Lake Tahoe TMDL Pollutant Reduction Opportunity Report

March 2008
v2.0

California Water Boards
State Water Resources Control Board
Regional Water Quality Control Boards

ndep
Nevada Division of Environmental Protection
protecting the future for generations

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Acronyms

BAP	Bioavailable phosphorus
BLM	Bureau of Land Management
BMP	Best management practices
BOR	Bureau of Reclamation
BPJ	Best professional judgment
BSTEM	Bank Stability and Toe Erosion Model
CARB	California Air Resources Board
CAREC	California Alpine Resort Environmental Cooperative
cfs	Cubic feet per second
CICU	Commercial/Institutional/Communications/Utilities
CONCEPTS	Conservational Channel Evolution and Pollutant Transport System
CSP	California Department of Parks and Recreation
CTC	California Tahoe Conservancy
DCIA	Directly connected impervious area
DFMEA	Design Failure Modes and Effects Analysis
DN	Dissolved nitrogen
DP	Dissolved phosphorus
DSS	Decision support system
EIP	Environmental Improvement Program
EMC	Event mean concentration
EP	Erosion Potential
EPA	U.S. Environmental Protection Agency
ERA	Equivalent Roaded Area
FISRWG	Federal Interagency Stream Restoration Working Group
FMEA	Failure Modes and Effects Analysis
FUSCG	Forested Uplands Source Category Group
GIS	Geographic information system
HSC	Hydrologic source control
HSPF	Hydrologic Simulation Program Fortran (modeling platform on which LSPC is based)
ICIA	Indirectly Connected Impervious Area
IERS	Integrated Environmental Restoration Services
IWQMS	Integrated Water Quality Management Strategy (Integrated Strategy)
km	Kilometers
kPa	Kilopascals
Ksat	Infiltration capacity
LSPC	Loading Simulation Program C++ (Lake Tahoe TMDL watershed model)
LTBMU	Lake Tahoe Basin Management Unit, (U.S. Forest Service)
LTIMP	Lake Tahoe Interagency Monitoring Program
LWD	Large woody debris
m	Meters
MFR	Multifamily residential
mm	Millimeters
MT	Metric ton
N	Nitrogen
NDEP	Nevada Division of Environmental Protection
nhc	northwest hydraulic consultants
NO_x	Oxides of nitrogen

NRCS	Natural Resource Conservation Service (USDA)
NRRSS	National River Restoration Science Synthesis
NSL	Agricultural Research Service-National Sedimentation Lab (USDA)
O&M	Operations and maintenance
P	Phosphorus
PCO	Pollutant Control Option
PLRE-STS	Pollutant Loading Reduction Estimator – Spreadsheet for Tahoe Stormwater
PSC	Pollutant Source Control
PSD	Particle-Size Distribution
RGA	Rapid Geomorphic Assessment
RS	Rainfall simulation
RWC	Residential wood combustion
SCG	Source Category Group
SCIC	Source Category Integration Committee
SCSCG	Stream Channel Source Category Group
SEZ	Stream Environment Zone
SFR	Single family residential
SGF	Soils-Geology [scaling] Factor
SMURRF	Santa Monica Urban Runoff Recycling Facility
STPUD	South Tahoe Public Utility District
SWQIC	Storm Water Quality Improvement Committee
SWT	Storm water treatment
SY	Sediment yield
TERC	Tahoe Environmental Research Center
TMDL	Total Maximum Daily Load
TN	Total nitrogen
TP	Total phosphorus
TRCD	Tahoe Resource Conservation District
TRPA	Tahoe Regional Planning Agency
TSP	Total suspended particulates
TSS	Total suspended solids
TWG	Technical Working Group
UC	University of California
UGSCG	Urban Uplands and Groundwater Source Category Group
USDA	U.S. Department of Agriculture
USDA-ARS	U.S. Department of Agriculture–Agricultural Research Service
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WEPP	Water Erosion Prediction Project

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Version 2.0 Updates

This updated version of the *Lake Tahoe TMDL Pollutant Reduction Opportnity Report* provides a number of refinements to estimations of pollutant load reductions corresponding to various control efforts, and the costs associated with those controls. Further, certain breakdowns of costs and reductions have been revised to reflect useful sub-groupings for policy targets revealed through the TMDL public process.

The result is a new set of updated tables and figures for Chapter 6 of this report. The text has been updated as well to reflect these changes and highlight the reasons for the updates. The specific changes include:

1. Cost and load reduction description of atmospheric sources are divided into mobile and non-mobile sub-categories
2. Potential revenues from atmospheric pollutant control incentives have been removed from the cost tables, making them more comparable to other source category cost results
3. Cost and load reduction descriptions for Urban & Groundwater sources include a new composite set of controls called *Tier 3* that is more comparable to other Treatment Tiers
4. Baseline loading and load reduction potential values used by specific Source Category Groups are scaled to match the TMDL pollutant budget baseline

Executive Summary

The Lake Tahoe Basin is in a montane-subalpine setting above an altitude of approximately 1,900 meters (6,234 ft) in the Sierra Nevada Range of California and Nevada. Lake Tahoe is losing its famed clarity because of excess loading of fine sediments and nutrients. As a result, the California Regional Water Quality Control Board, Lahontan Region (Lahontan Water Board) and the Nevada Division of Environmental Protection (NDEP) initiated the Lake Tahoe Total Maximum Daily Load (Lake Tahoe TMDL). The Lake Tahoe TMDL program includes a comprehensive research component and a restoration planning effort. The Lake Tahoe TMDL is answering a set of core questions summarized in Table ES-1.

This report represents a significant step forward in the development of the Lake Tahoe TMDL. It provides a first estimate of the potential Basin-wide pollutant load reductions at several levels of effort. Targeted research will refine these initial estimates over the coming years through a continual improvement and adaptive management process.

Table ES-1. Lake Tahoe TMDL synopsis with this work highlighted

TMDL phase	Questions	Products
Phase One— Pollutant Capacity and Existing Inputs	**What pollutants are causing Lake Tahoe's clarity loss?**	Research and analysis of fine sediment, nutrients and meteorology
	How much of each pollutant is reaching Lake Tahoe?	Existing pollutant load to Lake Tahoe from major sources
	How much of each pollutant can Lake Tahoe accept and still achieve the clarity goal?	Linkage analysis and determination of needed pollutant load reduction
		Document: TMDL Technical Report
Phase Two— Pollutant Reduction Analysis and Planning	**What are the options for reducing pollutant inputs to Lake Tahoe?**	Estimates of potential pollutant load reduction opportunities **Document:** Lake Tahoe TMDL Pollutant Reduction Opportunity Report
	What strategy should we implement to reduce pollutant inputs to Lake Tahoe?	Integrated Strategies to control pollutants from all sources
		Load reduction allocations and implementation milestones
		Implementation and Monitoring Plans
		Document: Final TMDL
Phase Three— Implementation and Operation	**Are the expected reductions of each pollutant to Lake Tahoe being achieved?**	Implemented projects & tracked load reductions
	Is the clarity of Lake Tahoe improving in response to actions to reduce pollutants?	Project effectiveness and environmental status monitoring
	Can innovation and new information improve our strategy to reduce pollutants?	Lake Tahoe TMDL continual improvement and adaptive management system, targeted research
		Document: Periodic Milestone Reports

Phase One

Phase One of the Lake Tahoe TMDL answered three important questions:

1. **What pollutants are causing Lake Tahoe's clarity loss?**
2. **How much of each pollutant is reaching Lake Tahoe?**
3. **How much of each pollutant can Lake Tahoe accept and still achieve the clarity goal?**

Extensive scientific research conducted for the Lake Tahoe TMDL has identified five major sources of pollutants and estimated the annual load of pollutants that are delivered from each source. The numeric results are summarized in the pollutant budget Table ES-2. It is useful context for the results presented in this report. The Lake Clarity Model was also developed to help evaluate the load reduction necessary to meet the Lake Tahoe TMDL water clarity target of 29.7 m (97.4 ft.) annual average Secchi depth. This information is presented in detail in the Lake Tahoe TMDL Technical Report (Technical Report), which can be found on the Lahontan Water Board web site (http://www.waterboards.ca.gov/lahontan/TMDL/Tahoe/Tahoe_Index.htm).

Table ES-2. Pollutant loading budget for Lake Tahoe from Phase One Technical Report

Source category		Total nitrogen (metric tons/year)	Total phosphorus (metric tons/year)	Number of fine sediment particles ($x10^{18}$/ year)
Upland	Urban	63	18	348
	Non-Urban	62	12	41
Atmospheric Deposition	Wet + Dry	218	7	75
Stream Channel Erosion		2	< 1	17
Groundwater		50	7	NA*
Shoreline Erosion		2	2	1
TOTAL		**397**	**46**	**481**

*NA = Not applicable because it was assumed that groundwater does not transport fine sediment particles.

Phase Two

Phase Two began in 2005 and is the focus of current efforts to answer two additional questions:

1. **What are the options for reducing pollutant inputs to Lake Tahoe?**
2. **What strategy should we implement to reduce pollutant inputs to Lake Tahoe?**

This report answers the first question by providing initial estimates of the potential Basin-wide pollutant load reductions at several levels of effort. This information will form the basis for the development and selection of an Integrated Water Quality Management Strategy (Integrated Strategy). During the fall of 2007 the public and stakeholders will be engaged to inform the development of potential Integrated Strategies. Load allocations, a TMDL element required by the federal Clean Water Act, will be informed by the preferred Integrated Strategy. Load allocations ultimately assign responsibility for achieving the required load reductions and may be made to watersheds, management/regulatory programs, jurisdictions, or a combination of these. In addition, water quality crediting and trading will be analyzed as a programmatic means to assist implementation of projects designed to achieve load reduction requirements. These elements will compose the Final TMDL report that is planned for completion in the winter of 2008/2009.

Phase Three

Phase Three is the implementation phase of the Lake Tahoe TMDL restoration plan and addresses three additional questions:

1. **Are the expected reductions of each pollutant to Lake Tahoe being achieved?**
2. **Is the clarity of Lake Tahoe improving in response to actions to reduce pollutants?**
3. **Can innovation and new information improve our strategy to reduce pollutants?**

The Lake Tahoe TMDL will be implemented through projects, programs and regulations included in the Tahoe Regional Planning Agency (TRPA) Regional Plan, the USDA Forest Service (USFS) Land and Resource Management Plan, state funding agency programs, and permits issued through the Lahontan Water Board and NDEP. Load reductions related to projects and programs will be tracked and project effectiveness will be monitored. Ongoing research and monitoring will improve the scientific basis for adjusting the Lake Tahoe TMDL and Integrated Strategy over time. A formal, continual improvement and adaptive management process will be used to focus implementation on the most effective and appropriate pollutant controls.

General Approach

This analysis estimated potential pollutant load reductions and associated costs at a Basin-wide scale. This is the first comprehensive estimate of possible load reductions based on differing levels of effort applied to the to major pollutant sources. The Lahontan Water Board and NDEP intend to use this information as a basis for discussion with stakeholders on developing a broad Basin-wide strategy to protect water quality.

The analysis was performed in three steps including an evaluation of potential pollutant controls, a site-scale analysis, and an extrapolation to the Basin-wide scale (See Figure ES-1). The steps were pursued independently by each of four groups of experts known as Source Category Groups (SCGs). The groups were overseen by a committee responsible for providing direction and maintaining consistency of results called the Source Category Integration Committee (SCIC). The approach and results were further reviewed by experts not previously involved with the Lake Tahoe TMDL program. The results of each SCG were processed by the project team and combined into two related sets of tables that are summarized in the results section of this Executive Summary.

In many cases the SCGs took necessarily individualized approaches to their analyses. The unique details of each SCG's approach are explained in their specific chapters.

Key Participants

SCGs
The Lahontan Water Board and NDEP identified and assembled respected experts into Source Category Groups (SCGs) to investigate pollutant control options for each major source of pollutants entering Lake Tahoe. Each SCG included a group lead that coordinated the technical investigations and overall staffing of the group.

SCIC
Review and cross-SCG coordination has been provided by a Source Category Integration Committee (SCIC). The SCIC included staff from the Lahontan Water Board, NDEP and TRPA, a Pathway Coordination Team representative, and a Science Advisor involved with long-term TMDL development experience.

Step 1: Pollutant Control Option Evaluation

These analyses began with evaluations of pollutant control options (PCO) that could be applied. Each SCG compiled a list of potential PCOs on the basis of professional experience, local knowledge, and input from the SCIC, Pathway Technical Working Groups, the Pathway Forum, and other sources. The SCGs then screened the list of PCOs and focused investigations on PCOs that were expected to produce large Basin-wide pollutant load reductions and could be quantified well enough at this time to be used in calculations.

