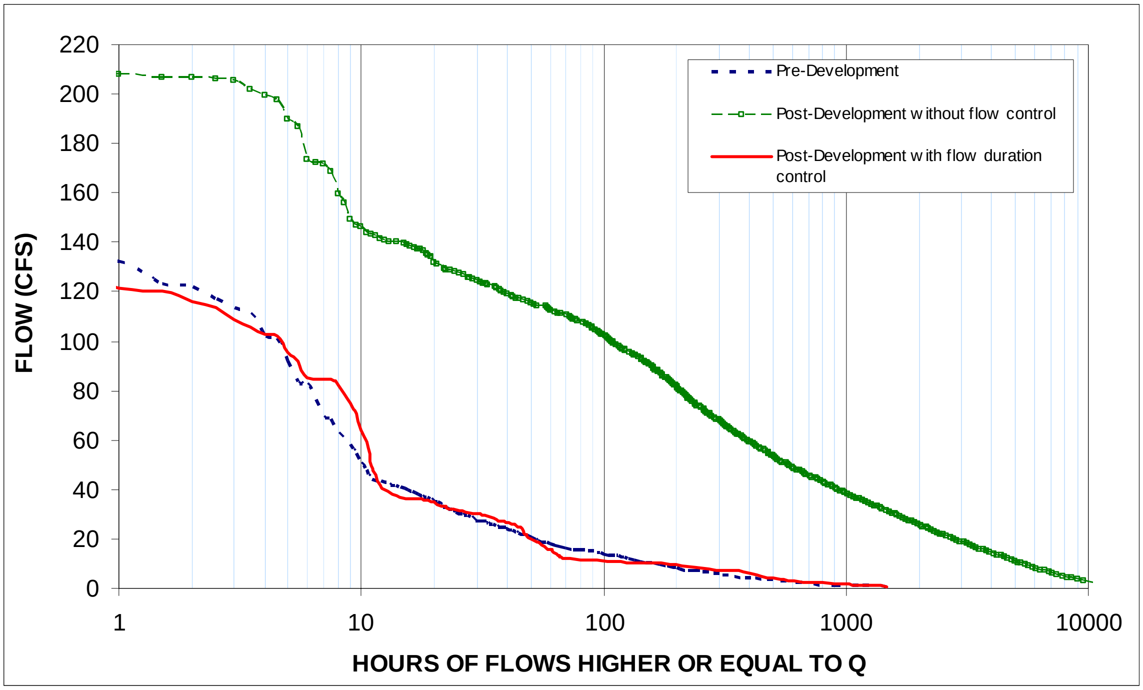

Figure 9. Flow Duration Curve Comparison for Flow Duration Control Strategy

APPENDIX C

Post-Construction Hydromodification Regulation Policy Paper prepared for the CBIA by Nossaman Guthner Knox Elliott LLP and Geosyntec Consultants, August 27, 2007

STATE WATER RESOURCES CONTROL BOARD
PRELIMINARY DRAFT GENERAL CONSTRUCTION PERMIT
POST-CONSTRUCTION HYDROMODIFICATION REGULATION
POLICY PAPER

I. Introduction and Background

As a part of the current Preliminary Draft General Permit for Storm Water Discharges Associated with Construction Activities (Preliminary Draft Permit), the State Water Resources Control Board (State Board) has proposed new measures for controlling post-construction and development "hydromodification" impacts. EPA defines hydromodification as "the alteration of flow characteristics through a landscape which has the capacity to result in degradation of water resources." Because hydromodification does not typically result in the discharge of pollutants from a discrete conveyance, the Board has previously recognized hydromodification as a source of non-point source (NPS) pollution.[1] EPA and the Board are concerned that changes in drainage patterns, soil composition consistency, degree of imperviousness, and irrigation associated with development can lead to changes in natural hydrologic and geopmorphic processes resulting in erosion, scour, sedimentation or destabilization of natural receiving water channels and/or changes in seasonality of flow—thereby causing NPS impairment of beneficial uses.[2]

II. The Board's Current Proposal for Regulation of Hydromodification and Associated Concerns

We recognize that hydromodification impacts can present legitimate concerns when the physical characteristics of receiving water drainages make them susceptible to destabilization. Accordingly, additional regulatory guidance/management may be necessary to some extent. However, the Preliminary Draft Permit seeks to implement absolute, "one-size-fits-all" rules pertaining to hydromodification control that would mandate at the grading permit stage the incorporation of control measures into already planned, entitled, and environmentally reviewed, approved and permitted projects. The application of these rules as part of the General Construction Permit extends water quality regulation of construction sites well into the post-development phase and is outside of the appropriate scope of the General Construction NPDES Permitting program.[3] Further, wrapping requirements for post-development control of non-point

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[1] See California Non-Point Source Program Plan (Program Plan), Volume I: Strategy and Implementation Plan at 5 (January 2000) (identifying hydromodification as one of six "major sources" of non-point source (NPS) pollution in California).