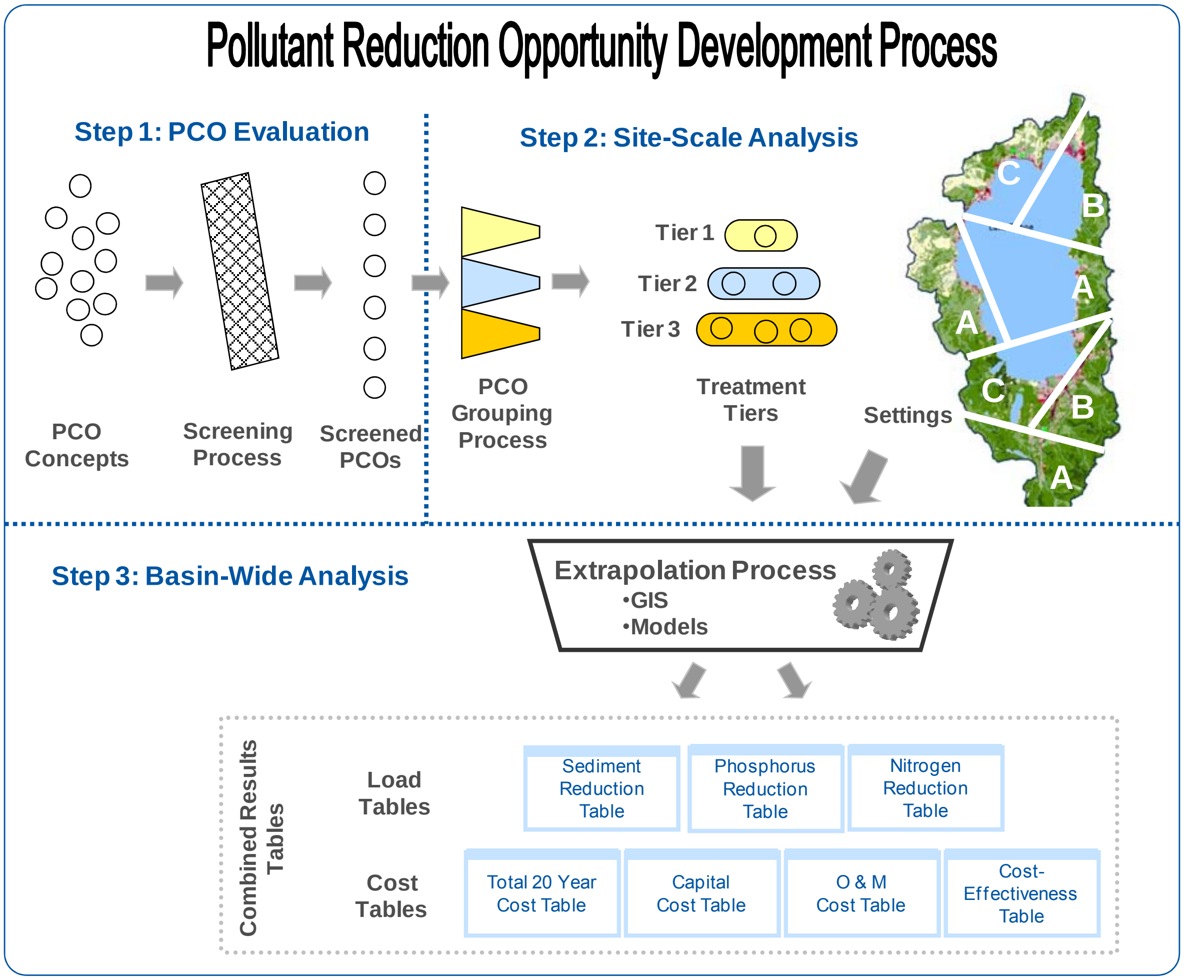

Figure ES-1. The pollutant reduction opportunity development process showing three analysis steps. Step 1: consider wide-ranging Pollutant Control Options and select PCOs most likely to produce large load reductions and quantifiable results. Step 2: group PCOs into several Treatment Tier that could be applied to Settings representative of the landscape characteristics. Step 3: extrapolate site-scale results Basin-wide using tools such as GIS and predictive models. Combined results were captured in a set of spreadsheet tables.

Step 2: Site-scale Analysis

Each SCG analyzed pollutant load reductions and implementation costs of applying PCOs on a representative site scale. During this step, the SCGs defined the representative site areas, called *Settings* and packages of PCOs, called *Treatment Tiers* (Tiers) that could be applied.

Settings

Each SCG categorized the physical area of the Lake Tahoe Basin into a number of representative Settings on the basis of several criteria. Settings were largely determined by the physical characteristics of the land such as average slope or soil type. Settings were in part determined by the applicability of PCOs. For example, water quality projects use different PCOs depending on how much impervious coverage is present. In other cases, Settings were determined by the way that they deliver pollutants to Lake Tahoe. For instance, atmospheric loads are highly affected by the distance of the source from the Lake, so the atmospheric SCG defined Settings according to distance from the Lake. Settings were selected to ensure that all treatable areas of the Lake Tahoe Basin were included while maintaining a manageable number of Setting-PCO combinations. Summary definitions of each SCG's Settings are provided in Table ES-3.

Table ES-3. Summary definition of Settings for each source category

Setting name	Definition
Atmospheric Settings	
Setting 1	The entire band of land less than 0.2 kilometer from the Lake. Pollutant emissions from this Setting will reach the Lake most readily.
Setting 2	The entire band of land less than 1 kilometer from the Lake (includes Setting 1).
Setting 3	The entire band of land less than 3 kilometers from the Lake (includes Settings 1 & 2)
Setting 4	The entire Lake Tahoe Basin (includes Settings 1, 2, & 3)
Urban and Groundwater Settings	
Concentrated – Steep	Areas where impervious coverage is relatively concentrated and there is minimal space for PCOs to be constructed. Average slope of the area is *greater than* 10%.
Concentrated – Moderate	Areas where impervious coverage is relatively concentrated and there is minimal space for PCOs to be constructed. Average slope of the area is *less than* 10%.
Dispersed – Steep	Areas where impervious coverage is relatively dispersed and there is adequate area for PCOs to be constructed among the impervious coverage or downhill from it. Average slope of the area is *greater than* 10%
Dispersed – Moderate	Areas where impervious coverage is relatively dispersed, and there is adequate area for PCOs to be constructed among the impervious coverage or downhill from it. Average slope of the area is *less than* 10%.
Forested Uplands Settings	
Setting A	Highly disturbed areas with significant compaction such as unpaved roads.
Setting B	Areas subject to major soil disturbance such as ski runs, campgrounds, and steep bare slopes. These areas are characterized by moderate vegetative cover, little mulch or duff, and low-infiltration capacity.
Setting C	Typical Tahoe forested areas that are managed for forest health and defensible space. These areas are characterized by well-established plant communities, thick duff layers and high soil-hydrologic function. The large majority of the Basin land area falls into Setting C.
Stream Channel Settings	
Upper Truckee River	The entire restorable channel of the Upper Truckee River.
Blackwood Creek	The entire restorable channel of Blackwood Creek.
Ward Creek	The entire restorable channel of Ward Creek.

Treatment Tiers

The SCGs combined screened PCOs into Treatment Tiers designed to provide a spectrum of potential load reduction and effort level within each Setting. Each SCG specifically defined its own Treatment Tiers however the following descriptions provide a general understanding of the definitions that guided the SCG's work.

- Tier 1—A basic set of PCOs that represented a step forward in practices generally used for existing projects in the Lake Tahoe Basin. Constraints to implementation and cost-effectiveness of particular PCOs selection for this Tier. This Tier was often the least expensive to implement of the three Tiers and represented the lowest level of effort relative to the other Tiers.
- Tier 2—A mix of the PCOs used in Tiers 1 and 3. The Tier 2 analysis generally provided a greater load reduction and cost than Tier 1.
- Tier 3—The maximum load reduction potential evaluated by the SCG. Land ownership, cost-effectiveness and other constraints were considered less important in formulating this Tier. This Tier was generally the most expensive to implement of the three Tiers.

Treatment Tier definitions for each SCG are summarized in Table ES-4.

Table ES-4. Summary definitions of Treatment Tiers for each source category

Treatment Tier name	Summary definition
Atmospheric	
Tier 1	A baseline of existing loading from which to compare. This source category was different than others because this *Tier* does not result in load reductions.
Tier 2*	A set of PCOs that is deemed effective and particularly cost effective. Numeric estimates are based on average literature values.
Tier 3	A set of PCOs deemed more effective and difficult to implement. Estimates based on literature values that were the most favorable for load reduction.
Urban & Groundwater	
Tier 1*	An upper-end use of existing practices and technologies. Spatial application within the treatment area considers typical site and funding constraints. Assumes 50% completion of residential best management practices (BMPs).
Tier 2	A significantly higher-use, advanced, gravity-driven treatment technologies applied more aggressively within the treatment area. Traditional limitations on property acquisition and maintenance rates are relaxed in this Tier. Assumes 100% completion of residential BMPs.
Tier 3	A composite of pumping and centralized treatment systems for concentrated settings (both moderate and steep) and Tier 2 treatments for dispersed settings (both moderate and steep).
Forested Uplands	
Tier 1*	Includes *standard* treatments used or required by management agencies in current practice.
Tier 2	A middle level of treatment that includes *state-of-the-art* practices designed to achieve *functional* rehabilitation of hydrologic properties.
Tier 3	Treatments designed to develop site conditions that will mimic undisturbed, *natural* conditions after a period of time. This Tier represents the maximum load reduction possible in the Setting.

(table continues next page)

Stream Channel	
Tier 1	Restoration. A set of treatments that modifies planform, increases length and sinuosity, connects floodplain and decreases slope such that a *restored* condition is eventually reached. This Tier is designed to achieve load reductions as well as other ecosystem objectives such as riparian habitat, flood control, and recreation value.
Tier 2*	Rehabilitation. A combination of channel restoration (Tier 1) and simple bank protection (Tier 3) that focuses on cost-effective treatments, and property ownership is considered a factor.
Tier 3	Bank protection. A basic set of channel armoring and minor bank slope reductions that increase hydraulic resistance and reduce bank failure. This Tier does not achieve multiple ecosystem objectives.

* These Tiers include pollutant controls that are most closely related to those used in the most effective EIP projects however; they do not represent a baseline or status quo condition that applies to existing projects.

Step 3: Basin-wide Extrapolation

The SCGs used models and spatial analysis to estimate the pollutant load reduction potential and associated cost of applying each Treatment Tier to each applicable Setting within their source category. The tools and procedures used to complete the extrapolation step are described more completely within each SCG's chapter. The result of the extrapolation step is a Basin-wide estimate of potential pollutant load reductions and associated costs.

Results

Summary results from all SCGs are combined in Figure ES-2 and Table ES-5 to describe potential load reductions and estimated costs. Additional data including results for each Setting is available in Chapter 6 (*Combined Results: Load and Cost Tables*) of this document. Review of the more detailed analysis results will be necessary to understand the subtleties of the information and select an Integrated Strategy.

Load reductions are critical to determine whether the Lake Tahoe TMDL clarity goals can be achieved while costs are a consideration for implementation of pollutant controls. Figure ES-2 summarizes the potential load reduction estimates from each SCG in relation to the Technical Report's total pollutant budget. It also includes the total 20-year cost of the Treatment Tier that could achieve the relative reductions. This cost includes all capital investment and operations & maintenance (O&M) costs necessary to ensure ongoing load reductions. No attempt has been made to separate the cost to control a particular pollutant because most controls contribute to reductions of more than one pollutant. Table ES-5 contains the data displayed in Figure ES-2 and makes it possible to compare results between different source categories or Tiers (columns) but not between the differing pollutants (rows).

These results must be viewed within the context with which they were estimated. The values assume that all pollutant controls are applied to the maximum applicable area on which they could be used. The SCGs did not consider how long it would take to achieve full implementation in their analyses. The values presented signify the total load reduction possible once the PCOs are fully installed, Basin-wide.

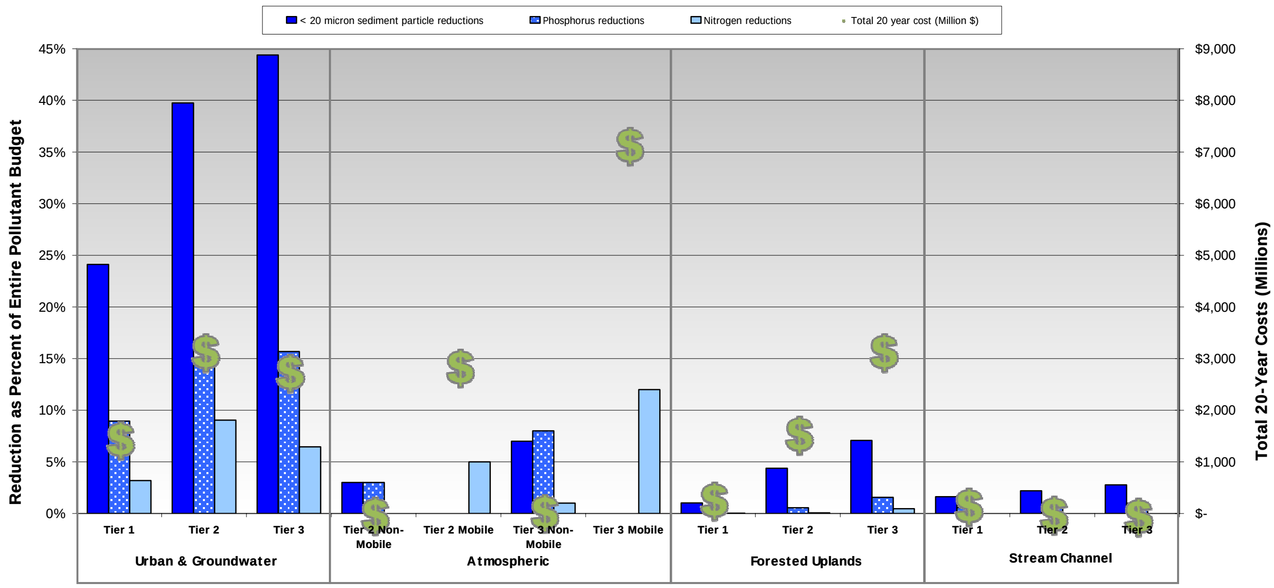

Figure ES-2. This chart presents two separate data sets for comparison. Estimated load reductions as a percent of the entire Lake Tahoe TMDL pollutant budget are shown by vertical bars that can be read on the left axis. Total 20-year costs for each Tier are represented as dollar signs that can be read on the right axis. Each cost is associated with all three pollutant load reductions represented by the vertical bars.

Table ES-5. Summary table of estimated potential load reductions as a percent of the total pollutant budget and total 20-year costs

Source Category and Tier	< 20 micron sediment particle reductions	Phosphorus reductions	Nitrogen reductions	Total 20 year cost (Million $)	20 year capital cost (Million $)	Annual O&M cost (Million $)
Atmospheric[4]						
Tier 2 Non-Mobile	3%	3%	0%	$35	$28	$0
Tier 2 Mobile	0%	0%	5%	$2,900	$280	$130
Tier 2 Sub-total	3%	3%	5%	$2,900	$300	$130
Tier 3 Non-Mobile	7%	8%	1%	$88	$74	$1
Tier 3 Mobile	0%	0%	12%	$7,200	$690	$330
Tier 3 Sub-total	8%	8%	13%	$7,300	$760	$330
Urban & Groundwater						
Tier 1	24%	9%	3%	$1,500	$1,400	$3
Tier 2	40%	15%	9%	$3,200	$2,800	$21
Tier 3	44%	16%	6%	$2,800	$2,500	$15
Forested Uplands						
Tier 1	1%	0%	0%	$320	$193	$6
Tier 2	4%	1%	0%	$1,600	$1,400	$7
Tier 3	7%	2%	0%	$3,200	$3,100	$0
Stream Channel						
Tier 1	2%	1%	N/A	$210	$210	$0
Tier 2	2%	1%	N/A	$50	$51	$0
Tier 3	3%	1%	N/A	$15	$15	$0

Notes:
1. These results are based on the assumption that controls are applied to the maximum applicable area.
2. Columns are not summed because Tiers are not additive. Only one Tier can be selected for each source category.
3. Rows are not summed because each represents a different quantity.
4. Atmospheric pollutant reduction opportunities have been split between 1) non-mobile sources, which consist of transportation infrastructure and stationary source reductions and 2) mobile sources, which consist of reductions from reduced vehicle emissions resulting from reducing vehicle miles traveled.

Figure ES-2 and Table ES-5 show the following results for loads and costs.

Load Results

1. Urban and groundwater sources show the largest opportunity to reduce pollutants of concern.
    a. In general, these controls show several times more load reduction potential than fine sediment particles from the three other source categories combined. Fine sediment particle load reductions come from urban runoff pollutant controls, not groundwater treatment.
    b. Nutrient loads from this source are also controllable, but to a lesser extent.
2. Atmospheric controls provide the largest opportunity (13 percent) to reduce nitrogen loads and can reduce significant amounts of the fine sediment (8 percent) and phosphorus (8 percent) loads.
3. Forest and Stream Channel sources show moderate potential for load reductions in fine sediment and limited potential for reduction of nutrients.
4. Achieving clarity goals will require implementation of controls in all source categories.

Cost Results

1. Urban and groundwater pollutant controls show 20 year costs ranging from $1.5-3.2 billion. These costs are similar to forest upland costs and higher than costs for other source categories but higher load reduction potentials make urban and groundwater pollutant control relatively cost effective.
2. Forested uplands costs show a broad range ($320 million to $3.1 billion) that corresponds positively with increasing load reductions. The estimates show somewhat lower cost effectiveness than urban and groundwater sources and emphasize the need to focus restoration on high priority, disturbed areas to make these controls cost effective.
3. Atmospheric cost results do not include the potential revenue that could be generated through VMT reduction incentives. Atmospheric non-mobile costs ($35-$88 million) are orders of magnitude less than mobile costs ($2.9 to $7.2 billion). Non-mobile fine sediment controls are highly cost effective.
4. Stream channel costs are lower for higher numbered Treatment Tiers, unlike other source categories. This is because Tier 3 controls involve basic bank hardening that is inexpensive and effective for reducing stream channel erosion. However, this analysis did not include the potential treatment of upland loads being transported by the stream. Tier 1 restorations are considered likely to provide water quality benefits by allowing sedimentation in flood plains, as well as other benefits such as flood control and enhanced riparian habitat. Thus, these results could be adjusted upward in the future as tools for estimating all benefits are fully developed.

Source Category Considerations

This section presents key considerations and additional findings related to each source category that provide important context for understanding load reduction and cost results.

Atmospheric Sources

1. Atmospheric cost results do not include the potential revenue that could be generated through VMT reduction incentives.
2. There is a significant cost difference between mobile source PCOs that target nitrogen and non-mobile controls that typically target fine sediment and phosphorus. In general, Basin-wide total costs to control nitrogen from mobile sources are two orders of magnitude higher than comparable costs to control fine sediment and phosphorus. It is possible to focus effort on stationary sources or mobile sources separately.
3. The atmospheric estimates presented in the results tables do not attempt to include entrained dust deposition to Lake Tahoe from mobile sources. After this report was complete, the SCG completed a preliminary estimate of this load and found that VMT reductions up to 25 percent resulted in fine sediment particle load reductions less than half of one percent. This result supported the initial assumption that VMT reductions do not provide a significant opportunity for significant fine sediment particle load reductions. However it is important to note that current scientific understanding of the linkage between VMT and fine sediment loading to Lake Tahoe is not well characterized and this research need has been identified for inclusion within the Tahoe Science Consortium's Draft Science Plan.
4. In some instances, atmospheric PCOs overlap with Urban and Forest PCOs. As a result, Integrated Strategies that employ both atmospheric and urban or forest controls will include some double counting of costs. Integrated Strategies that do not employ both atmospheric controls, but do employ urban or forest controls will not account for the associated atmospheric pollutant reductions. Examples of such overlap include:
    - Paved roads where the atmospheric group estimated the total costs of street sweeping and the urban and groundwater group estimated the cost of PSC-1 which includes street sweeping/vacuuming.
    - Unpaved roads where atmospheric dust control strategies could potentially overlap forested uplands particulate runoff controls.

Urban and Groundwater Sources

1. Tier 3 has the greatest estimated pollutant load reduction capabillity and is more cost effective than Tier 2. Tier 3 has the potential to reduce sediment particle loads of approximately 4% more than Tier 2 controls and it costs approximately 13% less for Basin-wide application. Additionally, as the concentration of urban development increases Tier 3 appears to become more cost effective. Source controls with both pollutant concentration and hydrologic volume effects (e.g. private property BMPs) are an important component of this tier.
2. The investment in a Tier 2 level of O&M activities is a significant cost that is at least an order of magnitude greater than the current resources devoted to water quality O&M. While, O&M cost estimates are preliminary and must be verified and compared to existing storm water utility programs, an increase in O&M activity will be needed to increase pollutant reductions.
3. The estimates of potential load reduction for the centralized pumping and treatment controls that make up part of Tier 3 have the lowest confidence among all urban Treatment Tiers because of the numerous assumptions that were made about the design of centralized treatment systems. Additional work has already begun to better characterize the feasibility of these kinds of pollutant controls.

Forested Uplands Sources

1. Unpaved roads represent a small fraction of forested upland land-uses in the Basin, however, annual per acre fine sediment loading rates from unpaved roads are roughly double that from ski trails and 20–40 times greater than loading rates from undeveloped forested areas.
2. Obliteration of *legacy areas*—such as old logging roads, trails, abandoned landings, and other erosion *hot spots*—has the greatest potential to efficiently reduce loading from forested areas, especially if conducted in combination with planned thinning and fuels reduction treatments.
3. This analysis does not consider wildfire or controlled-burn effects on subwatershed hydrologic dynamics and subsequent stream loading. The effect of fire on runoff, sediment, and nutrient yield in the Basin is a topic that requires additional research and focused analyses beyond those considered here. The analysis framework developed here could be applied to future fire analysis and continued investigation into the water quality effects of fire should be considered a top priority.
4. Results show little nitrogen removal by forested upland controls because regression equations used in the model applied could not be adjusted to match existing datasets. Additional work has shown that estimates for nitrogen removal by the SCG were particularly conservative. Future results are expected to show larger load reductions of nitrogen for this source category.
5. There is a general need to define terms and establish clear, quantitative success criteria for different treatments and PCOs within the Basin. One important reason that costs are so difficult to generalize is that some treatments are poorly defined or defined very differently from agency to agency, and contractor to contractor.

Stream Channel Sources

1. The total load reductions available from reducing stream channel erosion are relatively small, however, they are quite cost effective. In addition, current load reduction estimates do not account for treatment of upland loads during flood events, which would further improve the cost effectiveness of stream channel restoration. Future research is targeted to quantify the potential load reductions achievable by increasing floodplain connectivity and over-bank flows.
2. The uncertainty about PCO effectiveness for bank protection (Tier 3) is more likely to overestimate load reductions and underestimate costs than visa versa.

Next Steps

The results of the SCG efforts will form the basis for the development and selection of Integrated Strategies. Initial Integrated Strategies will be used to stimulate discussion during the Lake Tahoe TMDL 2007 Public Participation Series. This set of workshops and discussions will solicit valuable input from the engaged public, local governments, and the Pathway Forum. Lake Tahoe TMDL decision makers including Lahontan Water Board, NDEP and TRPA will use the input gathered to select the most acceptable package of pollutant controls.

Load Allocations

Results from the Lake Tahoe TMDL 2007 Public Participation Series and Integrated Strategy development will guide selection of the most acceptable load allocations. Load allocations are assignments of allowable loads and load reduction requirements allocated to appropriate agencies, programs, business sectors, or other legal entities. While the sum of all Tahoe Basin allocations must eventually result in attainment of the 29.7 meter clarity standard, initial milestones will be set to reach a series of achievable targets. Load allocations will be based on at least one of several methods and are expected to satisfy principles of cost-effectiveness, equitability, public acceptance, and accountability.

Final TMDL

Under the Clean Water Act and California law, final TMDLs must contain all the elements addressed during Phase One and Two of the Lake Tahoe TMDL. A complete description of the Lake Tahoe TMDL elements is presented in the Technical Report.

The Lake Tahoe TMDL implementation plan will present a detailed process for achieving load reductions over a specified time frame. Preparation for the implementation plan is ongoing, but several expectations have emerged among Lake Tahoe TMDL collaborating agencies. The Lake Tahoe TMDL will integrate with the Pathway efforts to update resource management plans by providing load reduction targets that can be incorporated into the TRPA Regional Plan, the Environmental Improvement Program, and Lake Tahoe Basin Management Unit Forest Plan. The Lahontan Water Board and NDEP will incorporate the Lake Tahoe TMDL implementation needs into the Lahontan Basin Plan and NDEP Continuous Planning Process documents.