[2] In setting regulatory policy it is important to distinguish between sediment that is a source of water quality impairment, and sediment loading that, in a properly managed watershed or natural situation, may improve beneficial uses of receiving waters due to the ecological role that sediment plays in many of California's drainage systems. Similarly, certain types of hydromodification, such as change in seasonality of flow that leads to additional flow in dry times of the year, can create a net benefit for the entire riparian ecosystem, particularly if riparian or wetland habitat or restoration is a project goal. See PUD No. 1 of Jefferson County v. Washington Department of Ecology, 511 U.S. 700, 719 (1994) ("[A] sufficient lowering of the water quantity in a body of water could destroy all of its designated uses, be it for drinking water, recreation, navigation or, as here, as a fishery."). Regulatory policy must distinguish increased flow and sediment loads as an undesirable "pollutant" from increased flow and sediment loads that form an ecologically important part of a particular environment.

[3] Cf. EPA Proposed Stormwater General Construction Permit, 69 Fed. Reg. 22480 (proposed April 26, 2004) (to be codified at 40 C.F.R. pt. 450); 67 Fed. Reg. 42644 (June 24, 2002) (to be

source pollution into a statewide General NPDES permit designed to control industrial (construction site) stormwater discharges is a poor fit and will lead to greater costs and confusion for regulated parties and other stakeholders.

As previously identified for the Board in comments dated May 4, 2007 (prepared by the California Building Industry and the Construction Industry Coalition for Water Quality), there are a variety of policy reasons supporting the conclusion that the current approach advocated in the Preliminary Draft Permit is unworkable.[4] Our primary concerns[5] include, first, the compliance difficulties created by duplicative but conflicting hydromodification control requirements that result from inclusion of control measures in the Preliminary Draft Permit. General permits governing discharges from municipal separate stormwater sewers (MS4s) currently require, or are being modified during renewal and update proceedings to require, comprehensive hydromodification control measures. The hydromodification control criteria set forth in local MS4 permits often differ substantially in substance and application from those proposed in the Preliminary Draft Permit, making compliance with both requirements technically challenging at best, and with respect to some permits, completely infeasible.

Second, the Preliminary Draft Permit seeks to regulate hydromodification at the time of obtaining a grading permit. This is simply too late in the land use/development planning, entitlement and environmental review process to meaningfully and cost-effectively address hydromodification control. Mandating compliance after all development planning and design has been concluded, and after all entitlements, approvals, environmental review and environmental permits have been completed and obtained, wreaks havoc on California's well-established land use and environmental planning and approval process. Technical literature and policy studies conducted to date unanimously conclude that to effectively address hydromodification, regulatory and management strategies must be developed for, and integrated into, the project planning, design and environmental review and approval phases of development.[6]

Third, creating "one-size fits-all," statewide rules regarding hydromodification control effectively precludes the evaluation of local physical characteristics that are critical in determining the

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codified at 40 C.F.R. pt. 122 and 450) (declining to regulate post-construction hydromodification through general construction permits and noting "lack of data that indicates such provisions would result in notable improvements" in the existing *construction* stormwater programs).

[4] Those previously submitted written comments and suggestions, entitled *Comments on: National Pollutant Discharge Elimination System (NPDES) General Permit for Storm water Discharges and Associated Construction and Land Disturbance Activities,* dated May 4, 2007, prepared by the California Building Industry Association, Building Industry Legal Defense Foundation, Construction Industry Coalition on Water Quality and Construction Employers' Association, are incorporated by reference herein.

[5] Other concerns previously identified (and briefly summarized herein) include confusion over the control standard pursuant to which hydromodification control measures are adopted (not a BAT/BCT measure); the absence of meaningful State Board guidance on how hydromodification permit decisions are to be made; preclusion of ecological enhancement or restoration opportunities and/or inefficiency of hydromodification procedures in certain types of intermittent, dry or channelized watercourses (that could perhaps benefit from additional flow or sediment); and the potential to undermine wetland restoration/creation projects.

[6] Geosyntec Consultants, Hydromodification Management Technical Memorandum, (August 24, 2007) See Attachment A to this Issue Paper) . See, also Eric D. Stein, and Susan Zaleski, Managing Runoff to Protect Natural Streams: The Latest Developments on Investigation and Management of Hydromodification in California. Technical Report No. 475 (December 2005).

potential for adverse hydromodification impacts on beneficial uses and for identifying appropriate management approaches. As a result, the Preliminary Draft Permit's proposed hydromodification control requirements may result in inefficient and cost ineffective hydromodification control measures. In addition, the evaluation of relevant local characteristics is critical to maximizing the avoidance, minimization and mitigation of substantial adverse hydromodification effects, and such consideration appears to be precluded by the Preliminary Draft Permit approach.

III. Proposed Alternative Courses of Action—More Appropriate Hydromodification Control Regulatory Mechanisms.

Applicable law and policy indicates that the most appropriate mechanism for addressing pollution associated with hydromodification is via Clean Water Act Section 319 (33 U.S.C. § 1329) non-point source (NPS) management plans.[7] Indeed, the Board has recognized NPS management plans as an appropriate tool for addressing hydromodification impacts. See generally California Non-Point Source Program Plan (NPS Program Plan), Volume II: California Management Measures for Polluted Runoff at §§ 5.0-5.1 (January 2000) (listing extensive authorities of Regional Boards, and other state/local agencies to control NPS pollution from hydromodification). See also Policy for Implementation and Enforcement of the Nonpoint Source Pollution Control Program, at Section VI (May 2004) (NPS Implementation and Enforcement Policy) (listing existing actions/programs of the Regional Boards throughout the state to address hydromodification concerns in urban areas).

For the reasons explained below, we suggest that rather than using the General Construction Permit, the better mechanism for addressing hydromodification control to assure maintenance of all pertinent beneficial uses is for the State Board to amend the NPS Program Plan or NPS Implementation and Enforcement policy to direct Regional Boards to utilize ample existing regulatory authorities (as described in detail below) to implement strategies and BMPs for addressing post construction hydromodification impacts at the local level.

The Board's NPS Program Plan and NPS Implementation and Enforcement Policy indicate that the Board has already expended significant effort on developing general strategies and guidance for addressing hydromodification. See NPS Program Plan, Vol. II at §§ 3.2; 5.1. To the extent that additional uniform guidance from the State Board on control of hydromodification associated with post-development management measures is necessary, the Board could readily amend either the NPS Program Plan or the NPS Implementation and Enforcement Policy directing Regional Boards to address post-development hydromodification impacts utilizing existing regulatory and planning authority.

Whether or not additional State Board regulatory guidance is promulgated, we suggest that the State Board should rely upon local approaches to hydromodification control. Such approaches may include (but are not limited to) regulation through existing locally managed water quality programs such as: Phase I and Phase II MS4 Permit stormwater programs; provision of hydromodification control standards in basin plan updates conducted under Section 303 (e) of the CWA; consideration and identification of hydromodification control measures in Section 303 (d)

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[7] See generally National Wildlife Federation v. Gorsuch, 693 F.2d, 156 (D.C. Cir. 1982) (Deferring to EPA determination that hydromodification—in the form of the lowering of water levels from dam operations--is not considered point source pollution because of the absence of a discharge of a pollutant). See also Missouri ex rel. Ashcroft v. Department of Army, 672 F. 2d 1297 (8th Cir. 1982) (hydromodification resulting in downstream erosion from dam operation is non-point source pollution).

listings/ Total Maximum Daily Load (TMDL) development and planning; and CWA Section 401 certification review. Effective alternative approaches to hydromodification control might also include Regional Board participation in land use decision-making processes such as California Environmental Quality Act (CEQA) review of local agency decisions or participation in local government land use plan approvals.

These existing local programs are a technically superior approach for achieving feasible hydromodification control at the most reasonable cost. Local programs better account for watershed specific physical characteristics and hydrologic and geomorphic considerations, and local understanding of a particular watershed (and the potential stressors on beneficial uses) is paramount to the establishment of effective hydromodification controls. A hydromodification strategy that might be effective in the wet and heavily wooded climate of Northwestern California may adversely impact beneficial uses in the dry washes of the Mojave Desert. Rather than implement the "one-size-fits-all" approach advocated in the Preliminary Draft Permit, the State Board should consider directing Regional Boards to utilize the following mechanisms to address potential impairment from post-development hydromodification at the local level.

a. Hydromodification Control Via Phase I and Phase II MS4 NPDES Permit Stormwater Programs

In urbanized or semi-urbanized areas of the State, the very areas where danger of impairment of beneficial uses from hydromodification is likely to be most acute, the State Board's MS4 Stormwater program provides a potentially comprehensive platform for Regional Board regulation of hydromodification impacts that may be associated with post-development stormwater and runoff discharges via storm drain systems. Under Porter-Cologne, the Regional Boards have the discretion to incorporate hydromodification controls to address resulting non-point source pollution into the General MS4 NPDES Permits/Waste Discharge Requirements (WDRs) as appropriate to ensure protection of the beneficial uses of a region's receiving waters.[8] Several Regional Boards have done exactly that.[9] With additional guidance from the State Board, all Regional Boards can be directed to address hydromodification control not only in Phase I MS4 permits, but in Phase II MS4 permits, and Phase II MS4 Permit Conditional Waivers as well.[10]

Directing Regional Boards to include hydromodification control requirements in Phase I and Phase II MS4 permits statewide will assure regulation of all urban and urbanizing areas, which are the primary areas where adverse hydromodification impacts are of environmental concern. Because either a Phase I or Phase II MS4 permit is required by federal regulations for all MS4s in urbanized areas serving 10,000 people or more,[11] and a conditional waiver[12] can be required for

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[8] *See generally* Wat. Code §§13263, 13370-13389 .

[9] *See*, *e.g.*, 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 Cites of San Diego County, the San Diego Unified Port District and the San Diego Regional Airport Authority, R9-2007-0001; Waste Discharge Requirements for Discharges of Urban Runoff from the Municipal Separate Storm Sewer System (MS4s) Draining the Watersheds of the County of Orange, The Incorporated Cities of Orange County, and the Orange County Flood Control District Within the San Diego Region, Tentative Order R9-2007-0002; Storm Water Discharges From the Municipal Separate Storm Water Sewer System Within the Ventura County Watershed Protection District, County of Ventura and the Incorporated Cities Therein, Tentative Order 07-xxxx (December 27, 2006).