The Lake Tahoe TMDL monitoring plan will describe procedures for tracking load reductions and documenting progress toward achieving milestones. It will also describe how project effectiveness measurements and ongoing research will refine the understanding of factors driving loading to the Lake. The monitoring plan will become the scientific basis for the formal cycles of continual improvement and adaptive management that will be initiated during Phase Three of the Lake Tahoe TMDL.

All elements from Phases One and Two will be packaged in a Final TMDL document that will complete Phase Two. The Gantt chart in Figure ES-3 provides an overview of the time frames expected to develop each element and complete each phase. Note that the implementation and operation phase of the Lake Tahoe TMDL is expected to continue for a period of decades beyond 2009. Current discussions of likely time frames for achievement of the Lake Tahoe TMDL load reductions range from 30 to 100 years.

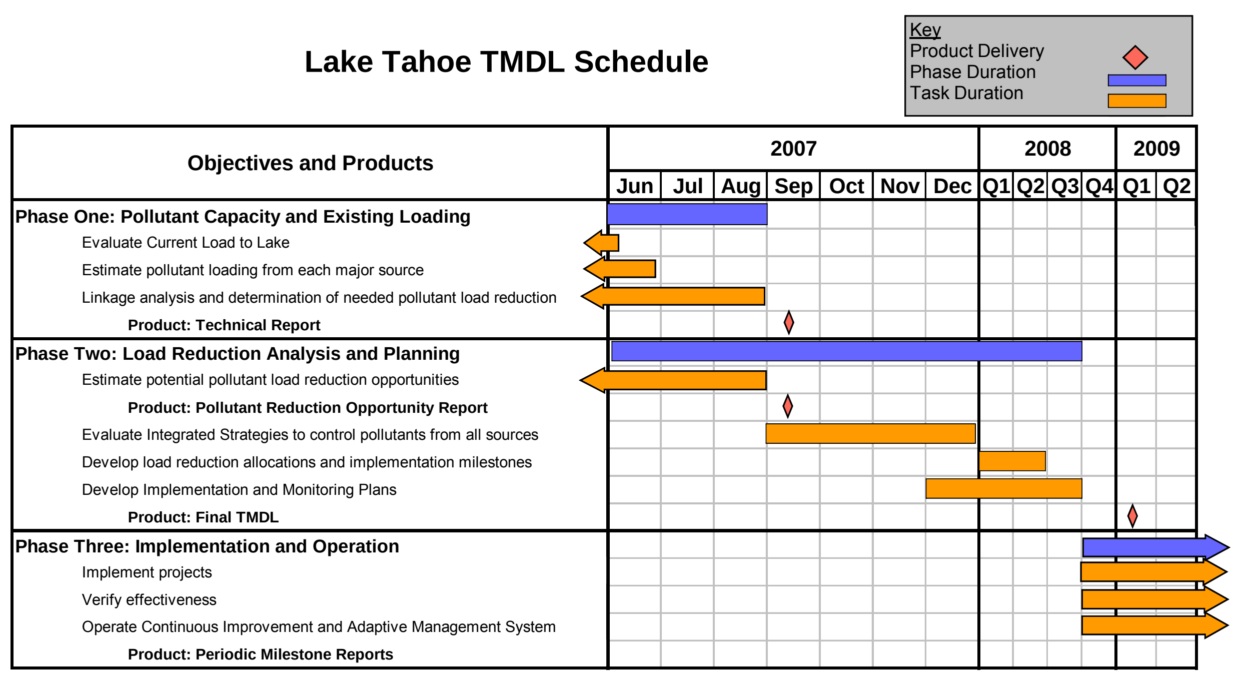

Figure ES-3. A Gantt chart showing the three phases of the Lake Tahoe TMDL.

1. Introduction

Lake Tahoe is losing its famed clarity because of excess loading of fine sediments and nutrients. As a result, the California Regional Water Quality Control Board, Lahontan Region (Lahontan Water Board) and the Nevada Division of Environmental Protection (NDEP) have initiated a total maximum daily load program including a comprehensive research and restoration planning effort.

The Lake Tahoe TMDL Pollutant Reduction Opportunity Report represents a significant step forward in the development of the Lake Tahoe Sediment and Nutrients TMDL (Lake Tahoe TMDL). This report provides the first comprehensive estimate of the potential Basin-wide pollutant load reductions at several levels of effort and load reduction potential. It also reports estimated costs associated with reducing the loads. These estimates have been compiled by respected experts who have used the best available science from local and nationwide sources. Technical reviewers have inspected the approach and results and have found them to be appropriate given the time and resources available. The load reduction and cost estimates from the experts have been combined into a set of related tables. These tables will be updated and refined by future analyses through a formalized Lake Tahoe TMDL continual improvement and adaptive management process.

The Lake Tahoe TMDL results presented in this report will form the basis for discussion during the Lake Tahoe TMDL 2007 Public Participation Series. The input provided during this series of workshops and meetings will help to craft the most acceptable approach to achieving pollutant load reductions. This input will guide decision makers from the Lake Tahoe TMDL agencies to select an integrated package of pollutant controls that will be the basis for load allocations and will be incorporated into the planning documents used by Tahoe Basin agencies.

1.1. Lake Tahoe TMDL Background

The Lake Tahoe TMDL was initiated in 2001, strategically building upon existing and ongoing research, monitoring, and modeling efforts. The Lake Tahoe TMDL is being developed in three phases. [1] Each of these phases answers seemingly simple questions with rigorous results. The Lake Tahoe TMDL is completing several objectives and producing the elements required for a *Final TMDL.* Table 1-1 provides an overview of the entire Lake Tahoe TMDL and highlights the current effort.

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[1] The use of the term *phase* in this document refers to the phases of the Lake Tahoe Clarity TMDL and is consistent with Lake Tahoe TMDL planning efforts over the past 5 years. The term phase has a different meaning in the context of the California Regional Water Quality Control Board TMDL program.

Table 1-1. Lake Tahoe TMDL synopsis with the current effort highlighted

TMDL phase	Questions	Products
Phase One— Pollutant Capacity and Existing Inputs	**What pollutants are causing Lake Tahoe's clarity loss?**	Research and analysis of fine sediment, nutrients and meteorology
	How much of each pollutant is reaching Lake Tahoe?	Existing pollutant load to Lake Tahoe from major sources
	How much of each pollutant can Lake Tahoe accept and still achieve the clarity goal?	Linkage analysis and determination of needed pollutant load reduction
		Document: TMDL Technical Report
Phase Two— Pollutant Reduction Analysis and Planning	**What are the options for reducing pollutant inputs to Lake Tahoe?**	Estimates of potential pollutant load reduction opportunities **Document:** Lake Tahoe TMDL Pollutant Reduction Opportunity Report
	What strategy should we implement to reduce pollutant inputs to Lake Tahoe?	Integrated Strategies to control pollutants from all sources
		Load reduction allocations and implementation milestones
		Implementation and Monitoring Plans
		Document: Final TMDL
Phase Three— Implementation and Operation	**Are the expected reductions of each pollutant to Lake Tahoe being achieved?**	Implemented projects & tracked load reductions
	Is the clarity of Lake Tahoe improving in response to actions to reduce pollutants?	Project effectiveness and environmental status monitoring
	Can innovation and new information improve our strategy to reduce pollutants?	Lake Tahoe TMDL continual improvement and adaptive management system, targeted research
		Document: Periodic Milestone Reports

Phase One

The scientific underpinnings of the Lake Tahoe TMDL include nearly four decades of Lake clarity and stream monitoring. Collection of this data, a wealth of supporting information, and two custom predictive models made up the bulk of the efforts in Phase One.

Phase One efforts answered the important questions, "**What pollutants are causing Lake Tahoe's clarity loss?" and "How much of each pollutant is reaching Lake Tahoe?"** by producing estimates of the total pollutant loads to the Lake in each of five major source categories (See Table 1-2). These efforts also partially answered a second important question, **"How much of each pollutant can Lake Tahoe accept and still achieve the clarity goal?"** by producing the Lake Clarity Model. This tool estimated Tahoe's clarity when provided pollutant loads. There are many ways to achieve the clarity target, several are discussed in the Lake Tahoe TMDL Technical Report (Technical Report). The final answer to the question of pollutant capacity will not be determined until Phase Two is completed. Phase One concluded with the release of the Technical Report in September 2007. This report is available on the Lahontan Water Board Web site at: http://www.waterboards.ca.gov/lahontan/TMDL/Tahoe/Tahoe_Index.htm.

Table 1-2. Lake Tahoe pollutant budget

Source Category		Total nitrogen (metric tons/year)	Total phosphorus (metric tons/year)	Number of fine sediment particles ($x10^{18}$/ year)
Upland	**Urban**	**63**	**18**	**348**
	Non-Urban	**62**	**12**	**41**
Atmospheric Deposition	**(wet + dry)**	**218**	**7**	**75**
Stream Channel Erosion		**2**	**<1**	**17**
Groundwater		**50**	**7**	**NA****
Shoreline Erosion		**2**	**2**	**1**
		397	**46**	**481**

**NA=Not Applicable since it was assumed that groundwater does not transport fine sediment particles.

Phase Two

Phase Two is focusing on the identification of load reduction opportunities and development of Basin-wide implementation and monitoring plans. These efforts are answering the question, "**What are the options for reducing pollutant inputs to Lake Tahoe?"** Once a spectrum of pollutant load reduction opportunities are outlined for each of the five source categories, an integrated set of pollutant controls can be selected from all the source categories. This integrated set of pollutant controls is known as an Integrated Water Quality Management Strategy (Integrated Strategy). Several candidate Integrated Strategies will provide the basis for engaging project implementers and public stakeholders during the Lake Tahoe TMDL 2007 Public Participation Process. Input and comments from this series of workshops and meeting will help to guide agency decision makers as they answer the second question of Phase Two, "**What strategy should we implement to reduce pollutant inputs to Lake Tahoe?"**

In addition, Phase Two will include development of two required elements of a Lake Tahoe TMDL and analysis of water quality crediting and trading. The state of California requires development of an implementation plan that provides additional detail of the process that will achieve necessary load reductions. All TMDLs must include a monitoring plan to measure the load-reduction effects of projects and programs. Water quality credits can act as a programmatic means to assist implementation; and water quality trading, if feasible, may allow greater flexibility and reduce the costs of controlling pollutants. Phase Two will conclude with the adoption of the Final TMDL in the winter of 2008/2009.

Phase Three

In Phase Three, the Lake Tahoe TMDL restoration plan will be implemented, and new information will be incorporated into the analyses through continued monitoring, modeling, and research. The Lake Tahoe TMDL will be implemented through projects, programs and regulations included in the Tahoe Regional Planning Agency (TRPA) Regional Plan, the USDA Forest Service (USFS) Land and Resource Management Plan, state funding agency programs, and permits issued through the Lahontan Water Board and NDEP. Load reduction credits related to projects and programs will be tracked and their effectiveness monitored. This work will answer the questions, "**Is the clarity of Lake Tahoe improving in response to actions to reduce pollutants?**" **and "Are the expected reductions of each pollutant to Lake Tahoe being achieved?"**

Ongoing research and monitoring will improve the scientific basis for the Lake Tahoe TMDL and Integrated Strategy over time. A formal continual improvement and adaptive management system will provide the platform for increasing accuracy of load reduction estimates and for focusing implementation on effective and appropriate pollutant controls. This system will also provide the answer to the question, **"Can innovation and new information improve our strategy to reduce pollutants?"**

1.2. Source Category Groups, Reviewers, and Advisors

SCG Leaders

Atmospheric—Dr. Richard Countess, a nationally recognized fugitive dust expert with 30 years' experience

Urban and groundwater—Ed Wallace, P.E., a Principle of Northwest Hydraulics Consultants with 40 completed projects in Lake Tahoe
Dr. Nicole Beck, Principle of 2ND Nature, LLC, led the groundwater studies
Results from these SCGs are presented together in this report because of the extensive interactions between these source categories.

Forested uplands—Michael Hogan, Principle of IERS, Inc., with 15 years of locally based erosion control experience

Stream channel—Virginia Mahacek, Principle of Valley & Mountain Consulting, with more than 10 years of experience designing geomorphic restorations

The Lahontan Water Board and NDEP assembled regional and national experts into Source Category Groups (SCGs) to investigate Pollutant Control Options (PCOs) for each major source of pollutants entering Lake Tahoe. The SCGs were lead by respected experts with distinguished careers within each field of study. The SCG Leaders coordinated the technical investigations and were responsible for the products and findings of the SCG. Each SCG was further composed of members who provided background research, reviewed internal products, and assisted with the final report. The SCGs were kept small and focused to produce results in the short time frame available.