[10] See generally Wat. Code §§13261; 40 CFR §122.32 (e) regarding criteria for granting conditional waivers.

[11] See 40 CFR §122.32 (e) (indicating that waivers may be available for MS4s that serve urbanized populations less than 10,000 if certain criteria apply).

urbanized areas characterized by a sufficiently dense population of 1,000 persons or more,[13] most urban or urbanizing areas of the state are currently (or can readily be made) subject to a Phase I or Phase II MS4 permit or conditional waiver. Regional Boards have authority, and the State Board can provide direction that each MS4 permit or permit waiver must contain hydromodification control requirements. Additionally, small MS4s that were not originally listed by the EPA as regulated under the Phase II stormwater program may still be regulated by states (at the state's discretion) where designation is undertaken pursuant to 40 CFR §§ 123.35(b)(3),(b)(4) or is based upon a petition filed under 40 CFR § 122.26(f). Based on this EPA guidance, the State Board has taken the position that MS4s not otherwise listed may be designated if they: have a high population density; have high growth or growth potential; are a significant contributor of pollutants to an interconnected MS4 or to waters of the U.S.; or they discharge to sensitive water bodies.[14] Given these broad criteria for MS4 permit coverage, the existing MS4 permit stormwater program, when considered in its entirety, provides sufficient authority to impose hydromodification control requirements on the vast majority of urbanizing areas, as well as particularly sensitive watersheds within otherwise rural areas. Conversely, most areas that are not within the reach of the MS4 program's jurisdiction will be comprised of lands subject to rural land use or zoning designations, or land management plans for state and federal lands (up to 50% of the landmass of California). These existing programs effectively limit the potential for the type of development and urbanization that could result in hydromodification.

b. Hydromodification Control Via Basin Planning Process

While hydromodification control via the MS4 stormwater program would only apply to urbanizing areas that are currently subject to MS4 regulation (and those areas that are designated in the future), the State Board can also direct Regional Boards to tackle the issue of hydromodification directly during the basin planning process. California has a process for implementing local and regional controls to control point and non-point sources of pollution that could be made more robust by State Board direction to the Regional Boards to address hydromodification control. See State Water Resources Control Board, Report in Support of U.S. Environmental Protection Agency's Review of California's Continuing Planning Process 7 (2001). Basin planning and the triennial review process, which forces a "fresh look" at each Basin Plan every three years—throughout the entire state—can provide a useful mechanism for Regional Boards to implement post-development hydromodification control strategies. Such strategies could be implemented in urban and non-urban watersheds alike—on a watershed specific basis—after consideration of local factors that impact feasibility, effectiveness and cost of available control measures. See id. As noted in the Board's NPS Program Plan, once implementation

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[12] Conditional waivers can serve the same function as an issued discharge permit—by requiring an MS4 to engage or refrain from engaging in certain activities, to gather data, or to undertake such actions as the permitting entity deems necessary to assure maintenance of all water quality objectives. See Wat. Code §13269 (authorizing waivers of WDRs if in public interest, appropriate monitoring of water quality takes place and discharger agrees to pay a fee [in appropriate cases] to support future implementation of the waiver program). See also 40 CFR §122.32 (e) (conditioning waiver approval on demonstration that water quality impairment will not occur as result of decision to forego designation as regulated MS4).

[13] According to 2002 U.S. Census Bureau Regulations, an urbanized area encompasses a densely settled territory which consists of core census block groups or blocks that have a population of at least 1,000 people per square mile and surrounding census blocks that have an overall density of at least 500 people per square mile.

[14] . . . See Fact Sheet for State Water Resources Control Board (SWRCB) Water Quality Order No. 2003 – 0005 – DWQ (2003)

strategies (such as for hydromodification) are incorporated in Basin Plans, the Regional Boards have a variety of regulatory and non-regulatory tools (voluntary and or mandatory BMPs) at their disposal to ensure that receiving water beneficial uses are protected.

c. Hydromodification Control Via TMDLs

Section 303(d) of the CWA requires the State Board (and through it, the Regional Boards) to propose lists of watershed segments which have beneficial uses that are impaired because they do not (and are not anticipated to) meet pertinent water quality objectives (due to point and/or non-point source pollution). The Regional Boards then investigate the cause of impairment, and ascertain TMDL targets that will ensure attainment of standards and protection of use. They then develop TMDLs for pollutants causing impairment, and incorporate those TMDLs along with required implementation measures and any necessary implementation schedules into local basin plans.

The 303(d) listing process and TMDL development and implementation plans are good opportunities to address post-development hydromodification impacts because these processes can be targeted to local conditions and specific reaches where hydromodification related impairment of beneficial uses is of concern. In the 303(d) context, implementation measures can be developed and recommended to address post-construction hydromodification controls. Upon TMDL development, Regional Boards can enforce hydromodification control (if pertinent to the impairing pollutant) by incorporating hydromodication BMPs on a watershed or site specific basis into the Basin Plan. In addition, regulated stakeholders may be willing to voluntarily implement post-construction hydromodification controls through memoranda of agreement if such implementation will facilitate delisting of an impaired water (or result in future credit in the TMDL if delisting is not successful). Using this regulatory tool, the areas of the state that most need post-construction modification management plans (impaired watersheds) will get them in an enforceable manner that accounts for the uniqueness of each watershed.

d. CWA Section 401[15] Certifications:

Section 401 provides Regional Boards with yet another mechanism to address hydromodification control. Under Section 401 of the federal Clean Water Act, Regional Boards ensure that federally-permitted activities, such as permits issued by the Army Corps of Engineers under Section 404 of the CWA, are adequately protective of beneficial uses and pertinent water quality objectives. Where a construction project is likely to result in the addition of fill to jurisdictional waters, Regional Boards have the ability to condition their certification of the required Army Corps of Engineers Section 404 permit upon implementation of appropriate post-development hydromodification BMPs. Again, utilizing a targeted and locally sensitive process such as a 401 certification—that considers site specific conditions in receiving waters—allows project proponents to tailor their post-construction footprint in such a way as to ensure compliance with all water quality objectives at the most reasonable cost.

e. California Environmental Quality Act (CEQA)[16]

CEQA is a powerful tool in the regulatory arsenal of the Regional Boards. CEQA is triggered by discretionary approval by a public agency of a project that has the potential to cause a significant effect on the environment. Pub. Res. Code § 21080 (a). Because CEQA is triggered whenever a

[15] 33 U.S.C. §1341
[16] See Pub. Res. Code § 21000 *et. seq*

lead agency is required to exercise discretion with respect to approval of a private project, see id., the vast majority of projects that would trigger review under the Board's Preliminary Draft Permit will also trigger CEQA review by the local government charged with review and approval of the development project.

CEQA puts the Regional Boards (and concerned stakeholders) on notice that a project with potential water quality impacts is in the planning and design stage. The Regional Boards, as trustee agencies,[17] have the ability, and can be directed by the State Board to exercise their authority to comment on proposed developments and recommend project design features, site-specific best management practices, and other mitigation measures for post-development hydromodification impacts. The CEQA lead agency may only disregard the recommendations of the Regional Boards pertaining to environmental mitigation upon findings (based on substantial evidence in the record) that both (i) recommended hydromodification control measures (or alternative control measures) are not feasible;[18] and (ii) any significant but unavoidable adverse hydromodification effects resulting from the failure to incorporate project design features and mitigation measures are outweighed by economic, social, legal, technological or other compelling benefits of the proposed project. Pub. Res. Code § 21081 (detailing requirements for "Statement of Overriding Considerations").

Even upon a lead agency's filing of a Statement of Overriding Considerations, a Regional Board can still, in all likelihood, obtain the hydromodification mitigation desired. First, the Regional Board, or like-minded citizens' groups, can seek judicial review of the decision.[19] Even if judicial review is unsuccessful, the Regional Board could still, upon a proper showing, mandate that hydromodification impacts be addressed via other regulatory tools to the extent authorized by state law. Thus CEQA accomplishes the same goals as the Preliminary Draft Permit, but at an appropriate point in project planning, design and approval process. CEQA provides Regional Boards notice of projects with potential hydromodification impacts, and provides a site-specific mechanism for the Regional Boards to mandate the implementation of appropriate post development hydromodification controls.

f. Land Use Approvals:

To the limited extent that development projects may be outside of the reach of MS4 permit stormwater programs, but still of sufficient scope so as to trigger potential significant adverse hydromodification impacts, such projects will in many cases, not only require CEQA review, but will also require adoption or amendment of a local government's general plan, specific plan, or both. Adoption or amendment of a general or specific plan provides yet another opportunity for Regional Boards to impose hydromodification standards at the local level—either by requesting project specific requirements from the local government at the approval hearing, or by seeking a programmatic amendment of one or more of the elements of the general or specific plan to mandate post-construction hydromodification controls.[20]

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[17] See Pub. Res. Code § 21070.

[18] See Pub. Res. Code § 21002; 14 CCR § 15091 (CEQA Guidelines)

[19] See Pub. Res. Code § 21152 (a).

[20] The Los Angeles Regional Water Quality Control Board took exactly this approach to address stormwater runoff--requiring Ventura County, as a condition of approval of its MS4 permit, to amend its general plan to include "watershed and storm water quality and quantity management considerations" at the next update of its Land Use, Housing, Conservation or Open Space elements. See NPDES No. CAS004002.

Each city and county in California is required to promulgate a general land use plan, and once approved the general plan serves as the "constitution for all future developments within the city or county". Goleta Valley v. Board of Supervisors, 52 Cal. 3d 553, 570 (1990). If a proposed development project is inconsistent with elements of the general plan, it cannot go forward. Id. General plans must contain conservation, housing, land use and open space elements. See Government Code § 65302. The Governor's Office of Planning and Research (OPR) has taken the position that the Conservation element must address water quality. Governor's Office of Planning and Research, State of California General Plan Guidelines 200 (2003). Local governments are required to incorporate water quality policies from regional water quality plans—such as a Basin Plan—to the extent that such plans are relevant. Id. Thus, Regional Boards will be able, in all likelihood, to mandate the inclusion of hydromodification controls in a general plan once that Regional Board has incorporated such controls into its basin plan.