Each SCG and the committee guiding the Lake Tahoe TMDL identified a number of outside experts who were asked to comment on the approach and results after the SCGs presented draft products. These **Technical Reviewers** included 2–3 people per source category with advanced technical knowledge and experience. Comments from these reviewers were integrated into the final products produced by the SCGs.

Focus Teams of 5–20 people per source category have been asked to give input and advise on the use of the SCGs' results. The Focus Teams are composed of personnel from local governments and resource management agencies with extensive knowledge of the needs of Basin stakeholders and organizations. This report, the Technical Report and the overarching *Charting a Course to Clarity: The Lake Tahoe TMDL*, are the first products available to the Focus Teams.

1.3. Source Category Integration Committee and Project Team

Direction, review and cross-SCG coordination is provided by a Source Category Integration Committee (SCIC) and the Tetra Tech Project Team (Project Team). The SCIC includes agency staff from the Lahontan Water Board, NDEP, and TRPA; a Pathway Coordination Team Representative; and a Science Advisor involved with the long-term Lake Tahoe TMDL development and implementation of water quality control projects in the Lake Tahoe Basin. The SCIC does the following:

- Maintains consistency between SCGs to ensure the products and reports from each group are comparable and useful for cross-source category pollutant reduction estimation
- Assures that the overall load reductions needed to attain the Lake Tahoe TMDL will be achieved from the cross-category analysis
- Assures that an adequate range of PCOs are evaluated
- Translates between pollutant species and types when necessary
- Provides guidance regarding communications and interactions with the Focus Teams, Pathway Forum and other key stakeholders

The Project Team coordinates the day-to-day activities across the SCGs and works with SCGs to assist in operation of the Lake Tahoe Watershed Model and cross-category information exchange. The Project Team will continue to help develop the Integrated Strategy and other tasks that will take place during the remainder of Phase Two of the Lake Tahoe TMDL.

1.4. General Approach

The specific approach taken by each SCG is explained in its specific chapter, but each performed three general steps. Figure 1-1 diagrams the three steps of the pollutant reduction opportunity development process. This process resulted in initial estimates of potential pollutant reductions and the costs to implement them at a Basin-wide scale.

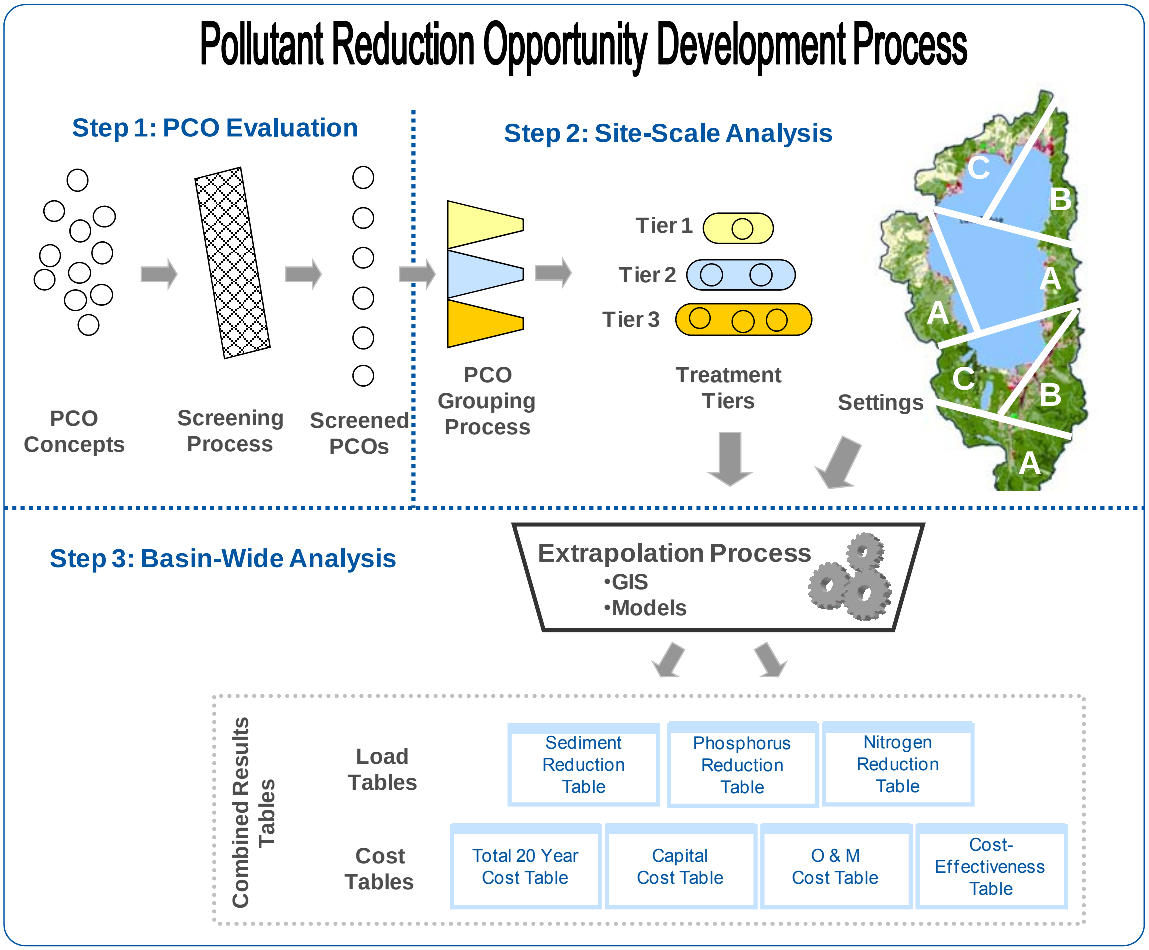

Figure 1-1. Diagram of the load reduction tables development process.

Step 1: Pollutant Control Option Evaluation

These analyses began with evaluations of PCOs that could be applied to the landscape. Each SCG compiled a list of potential PCOs on the basis of professional experience, local knowledge, and input from the SCIC, Pathway Technical Working Groups, the Pathway Forum, and other sources. This list of PCOs was screened on the basis of ability to quantify the load reduction and expected effectiveness of the PCO within the Lake Tahoe Basin. This initial screening focused investigations on PCOs that were expected to produce broad scale results and could be quantified well enough to be used in calculations.

Step 2: Site-scale Analysis

Each SCG analyzed the area of the Lake Tahoe Basin to estimate the potential for pollutant load reductions and implementation cost of applying PCOs on a representative site scale. During this step, the SCGs defined the representative site areas and the packages of PCOs that could be applied to each site.

Settings

Each SCG categorized the physical area of the Lake Tahoe Basin into a number of representative *Settings* using several criteria. Settings were primarily determined by the physical characteristics of the land such as average slope or soil type. Settings were in part determined by the applicability of PCOs. For example, water quality projects use different PCOs depending on how much impervious coverage is present. In other cases, Settings were determined by the way that they deliver pollutants to Lake Tahoe. For instance, atmospheric loads are highly affected by the distance of the source from the Lake, so this SCG defined Settings on the basis of distance from the Lake. Settings were selected to ensure that all treatable areas of the Lake Tahoe Basin were included and such that a manageable number of Setting-PCO combinations were created. Representative Settings are depicted as lettered sections of the Tahoe Basin map in the upper-right portion of Figure 1-1.

Key Definitions

Pollutant Control Options (PCOs)
PCOs are physical and nonphysical methods that can be employed to reduce pollutant loads to Lake Tahoe. Examples could include residential BMPs, a commuter shuttle system, or a fertilizer education program.

Settings
Settings are representative areas of the Lake Tahoe Basin that can include similar physical characteristics, PCO applicability, or loading effects.

Treatment Tiers (Tiers)
These are groups of PCOs that can be applied to representative landscape areas and demonstrate the broad spectrum of potential pollutant load reduction and treatment costs.

Treatment Tiers

The SCGs combined viable PCOs into *Treatment Tiers* (Tiers) designed to provide a spectrum of potential load reduction and effort level for each Setting. The Tiers were generally described as follows:

- **Tier 1:** A basic set of PCOs that represented a step forward in practices generally used in existing projects. This Tier can also have included application of current practices to all potential Settings in the entire Tahoe Basin. Constraints to implementation and cost-effectiveness of particular PCOs were considered strongly in this Tier. This Tier was often the least expensive to implement of the three Tiers.
- **Tier 2:** An intermediate mix of the PCOs used in Tier 1 and Tier 3. The Tier 2 analysis generally provided a greater load reduction and cost than Tier 1.
- **Tier 3:** The maximum load-reduction potential evaluated by the SCG. Often land ownership, cost-effectiveness, and other constraints were considered less important in formulating this Tier. This Tier was often the most expensive to implement of the three Tiers.

Costs

Costs of implementing and maintaining effectiveness of PCOs were estimated for each Settings and Tier combination during the site-scale analysis. For physical PCOs, engineering estimates were produced for representative sites on a cost per unit effort basis. Nonphysical and programmatic PCO costs were estimated using literature values from previous examples of the PCO and best professional judgment of practitioners with experience in the Tahoe Basin.

Step 3: Basin-wide Extrapolation

Each SCG used an array of different techniques to analyze the effects and costs of applying treatment Tiers to each of their Settings and extrapolating the results to the entire Lake Tahoe Basin. Each group did extensive background research to determine all information that was available for its source category. The most useful information was incorporated into spreadsheet and database models that allowed the SCG to simulate or estimate the load reductions and costs of applying each treatment Tier to each Setting. In most cases geographic information systems (GIS) analysis was used to determine the Basin-wide estimates. Additional tools and models used during this step ranged widely, and compose much of the content within each SCG's chapter.

Processing SCG Results

In some cases information provided by the SCGs required additional processing to provide consistent and comparable results. These calculations were performed by the SCIC and Tetra Tech Project Team. Because Lake Tahoe TMDL Phase One research showed that the number rather than the mass of fine sediment particles was more closely correlated with Secchi depth readings, all mass-based results were converted to particle numbers using a converter provided by U.C. Davis researchers. When necessary, relationships were developed to translate between pollutant species. Several cost calculations were also necessary.

1.5. Results Provided

Several tables capture the pollutant load reductions and cost results from each SCG. These results are typically provided after a series of intermediate results, which will assist the Project Team to apply Tiers in future analyses. The reader can use the results provided with the pollutant budget numbers to gain an initial sense for the PCOs that will be required to achieve the necessary load reductions and their costs.

Load reductions include the annual mass of each pollutant removed by applying each treatment tier to each applicable setting. Total nitrogen and total phosphorus results are provided in metric tons (MT) to maintain consistency with the pollutant budget results from Phase One of the Lake Tahoe TMDL. Sediment results are presented in units of 10^{18} particles less than 20 microns in diameter. The Lake Tahoe Clarity Model has shown that particles are the dominant factor that reduces the clarity of Lake Tahoe. Thus, it is more important to know how many particles, rather than sediment mass, are entering the Lake.

Cost results include three kinds of information. Capital investment costs that include the total cost to plan, design, and construct (or initiate) a Treatment Tier for a particular setting. Average annual operations and maintenance (O&M) costs that include all requirements to operate (e.g., electricity, personnel, materials) and maintain effectiveness (e.g., vactoring, replanting, inspections, policy enforcement) of the PCOs at the efficiency used in load-reduction calculations for the expected life of the project. Cost per unit effort is the total cost for the treatment option divided by the characteristic variable that describes how much of the treatment option was produced or implemented. For instance, the urban source category's unit effort is acres treated; in the Stream Channel Erosion source category, the unit effort is the linear feet of channel treated. The relevant unit of effort is defined for each Treatment Tier by the SCG.

1.6. Confidence Rating System

All calculations and estimates include uncertainty because of the current limits of scientific understanding. The SCGs noted uncertainties throughout their analyses and assigned an overall confidence rating to each set of results provided.