As part of the general planning process, local governments are required to notify Regional Boards that a particular project is under consideration. See Government Code § 65351 (requiring involvement "of public agencies" in amendment process). Any amendments to the Conservation Element that impact water resources "must be developed in coordination with all local agencies that deal with water in that community." Daniel J. Curtin, Jr., California Land Use and Planning Law 18 (2007). Thus, Regional Boards throughout the state (in rural and urban areas) will receive notice of development projects of sufficient scope to raise hydromodification control concerns, and local governments will be required to strongly consider the guidance provided by the Regional Boards before a project requiring general plan amendment can move forward.

Regional Boards will have similar opportunities to provide input and seek hydromodification controls in the context of specific plan amendments—which may be triggered for smaller projects that do not require amendment of a general plan. A specific plan is a tool for the systematic implementation of the general plan. It effectively establishes a link between implementing policies of the general plan and the individual development proposals in a defined area. The specific plan must be consistent with the policies detailed in the general plan. See Curtin, supra at 41-42. Thus, where a Regional Board has had hydromodification controls incorporated into one of the elements of a general plan, a developer will not be able to obtain a specific plan amendment unless it can demonstrate that the proposed project is consistent with the controls established in the general plan.

In addition to authority to provide guidance to local agencies on general plans and specific plans, Regional Boards also have authority, to the extent required by promulgated Regional Board regulations, to require local agencies to provide notice to the Regional Board whenever application for approval of a tentative subdivision map is filed. Wat. Code § 13266. Thus, even when the approving local government does not circulate a document for review in accordance with CEQA, a Regional Board has the authority to require notice of virtually any development within the region subdividing land into four or more lots. As with general and specific plans, Regional Boards may then provide guidance to local agencies regarding project design features, BMPs and other hydromodification mitigation measures that may be appropriate based on project and local conditions, and local agencies are required to consider and give due deference to the State Agency comments.

IV. Conclusion:

The current approach advocated by the Board in the Preliminary Draft Permit is unworkable—for the many reasons stated herein and in CBIA's previous comments. However, utilizing the existing authorities identified in this issue paper, the State and Regional Boards are in an excellent position to successfully address post-construction hydromodification impacts at the appropriate time—during the development planning process—and at the local level.

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Memorandum

Date: 27 August 2007

To: Mark Grey, Building Industry Association of Southern California (BIASC) and Construction Industry Coalition on Water Quality (CICWQ)

From: Peter Mangarella, Felicia Federico, and Lisa Austin, Geosyntec Consultants

Subject: Post-Construction Hydromodification Control Requirements in the Construction General Permit

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BACKGROUND

Provision K of the Preliminary Draft Construction General Permit (PCGP) contains New Development and Re-development Storm Water Performance Standards for hydromodification control. This memorandum is not intended to address the technical basis for those standards, but rather addresses the appropriateness of implementing such standards as part of compliance with the CGP.

PROJECT PLANNING FOR HYDROMODIFICATION CONTROL

A comprehensive review of recommendations within the technical literature and policy studies conducted to date shows a unanimous conclusion that to effectively address hydromodification impacts, regulatory and management strategies must be developed for, and integrated into, project planning, design and environmental review phases and processes.

Implementation of hydromodification control standards through the PCGP is not practical or appropriate because this approach is inconsistent with 1) good planning principles, 2) Phase I and Phase II municipal separate storm sewer (MS4) Permits, 3) municipal stormwater permitting, 4) entitlement policies and CEQA requirements, and 5) all other existing, proposed, or model ordinances or implementation plans reviewed by Geosyntec.

Good Planning Principles

Planning principles for controlling the adverse effects of new development and significant redevelopment emphasize the need to address potential impacts in the earliest stages of the development planning process, namely during the site assessment, site planning and layout, vegetation planning, and grading planning stages (Puget Sound Action Team, 2005). This is especially important in light of the emphasis that regulators and the development industry are now placing on utilizing Low Impact Development (LID) tools as part of an overall water quality and hydromodification control strategy.

Low Impact Development focuses primarily on site design at the individual lot level. LID implementation impacts all site design aspects, beginning with site plan preparation (Davis 2005; EPA 2000). However, LID is only one of several components of a comprehensive program to manage hydromodification impacts, including watershed-level land use and stream restoration planning, the integration of smart growth principles (EPA 2007), village or specific plan level site design Best Management Practices (BMPs), and regional/sub-regional volume reduction BMPs that can achieve and/or supplement the hydromodification control provided by LID, at the watershed scale. Therefore, planning scale and project design are important considerations in effectively managing hydromodification impacts. Accordingly, Stone (2004) emphasizes the need for a more complete integration of land use planning policy with environmental management. Davis (2005) cautions that cumulative impacts must be considered at the regional level, such as the potential for forced over-implementation of infiltration practices to encourage urban sprawl. Therefore, hydromodification control standards applying to new development and redevelopment projects must be incorporated as an integrated component of a jurisdiction's comprehensive planning strategy.

Moreover, it is generally recognized that effective planning for hydromodification control is not simply attained with the initial concept plan, but rather is an iterative process of development, evaluation, and modification. This process involves various stakeholders including the developer, the local jurisdiction, the Regional Water Quality Control Boards, environmental interest groups, community members, and other interested parties. It is infeasible to conduct an iterative process or to accommodate stakeholder input to stormwater planning at the construction phase of a development project.

Phase I and Phase II MS4 Permits

In requiring these standards at the General Construction Permitting phase, the State Board is essentially contradicting policy contained within the Phase I and Phase II MS4 Permits. These permits specifically emphasize the need for considering and incorporating controls as part of the planning process, the only point at which concepts such as conservation of natural areas, minimizing impervious cover, reducing effective imperviousness by routing runoff from impervious surfaces to landscaped areas, and other controls can be identified and implemented.

For example, in the NPDES Permit for the County of San Diego, adopted in January 24, 2007, Provision D. 1 .d requires the local agencies to update local Standard Urban Storm Water Mitigation Plans (SUSMPs) that "manages increases in runoff discharge rates and durations from Priority Development Projects that are likely to cause increased erosion of stream beds and banks..." And as part of the implementation process (Provision D. 1 .d (9)) "each Copermittee shall implement a process to verify compliance with SUSMP requirements. ***The process shall identify at what point in the planning process*** (emphasis added) Priority Development Projects will be required to meet SUSMP requirements."

The San Diego Permit also requires each Copermittee to participate in the development of a Hydromodification Management Plan (HMP) to manage increases in runoff discharge rates and durations from all Priority Development Projects, where such increased rates and durations are likely to cause increased erosion of channel beds and banks. The HMP is intended to define local standards, performance criteria, and how the HMP requirements will be incorporated into the local agency approval process. The HMP also may ***include implementation of planning measures*** (emphasis added) such as stream restoration that may result in much more cost-effective solutions than would be obtained through on site efforts alone. Again, this illustrates the need for comprehensive planning to be conducted to allow developers and local agencies to identify the most reasonable and environmentally effective solutions for a complex problem. Unfortunately the PCGP does not seem to recognize the need for such an approach.

The State Water Resources Control Board's Phase II Permit also contains language that emphasizes the need to incorporate hydromodification control goals in the planning phase. For example, areas subject to high growth or serving a population of at least 50,000 must comply with Attachment 4 of the permit that incorporates the following design standards: cluster development, limit clearing and grading of native vegetation, maximize trees and other vegetation, and preserve riparian areas and wetlands. Such options will tend not to be considered if the hydromodification requirements as currently contained in the PCGP were to go into effect.

Local Agency Planning Process, including the California Environmental Quality Act

Local planning agencies have developed a plan approval process that is designed to provide local agency approval and permits prior to construction. The local permitting process, depending on the nature of the development, may include the following steps:

- General Plan Amendment (GPA), including land use, transportation, bikeways and trails, and natural resources elements,
- Specific Plan Approval or Zone Change

- Development Agreement
- Tentative Tract Map Approval
- Grading and Erosion and Sediment Control (ESC) Permit
- Building Permit

In addition, the local permitting process must comply with environmental review and permitting requirements such as:

- CEQA analysis.
- Streambed Alteration Agreement - California Department of Fish and Game
- Clean Water Act Section 404 Permit - U.S. Army Corps of Engineers.
- Clean Water Act Section 401 Certification - California Regional Water Quality Control Board
- MS4 Permit Stormwater Mitigation Planning

Moreover, the approval process for a number of the above requirements includes a public review and comment process that ensures stakeholder input. Local planning agencies have developed a land use planning and environmental process to address meeting these requirements in the most efficient way possible. The proposal to incorporate the hydromodification requirement in the construction phase of the project is completely inconsistent with this established process.

Other Existing, Proposed, or Model Ordinances

Geosyntec is unaware of any other current or proposed regulation or implementation plan which relegates agency review and approval of post-development hydromodification management measures in the project construction phase.

The Center for Watershed Protection's model ordinance for post-construction runoff (CWP, 2007) covers water quality and channel protection (hydromodification) requirements for new development and redevelopment. This ordinance requires a Stormwater Management Plan which details how runoff will be controlled and which must be submitted as part of the application for development. The model ordinance stipulates that: "No building, grading, or sediment control permit shall be issued until a satisfactory final stormwater management plan, or a waiver thereof, shall have undergone a review and been approved by the (jurisdictional stormwater authority) after determining that the plan or waiver is consistent with the requirements of this ordinance."

CONCLUSIONS

In summary, the inclusion of post-development hydromodification control standards at the CGP phase is inappropriate and contrary to all current standards and precedents. It is impractical to implement and does not support the watershed planning and stakeholder processes critical to a successful management approach.