The assigned confidence values were rated on a one to five scale according to a system designed for the SCG's use. The rating was based on the SCGs own answers to 16 questions about the data sources used, the calculation results and modeling parameters. SCGs used the following guidance:

A rating of "1" generally indicates:

- Data sources were from a dissimilar area, were unreviewed and not supported by other research
- Calculation results were not similar to other investigations, used mostly professional judgment, had high calculation error, and required unlikely assumptions
- Models were not widely accepted, were poorly calibrated, or were not validated

A rating of "3" generally indicates:

- Data sources were from a similar, cold climate; were reviewed as agency drafts; or were partially supported by other research
- Calculation results were somewhat similar to other investigations, used some professional judgment; had intermediate calculation error or required reasonable assumptions
- Models had been used before, were reasonably calibrated but might not have been well validated

A rating of "5" generally indicates:

- Data sources were from Tahoe, published, and supported by other research
- Calculation results were similar to independent investigations, used little professional judgment, had low calculation error, and were based on conservative assumptions
- Models were widely accepted, well calibrated, and validated on non-calibration data

Overall, ratings of 1 and 2 were used when future values were considered likely to change significantly, and the SCG was not comfortable using them for significant management decisions. Ratings of 3, 4, and 5 were used when future values are not expected to change significantly, and the information is considered appropriate for management decisions.

1.7. Document Organization

This report is presented in seven chapters and a set of technical appendices. After this introductory chapter, each of the four SCG's chapters provides the methods and results according to the following outline:

x.1 Source Discussion. A discussion of the importance and characteristics of this source category including, sub-sources, pollutant budget commentary, and effects of pollutants.

x.2 SCG Analysis Overview. A brief overview of the SCG's analysis approach designed to orient the reader and prepare for detailed descriptions later in the report.

x.3 Pollutant Control Options. A description of all PCOs examined, the reasons that some PCOs were not analyzed, and data sources that provided information about each PCO.

x.4 Settings. A description of the different Settings and methods for designating Settings.

x.5 Treatment Tiers. A description of how the SCG defined each tier, the rational for their definition and discussion of potential overlap or exclusivity issues.

x.6 Analysis Methodology. A detailed explanation of all methodologies used by the SCG to produce the required results.

x.7 Results. Presentation and interpretation of qualitative and numeric results for the estimated potential load reductions and costs. Also contains commentary on confidence in results, sources of uncertainty, conclusions from current results, and recommendations for future research.

x.8 References. Citations for each SCGs data sources and methods follow each SCG chapter for the reader's convenience.

The final two chapters and appendices complete the Pollutant Reduction Opportunity Report by summarizing combined results, outlining next steps in the Lake Tahoe TMDL and providing supplementary information.

1.8. Next Steps

This effort provides the data that will be used for several immediate next steps, including the following:

1. The SCIC and Project Team will prepare several example Integrated Strategies that achieve the clarity goal.
2. These packages will be discussed with the Focus Teams and Pathway Forum during the Lake Tahoe TMDL 2007 Public Participation Series. This series of workshops and meetings will introduce the competing pressures and complexities inherent in selecting a single Integrated Strategy. Participants will be able to provide input and advise the SCIC on their needs.
3. Lake Tahoe TMDL decision makers will select the preferred Integrated Strategy that will be integrated into agency plans and permits.

Additional information about these and the future steps toward completing the Lake Tahoe TMDL is available in an overview document called *Charting a Course to Clarity: The Lake Tahoe TMDL,* available on the Lahontan Water Board Web site (http://www.waterboards.ca.gov/lahontan/TMDL/Tahoe/Tahoe_Index.htm).

2. Atmospheric Sources

Recent inventories of the pollutants entering Lake Tahoe indicate that more than half of the nitrogen reaching the Lake is delivered via atmospheric sources (Lahontan and NDEP 2007). An estimated 90 percent of the atmospheric nitrogen is produced by mobile sources such as cars, trucks, aircraft and boats. In addition, it is widely believed that significant amounts of fine sediment are delivered to the Lake via entrained and fugitive dust generated by mobile sources and bare soil.

The atmospheric source category is unique in that it represents a different delivery method of pollutant loads rather than a different land use or land area. Thus, atmospheric sources are intermixed with urban source areas and forested source areas. The unique nature of this source category necessitates using analysis tools and techniques that are different from other source categories.

2.1. Source Discussion

There are several important factors that affect atmospheric sources of pollutants to Lake Tahoe. Inorganic nitrogen sources are generally independent of the sources of fine sediment and phosphorus. Fine sediment and phosphorus loads are generated by the same sources. Several source subcategories are useful because the pollutants are controlled differently within each subcategory.

Atmospheric Sources of Fine Sediment and Nutrients

Pollutant load reduction estimates are based on emission reduction estimates. Thus, it is imperative to start with a robust emission inventory. To this end, many data sources have been queried to obtain the information (i.e., source activity levels and emission factor input parameters) for generating an accurate emission inventory for the Basin. Although the California Air Resources Board’s (CARB’s) emission inventory for the California portion of the Basin includes nonexistent sources (e.g., farming, Bureau of Land Management (BLM) unpaved roads) and uses poorly documented assumptions (e.g., source activity for travel on roads), it provides the best available information for identifying the major sources of the three pollutants of interest. CARB’s 2005 emission inventory for the California portion of the Basin (CARB 2006a) was scaled to the entire Basin using the multiplication factors recommended by researchers at the Desert Research Institute (DRI 2004a) as follows:

- 1.519 for on-road mobile sources as well as vehicle travel on paved and unpaved roads based on 2003 estimates of vehicle miles traveled (VMT) for the California and Nevada portions of the Basin
- 1.317 for all other sources based on the 2000 U.S. Census population estimates for the California and Nevada portions of the Basin

The major atmospheric sources of inorganic nitrogen, fine sediment, and phosphorus emissions generated from local sources within the Basin are discussed below.

Inorganic Nitrogen

Scaling CARB’s 2005 nitrogen oxides (NO_x) and ammonia (NH_3) emission inventories for the California portion of the Basin to the entire Basin indicates that mobile sources account for more than 90 percent of the NO_x emissions and about one-third of the NH_3 emissions. Residential wood combustion (RWC) and prescribed burning are also major sources of NH_3.

Fine Sediment and Phosphorus

Fine sediment of atmospheric origin has two sources: (1) resuspended fugitive soil dust in the total suspended particulate (TSP) size range (i.e., particles with a diameter of less than ~ 30 µm) generated from vehicles traveling on paved and unpaved roads as well as resuspended dust from disturbed land surfaces (e.g., construction and demolition sites), and (2) elemental carbon in the fine size mode (i.e., particles with a diameter of less than ~ 1 µm) generated from combustion sources (e.g., vehicle exhaust and RWC). Both fugitive dust and elemental carbon are inert species. CARB's 2005 TSP emission inventory for the California portion of the Basin includes farming operations, freeways, and unpaved BLM and farm roads. Because there are negligible farming operations within the Basin, no freeways, and no BLM or farm roads, these sources of fugitive dust emissions were deleted from further consideration. Scaling the balance of CARB's 2005 TSP emission inventory for the California portion of the Basin to the entire Basin indicates that the major sources of fugitive dust are resuspended road dust from vehicles traveling on paved and unpaved roads and dust generated by construction and demolition activities.

CARB's chemical source profile database for potential sources of elemental carbon within the Basin (Houck 1989) was used with the TSP emission inventory for the Basin to identify the following major sources of elemental carbon: RWC and mobile sources.

CARB's chemical source profile database for potential sources of phosphorus within the Basin (Houck 1989) plus information obtained by CE-CERT for prescribed fires and RWC sources within the Basin (CE-CERT 2004) were used with the TSP emission inventory for the Basin to identify the following major sources of phosphorus: resuspended dust from vehicles traveling on paved and unpaved roads, resuspended dust from construction activities, and RWC.

Characterization of Emission Sources

Mobile Sources

Mobile sources of inorganic nitrogen and elemental carbon include both on-road vehicles traveling on paved and unpaved roads, off-road sources (logging trucks, construction equipment, recreational vehicles), and other modes of transportation (aircraft, boats). CARB's mobile source emission estimates are based on models that contain emission estimates for different vehicle classes, vehicle ages, and different engine technologies.

Paved Roads and Parking Areas

Particulate emissions of resuspended dust caused by vehicles traveling on paved surfaces originate from material previously deposited on the travel surface such as road abrasives to improve traction on snow and ice and soil tracked onto the highway surface. Particulate emissions are a function of the road surface silt loading (defined as material ≤ 75 µm in diameter) and the average vehicle weight. CARB assumes that the average weight of vehicles traveling on paved roads is 2.4 tons. CARB breaks down emission estimates for paved roads into four categories with a different silt loading assigned to each category (CARB 2003) as follows: 0.02 grams per square meter (g/m^2) for freeways, 0.035 g/m^2 for major streets, 0.035 g/m^2 for collector streets, and 0.32 g/m^2 for local streets.

Unpaved Roads

As is the case for paved roads, particulate emissions occur whenever a vehicle travels over an unpaved surface. Unlike paved roads, however, the road itself is the source of the emissions rather than any surface loading. Fine particles are brought up from the road base, and the road surface material is pulverized by the force of rolling wheels. Dust is resuspended when it is picked up by the wheels and by the turbulent air currents caused by the passing vehicle. Resuspended unpaved road dust emissions for vehicles traveling on publicly accessible roads are a function of the surface material silt content and the mean vehicle speed and vary inversely with the surface material moisture content. CARB breaks down unpaved road dust emission estimates into four categories: city and county roads, USFS and park roads, farm roads and BLM roads (CARB 2003). CARB's TSP emission factor for resuspended unpaved road dust for all categories of unpaved roads is 3.723 lbs TSP/VMT, where VMT stands for *vehicle miles traveled*. CARB assumes that each mile of unpaved road receives 10 vehicle passes each day.

Bare and Disturbed Surfaces

The dominant source of resuspended dust from bare and disturbed surfaces in the Basin is construction. There are no agricultural tilling operations in the Basin and bare, disturbed surfaces from logging operations occur within forested land such that windblown dust from these areas is negligible. Consequently, this report will address only the load-reduction potential for control measures for bare, disturbed surfaces associated with construction sites.

Construction (and demolition) activities are temporary but important sources of resuspended soil dust. Road and building construction activities disturb the landscape and use heavy vehicles that grind geological material into a fine powder that is resuspended into the air. The quantity of dust emissions from construction operations is proportional to the area of land being worked and to the level of construction activity. Emissions from construction operations are positively correlated with the silt content of the soil as well as with the speed and weight of the construction vehicle and negatively correlated with the soil moisture content. In addition to dust emissions originating from on-site activities, substantial emissions are possible off-site because of material tracked out from the site and deposited on adjacent paved streets. Because all traffic passing the site (i.e., not just that associated with the construction) can resuspend the deposited material, this *secondary* source of emissions could be far more important than all the dust sources in the construction site. Furthermore, this secondary source will be present during all construction operations. CARB's TSP emission factors are 0.225 tons/acre/month for building construction activities and 0.17 tons/acre/month for paved road construction. CARB breaks down building construction emission estimates into four categories: residential, commercial, industrial, and institutional.

Wood Combustion

RWC in stoves and fireplaces in the Basin is a major source of elemental carbon that contributes to the fine sediment load. It is also a source of inorganic nitrogen and phosphorus. Prescribed burning of forest waste materials and campfires are minor sources of elemental carbon, inorganic nitrogen, and phosphorus compared to RWC. Emission factors derived by DRI for RWC, campfires, and prescribed burning based on source tests conducted in the Lake Tahoe area have been used to estimate emissions for this atmospheric source subcategory (DRI 2004a).

2.2. SCG Analysis Overview

The load reduction estimates are based on a Basin-wide control strategy approach as well as a function of source distance from the Lake. The technical approach, presented more completely in later sections, involved the following steps:

A baseline emissions inventory of local sources was generated for the entire Tahoe air Basin by making adjustments to CARB's 2005 annual emission inventory for the California portion of the Basin as described in Section 2.6.

An initial evaluation of PCOs for each of the five major local source subcategories (mobile sources, paved roads and parking areas, unpaved roads, bare and disturbed areas, and wood combustion). The PCOs were evaluated for ability of the SCG to quantify their pollutant load reductions and their applicability to each source subcategory (See Section 2.3).

A Baseline Tier and two Treatment Tiers were defined on the basis of the need to provide a broad spectrum of load reduction and cost of implementation. Tier 2 numeric estimates were based on average literature values to provide a *realistic* estimate of potential load reductions and costs. Tier 3 included a set of PCOs estimated to have higher load reduction potential and that would be more difficult to implement. Tier 3 estimates were based on literature values that are the most favorable for load reduction to provide an *upper bound* on the potential load reductions and costs from atmospheric sources. Treatment Tiers are described in Section 2.5.

Because pollutant sources close to the Lake have a higher probability of impacting Lake clarity, concentric areas at increasing distances from the Lake were defined as Settings. Each Setting was assigned a *Transport Fraction* using U.S. Environmental Protection Agency (EPA) methods to account for differences between emissions and loads that deposit on the Lake. The Transport Fraction approach is presented in Section 2.6.

Load estimates are based on accepted empirical formulas and cited literature values. The differences between baseline, Tier 2, and Tier 3 loading estimates were multiplied by the transport fraction to account for load reductions that actually deposit on the Lake (See Section 2.6).

Estimates of costs as well as cost-effectiveness (defined as the sum of the annualized capital costs plus annual O&M costs divided by the load reduction potential in MT) for each control measure are presented in Section 2.7.

2.3. Pollutant Control Options

Existing air quality/transportation control measures in place in the Basin (TRPA 2002) address timber harvesting, wood stoves, general aviation, emission standards for gas heaters/boilers and water heaters, stationary source controls, ban of 2-stroke engines, restrictions on open burning and prescribed burning, snow and ice control practices, idling restrictions, improved mass transportation plans (intercity bus services, passenger transit facilities, bikeways, pedestrian facilities), clean bus replacement programs, and vehicle congestion reduction programs. A large number of other PCOs exist that are applicable for reducing the pollutant loads to Lake Tahoe. This section provides an overview of these control measures (i.e., PCOs) adopted by air quality regulatory agencies in the United States for the major atmospheric sources of pollutants: inorganic nitrogen species, phosphorus, and fine sediment. Data sources were consulted for information on the control efficiency and costs of various control measure options applicable for the Basin. These data sources included the following:

- Western Regional Air Partnership's (WRAP) fugitive dust handbook (CE 2006).
- Sierra Research's BACM technological and economic feasibility analysis report for the San Joaquin Valley's PM10 SIP (Sierra Research 2003).
- Midwest Research Institute's (MRI's) fugitive dust document prepared for EPA (MRI 1992).
- MRI's best available control measures for fugitive dust sources (Cowherd 1991).
- South Coast Air Quality Management District's 1997 Air Quality Management Plan (AQMP) (SCAQMD 1997).
- Countess Environmental's report prepared for the Western Governor's Association containing cost-effectiveness of different fugitive dust control measures (CE 2004).

- CARB's evaluation of dust suppressants (CARB 2002).

Mobile Sources

Mobile sources account for most of the inorganic nitrogen species in the Basin (CARB 2006a) and probably most of the organic nitrogen species (DRI 2004b). Potential PCOs for mobile sources include the following:

- Provide trolley or elevated tram service
- Institute ski shuttle services
- Institute intercity bus services for casino guests
- Facilitate nonmotorized transportation (bike lanes, electric golf carts)
- Create a pedestrian friendly environment
- Provide incentives for the use of bike lanes
- Provide incentives for alternative fuel use
- Develop mass transit incentives
- Provide incentives for mandatory employer-based trip reduction programs
- Provide incentives for alternate driving days
- Provide incentives for vanpools for commuters
- Traffic signal synchronization to minimize vehicle idling time
- Limit travel during late evening/early morning hours when atmospheric dispersion is low
- Annual Smog Check for cars older than 4 years with no exemptions for old cars
- Require particulate filters for diesel trucks and buses
- Reduce commercial boating activities
- Prohibit recreational boating during late evening/early morning hours when atmospheric dispersion is low
- Require particulate filters or oxidation catalysts for diesel powered boats
- Retrofit vehicles/boats with cleaner engines
- Inspection program for off-road equipment
- Roadside inspection of heavy duty diesel trucks and buses
- Provide incentives to retire older vehicles
- Provide incentives for California and Nevada residents within the air Basin to purchase California fuel
- Restrictions on aircraft flights into South Tahoe airport

The list of PCOs presented above for mobile sources was reviewed by Gordon Shaw of the TRPA's Transportation Working Group and by Earl Withycombe of CARB to see which PCOs would be most effective as well as most feasible for implementation in the Basin. Their review indicated that several of the PCOs listed above are currently being implemented in the Basin to control air pollution as well as provide traffic congestion relief. In addition, EPA adopted a comprehensive national control program in 2004 for heavy-duty vehicles including nonroad diesel vehicles and marine vessels that include the use of high-efficiency particulate filters and the use of low sulfur fuel that will cut emission levels from construction and industrial diesel powered equipment by more than 90 percent by 2010 (Walsh 2007). According to Walsh (2007), the monetized benefits of the Non-Road Diesel Rule will dwarf the overall costs by more than a factor of 10. The atmospheric SCG did not have information on the effectiveness of control measures currently being implemented in the Basin, and, thus, they were not included in the analysis.

Since aircraft account for only about 2 percent of the inorganic nitrogen emissions in the Basin, no control measures were considered for aircraft. Limiting travel on roads during late evening/early morning hours when atmospheric dispersion is low was considered to be unworkable and dropped from further consideration. Commercial boating activities, consisting of fishing charters and private commercial enterprises involved in the tourist trade, account for about 14 percent of the inorganic nitrogen emissions for local sources in the Basin. Recreational boating accounts for about 4 percent of the in-Basin inorganic nitrogen emissions. Because any control measure for recreational boats would not have much effect in reducing the inorganic nitrogen load to the Lake, any control measures for recreational boating was dropped from consideration. An assessment of the viability and applicability of the remaining PCOs, with input from Gordon Shaw of the TRPA's Transportation Working Group (Shaw 2007), lead to selecting the following list of PCOs for implementation for mobile sources:

- **PCO #M1:** daily fee for visitors
- **PCO #M2:** extensive diesel electric hybrid bus service for both residents and visitors
- **PCO #M3:** reduce commercial boating activities

Descriptions of these three control measure options (PCOs) are provided below.

PCO #M1: Institute a daily fee for visitors driving into the air Basin. A fee for driving into the Basin would be required for visitors not availing themselves of free parking at park-and-ride lots at the major access points to the Basin.

PCO #M2: Extensive diesel electric hybrid bus transit service for both residents and visitors. This control measure would provide a large fleet of clean-fuel burning buses to provide (a) a shuttle service from no fee parking lots at park-and-ride lots at major access points to the air Basin, (b) a local transit service for both residents and visitors within the Basin, and (c) a shuttle services for employees commuting to work within the Basin. NO_x and NH_3 emission from electric/hybrid buses are estimated to be 59 percent lower than that for regular fueled (i.e., gasoline and diesel) bus fleets (www.hybridschoolbus.org/). [*Note:* Implementing PCOs #M1 and #M2 would provide a net reduction in air pollution by the simultaneous reduction in VMT and the use of cleaner shuttle vehicles, vis-à-vis private vehicles.]

PCO #M3: Reduce commercial boating activities. This control measure involves limiting the number of hours of operation of commercial boating activities each year.

It is the SCG's professional judgment that implementing the three PCOs listed above as well as other control measures implemented in the Basin since 2003 when CARB conducted the Lake Tahoe Deposition Study (which provided the basis for the pollutant load budget for atmospheric sources) including EPA's nonroad mobile source regulations that went into effect in 2004, would achieve an upper limit of 25 percent load reduction in inorganic nitrogen species from mobile sources for the Tier 3 treatment tier option, whereas a more realistic 10 percent load reduction would be achieved for Tier 2.

Paved Roads and Parking Areas

Because of the importance of road surface silt loading, control techniques for paved roads and parking lot surfaces (excluding parking garages) attempt either to prevent material from being deposited onto the surface (preventive controls) or to remove from the travel lanes material that has been deposited (mitigative controls). Water is used in many jurisdictions to wash material from the road to the curb and into storm drains. However, this control measure is not recommended for areas where the deposits can drain into waterbodies. Other mitigative measures for paved road dust include mechanical broom sweeping and vacuum sweeping. Water is often sprayed onto the road surface before sweeping to suppress dust resuspension caused by the sweeper. In most cases, mechanical broom sweepers resuspend small particles into the air, and vacuum sweepers have achieved widely varying degrees of success.

Consequently, one also must consider preventative measures for paved road dust resuspension. Covering loads in trucks and paving access areas to unpaved lots or construction sites are examples of preventive measures. Reducing the number of vehicles on the road would also reduce paved road dust emissions.

PCOs for paved roads and paved parking lots include the following:

- Switch from the use of anti-skid materials such as cinders and sand used for traction on snow/ice-covered roads to deicers or the mandatory use of tire chains
- Designate specific sites for snow removed from roadways rather than the sides of the road to minimize erosion of soil back onto the road as the snow melts
- Plant vegetation or install barriers for roads close to the Lake for road dust sequestration
- Pave shoulders to minimize mud/dirt carryout to road surface
- Clean gutters and curbs to reduce carryover of material to road surface
- Reduce traffic near the Lake by moving traffic to roads further inland
- Implement regular street-sweeping program with particulate matter (PM)-efficient vacuum units
- Replace street sweepers with PM-efficient vacuum units
- Clean up wind- or water-borne deposits as well as spills within 24 hours of discovery
- Remove abrasive, anti-skid material from roadway as soon as the road dries out after a snow storm
- Provide adequate off-street parking on paved parking lots to prevent parking on unpaved parking lots with subsequent track-out of dirt onto paved roads and an increase in resuspended paved road dust
- Clean paved parking lots at frequent intervals (perhaps monthly).

Several of these PCOs are being implemented in the Basin (e.g., many of the paved roads in the Basin have paved shoulders). Windblown dust is a minor source of resuspended dust in the Basin (i.e., < 0.5 percent; CARB 2006a); thus, road dust sequestration mitigation measures were eliminated from further consideration. An assessment of the viability of implementing the remaining PCOs plus an assessment of their emission reduction potential (See Tables 2-11 and 2-12 as examples of emission reduction calculations) using the interactive spread sheet tools associated with the Western Region Air Partnership's fugitive dust handbook (http://www.wrapair.org/) lead to selecting the following list of PCOs for implementation for paved roads and parking areas:

- **PCO #1:** PM-efficient vacuum sweeper (weekly for Tier 3; biweekly for Tier 2) for paved roads (including gutters).
- **PCO #2:** switch from sand and cinders as traction material to deicers (Tier 3 and Tier 2).
- **PCO #3:** pave a 100' section of unpaved road with 3" thick asphalt before each access point to a paved road minimize track-out of dirt onto the paved road (Tier 3 and Tier 2). Note: This PCO is more cost effective than installing either a pipe grid system or a gravel bed at each access point to control track-out.

Of the three PCOs listed above, the use of PM-efficient vacuum sweepers would have the largest impact on reducing resuspended paved road dust annually. The fugitive dust control efficiency of a PM-efficient vacuum sweeper is 45 percent for weekly sweeping and 23 percent for biweekly sweeping (MRI 1992). Additional information is required to estimate the impact of PCOs 2 and 3 (e.g., differences in paved road silt loading from switching from sand and cinders as traction material to deicers; number of access points to be paved). Furthermore, it is difficult to estimate the cumulative effect of implementing PCOs 1, 2, and 3 simultaneously. Thus, implementing all three PCOs would reduce paved road dust emissions by at least 45 percent for the Tier 3 option and by at least 23 percent for Tier 2. Although there might be differences in the current road maintenance practices on the California and Nevada sides of the Basin, the load reduction estimates presented in this report assume identical practices for both portions of the Basin.

Unpaved Roads

A wide variety of options exist to control emissions from unpaved roads. Options include (a) vehicle restrictions (i.e., source extent reductions) that limit the speed, weight, or number of vehicles on the road; (b) surface improvement by measures such as paving or covering the road surface with another material such as gravel or slag that has a lower silt content, and (c) surface treatment that requires periodic reapplication such as watering or treatment with chemical dust suppressants.

PCOs for unpaved roads include the following:

- Limit maximum speed on unpaved roads to 25 mph or less
- Limit weight or number of vehicles or both
- Pave unpaved roads and unpaved parking lots
- Cover unpaved roads and unpaved parking lots with gravel or slag
- Implement controls to minimize track-out of soil from unpaved roads onto paved roads (e.g., pipe-grid system, gravel bed, or paved section of unpaved road surface)
- Plant a vegetative cover
- Implement temporary or permanent road closures
- Apply chemical dust suppressant
- Plant vegetation or install barriers for roads close to the Lake for road dust sequestration

Several of these PCOs are currently being implemented in the Basin. Windblown dust is a minor source of resuspended dust in the Basin; thus, road dust sequestration mitigation measures were eliminated from further consideration. An assessment of the viability of implementing the remaining PCOs plus an assessment of their load reduction potential lead to selecting the following list of PCOs for implementation for unpaved roads:

- **PCO #4:** pave unpaved road with a 3” thick layer of asphalt over a 10” aggregate base (Tier 3)
- **PCO #5:** apply a 3” layer of gravel for 50 percent of unpaved roads (Tier 2)
- **PCO #6:** limit speed to 20 mph for the other 50 percent of unpaved roads (Tier 2); the cost of this PCO involves the cost of two speed limit signs every mile

Paving unpaved roads (i.e., Tier 3 option) would reduce unpaved road dust emissions by 99 percent (CE 2006). Implementing PCOs 5 and 6 with fugitive dust-control efficiencies of 46 percent (CE 2006) and 12 percent (USEPA 2006), respectively, would reduce unpaved road dust emissions by 29 percent (i.e., average of 46 percent and 12 percent) for Tier 2.