Rather than addressing post-development hydromodification controls through the CGP, the State should direct the Regional Boards to include hydromodification control requirements in Phase I and Phase II MS4 permits statewide. This will assure sufficient regulation of all urban and urbanizing areas, which are the primary areas of concern. For the most part, due to the low permitting thresholds for Phase II MS4 Permits, areas that are not regulated by either a Phase I or a Phase II Permit will either be subject to rural land use or zoning designations, limiting the potential for urbanization, or are areas in which urban uses are not permitted (such as State and National parks and forests, Bureau of Land Management lands, and similar restricted use areas, which are currently estimated to constitute approximately fifty percent of the State).

REFERENCES

The Center for Watershed Protection, 2007. Post-Construction Runoff Model Ordinance, available at http://www.stormwatercenter.net/Manual _Builder/stormwater _ordinance.htm (last accessed on 8-20-07)

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US EPA Office of Water, 2000. Low Impact Development, A Literature Review, EPA-841-B00-005, October.

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APPENDIX D

Attachment G from the PGCP –
New and Re-development Performance Standard Worksheet

ATTACHMENT G:
New and Re-development Performance Standard Worksheet

The discharger shall submit with their NOT the minimum amount of information (e.g., maps, worksheets, etc.) required to demonstrate compliance with the requirements.

Map Instructions

The discharger must submit a small-scale topographic map of the site shall be prepared to show the existing contour elevations and the pre- and post-construction drainage divides. If the project is required to demonstrate compliance with the "distribute controls" requirements, the map should show how these controls are distributed after construction is complete. Recommended scales include 1 in. = 20 ft., 1 in. = 30 ft., 1 in. = 40 ft., or 1 in = 50 ft. The suggested interval is usually 1 to 5 feet, depending upon the slope of the terrain. The contour interval may be increased on steep slopes. Other contour intervals and scales may be appropriate given the magnitude of land disturbance.

Worksheet Instructions

The discharger has the option of using the attached spreadsheet (**Volume_calculator.xls**, instructions below) or a more sophisticated, watershed process based model (e.g. SWMM, HSPF) to determine the required volume.

In* Volume_calculator.xls and o*n the Worksheet titled "Volume Calculator," you must complete the worksheet for each sub-drain area identified in the "drainage distribution" section.

Step 1: Enter the total area of project (acres) in cell B5.

Step 2: Enter the sub-watershed area (acres) in cell B6.

Step 3: Enter the existing amount of impervious area (acres) in cell B11.

Step 4: Enter the proposed additional amount of impervious area (acres) in cell B13.

Step 5: Enter the 85th percentile storm event (P_{85}) for the project area (in inches)[18] in cell B16.

Step 6: Determine the mean annual precipitation (P_{annual}) for the project area (in inches)[19] in cell B17.

Step 7: Enter the area credit claimed for non-structural practices in cells L14 through L19 and complete the appropriate credit certification worksheet(s). Volume that cannot be addressed using non-structural practices must be captured in structural practices and approved by the Regional Water Board.

[18] The 85th percentile storm event can be obtained from Appendix D in the California Best Management Practice New and Redevelopment Handbook (available at www.cabmphandbooks.com). The Handbook refers to the 85th percentile storm event as P6.
[19] Mean annual precipitation can be obtained from Appendix D in the New and Redevelopment Handbook, Natural Resources Conservation Service (NRCS) Field Offices, or local public works and flood control agencies.

Non-structural Practices Available for Crediting - Complete All Applicable Worksheets

Tree Canopy Cover

- Within 5 years of planting, the total tree canopy covers 75% of the area to be claimed.

Downspout Disconnections

- Downspouts and any extensions must extend at least six feet from a basement and two feet from a crawl space or concrete slab.
- Downspouts shall be at least 10 feet away from the nearest impervious area to eliminate "reconnection".
- The length of the disconnection shall be at least 75 feet.
- Where a gutter/downspout system is not used or when other roof runoff devices (e.g. rain chains) are used, the roof runoff shall drain as sheet flow from the structure or drain to a planter box or landscaped area.

Impervious Area Disconnection

- The maximum contributing impervious flow path length shall be 75 feet.
- The length of the disconnection shall be equal to or greater than the contributing length. A storage device (e.g. French drain, bioretention area, gravel trench) may need to be implemented to achieve the required disconnection length.
- The impervious area to any one discharge location cannot exceed 1,000 square feet.

Sheet flow to Streamway/Buffer

- Runoff shall enter the streamway or buffer as sheet flow. The maximum contributing length shall be 150 feet for pervious areas and 75 feet for impervious areas.
- The contributing overland slope shall be 5% or less, or a level spreader shall be used.

Vegetated Swales

- All vegetated swales must be designed in accordance with Treatment Control BMP 30 (TC-30 - Vegetated Swale) from the California Stormwater BMP Handbook, New Development and Redevelopment (available at www.cabmphandbooks.com).
- The maximum flow velocity for runoff for the 85th percentile rainfall event shall be less than or equal to 1.0 foot per second.

Permeable Pavers

- There are a `number of design considerations related to the use of permeable pavers, including the load requirement (e.g. vehicular), hydraulic requirements, and local climate of the installation.

See http://www.lowimpactdevelopment.org/epa03/pavespec.htm for more detail.