Bare and Disturbed Areas

Control measures for resuspended dust from bare and disturbed areas include traditional methods such as watering and windbreaks, as well as work practice related control methods such as wheel washes and phasing activities to minimize the extent of open exposed areas. Wet suppression and wind speed reduction are the two most common methods used to control open dust sources at construction sites. Trucks transporting soil to or from the site should use a tarp covering the load to avoid loss of soil onto paved roads. Because of the relatively short-term nature of construction activities, some control measures are more cost effective than others. For example, chemical dust suppressants are generally cost effective for relatively long-term projects with semipermanent unpaved roads.

PCOs for bare disturbed areas include the following:

- Apply water every 4 hours to disturbed areas with vehicle traffic
- Apply chemical, dust suppressants to disturbed areas without vehicle traffic
- Erect barriers around the site for soil dust sequestration
- Apply mulch to bare disturbed areas
- Prohibit demolition and grading activities when wind speeds exceed 25 mph
- Require minimum soil moisture of 12 percent for earthmoving operations
- Limit on-site vehicle speeds to 15 mph
- Install a tire cleaning system at each site exit to minimize track-out of soil onto paved roads (e.g., pipe-grid system or gravel bed)
- Pave construction access roads
- Clean access roads frequently

Several of these PCOs are currently being implemented in the Basin. Windblown dust is a minor source of resuspended dust in the Basin; thus, dust sequestration mitigation measures were eliminated from further consideration. Applying mulch to bare disturbed areas is much less effective in reducing resuspended dust than applying a chemical dust suppressant (30 percent versus 84 percent). Thus, this PCO was dropped from further consideration. An assessment of the viability of implementing the remaining PCOs plus an assessment of their load reduction potential lead to selecting the following list of PCOs for implementation for bare disturbed areas:

- **PCO #7:** chemical dust suppressant applied annually to disturbed land for road construction projects (Tier 3 and Tier 2) as well as for building construction projects (Tier 3)
- **PCO #8:** limit speed to 15 mph for vehicles at both road construction and building construction sites (Tier 2)
- **PCO #9:** require minimum soil moisture of 12 percent for earthmoving activities at both road construction and building construction sites (Tier 3 and Tier 2)

The fugitive dust control efficiency of PCOs 7, 8, and 9 are estimated to be 84 percent, 19 percent, and 68 percent, respectively (CARB 2002). It is difficult to estimate the cumulative effect of implementing multiple PCOs simultaneously. Thus, implementing all three PCOs would reduce road construction dust emissions by at least 84 percent for both the Tier 3 and Tier 2 treatment tier option and reduce building construction dust emissions by at least 84 percent for Tier 3 option and by at least 24 percent for Tier 2 (assuming that earthmoving activities account for 10 percent of the fugitive dust emissions at building sites).

Wood Combustion

Sources of wood combustion in the Basin include RWC, prescribed burning of forest waste materials and campfires. Because prescribed burning of forest waste materials and campfires are minor sources of pollutants compared to RWC and there are regulations in place that address these sources (limiting prescribed burning of forest waste materials to periods of high atmospheric dispersion, thinning rather than burning all forest waste materials, and restrictions on campfires), only control measures for RWC are addressed in this load reduction report.

PCOs for RWC include the following:

- Replace unapproved stoves with cleanest available burning wood stoves
- Mandatory curtailment during periods with poor atmospheric dispersion
- Ban new wood burning stoves and fireplaces

The first control measure is currently being implemented in the Basin. Because banning new wood burning stoves and fireplaces would not affect the current pollutant load, the load reduction potential of this control measure is not addressed in this report. Thus, the PCOs selected for implementation for RWC involve mandatory curtailment during periods with poor atmospheric dispersion are as follows:

- **PCO #10:** mandatory 50 percent curtailment for the Tier 3 option
- **PCO #11:** mandatory 20 percent curtailment for the Tier 2 option

The curtailment values of 50 percent and 20 percent represent suggested values for illustrative purposes only and are used in the load reduction estimate calculations presented later in this report. The actual percentage RWC curtailment adopted by the local regulatory agency for the two treatment tiers could differ from these values.

The PCOs selected for implementation for the five major atmospheric sources of pollutants are presented in Table 2-2.

2.4. Settings

The database used to develop load reduction estimates is based on a Basin-wide inventory of emission sources. Because pollutant sources close to the Lake have a higher probability of reaching the Lake compared to distant sources, and therefore impacting the Lake's clarity compared to distant sources, pollutant-load reduction estimates were derived for different settings within the Basin. These settings consist of concentric zones at various distances from the Lake. Because atmospheric sources of nitrogen account for approximately 50 percent of the total nitrogen pollutant budget for Lake Tahoe and mobile sources account for most of the total nitrogen emissions in the Basin, the spatial distribution of mobile source emissions within the Basin was used to designate the settings for atmospheric sources of pollutants.

The spatial distribution of vehicles traveling on paved and unpaved roads within the Basin is presented in Table 2-1 (TRPA 2007). Table 2-1 indicates that the spatial distribution of daily vehicle activity for vehicles traveling on paved and unpaved roads within the Basin expressed in units of VMT falls roughly into quartiles with approximately one-quarter of the daily vehicle activity and thus about one-quarter of the on-road vehicle emissions occurring within 0.2 km of the Lake, one-quarter occurring between 0.2 km and 1 km from the shoreline of the Lake, one-quarter occurring between 1 km and 3 km from the shoreline of the Lake, and one-quarter occurring between 3 km of the Lake and the outer boundary of the Basin. Thus, Setting 1 was designated as that portion of the Basin with an outer boundary 0.2 km from the shoreline of the Lake containing ~25 percent of the on-road mobile source emissions (including 100 percent of the boating emissions); Setting 2 was designated as that portion of the Basin with an outer boundary 1 km from the shoreline of the Lake containing ~50 percent of the on-road mobile source emissions (including 100 percent of the boating emissions), and Setting 3 was designated as that portion of the Basin with an outer boundary 3 km from the shoreline of the Lake containing ~75 percent of the on-road mobile source emissions (including 100 percent of the boating emissions). Setting 4 was designated as the entire Basin.

Figure 2-1 shows a map of the Lake Tahoe air Basin depicting the outer boundaries for each of the different settings. *Note:* The outer boundary of Setting 1 is not shown in the figure because of the scale used.

Table 2-1. Spatial distribution of traffic in the Basin

Setting	Outer boundary distance from Lake (km)	Cumulative fraction of vehicle traffic (VMT)
1	0.2	0.247
2	1.0	0.539
3	3.0	0.771
4	Entire Basin	1.000

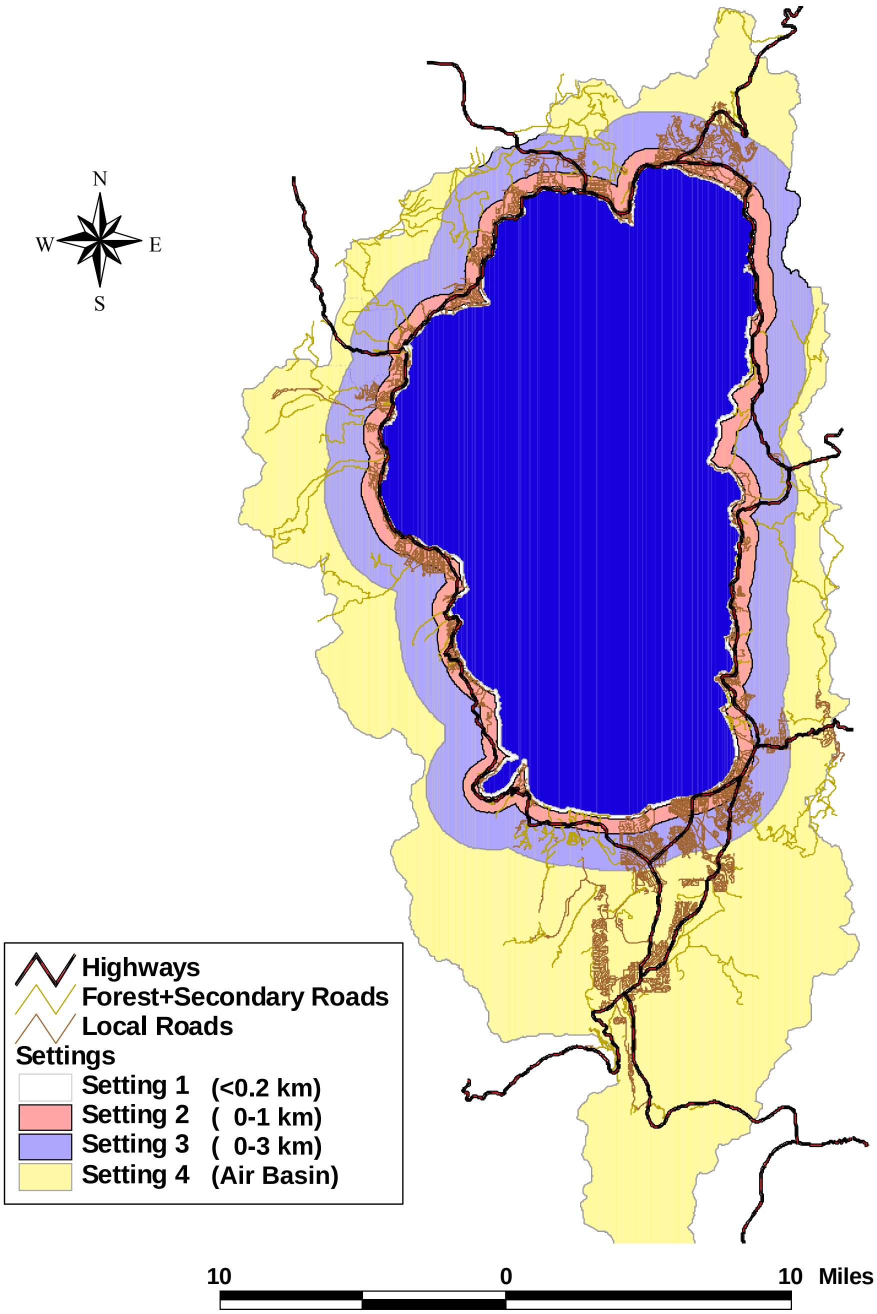

Figure 2-1. Map of Lake Tahoe air basin depicting Settings

2.5. Treatment Tiers

The Treatment Tiers being proposed for reducing sources of atmospheric sources of pollutants entering the Lake range from maintaining the status quo (i.e., Tier 1) to implementing controls that would provide an *upper bound* to load reductions without consideration of cost constraints (Tier 3). To provide an additional option, a middle Tier is defined.

Tier 1. This option represents maintaining the status quo approach. It is used exclusively to compare loading results of higher tiers to understand relative load reductions.

Tier 2. This option represents implementing a package of realistic control measures that would successfully reduce the pollutant load to the Lake from atmospheric sources. These control measures have a long history and are being implemented in other areas of the country. Furthermore, these control measures generally have a lower control efficiency and associated implementation costs compared to the control measures being considered for Tier 3. Several control measure are being proposed for both the Tier 3 option and the Tier 2 option with a higher penetration associated with the Tier 3 option.

Tier 3. This option represents the best one could do approach and provides an upper limit on pollutant control. This option involves the following assumptions: implementing the control measure with the highest published control efficiency for that source category, applying the control measure to all sources in the Basin (i.e., 100 percent penetration of the control measure throughout the Basin) without regard to cost or any other constraints, and sustainable control efficiency of the control measure from year to year.

The PCOs selected for implementation for atmospheric sources of pollutants in the Basin are identified in the table below for the two Treatment Tier options.

Table 2-2. PCOs selected for atmospheric sources of pollutants

Source category	PCO	Tier 3	Tier 2
Mobile	M1. Fee for visitors	X	X
	M2. Shuttle service for visitors and residents	X	X
	M3. Commercial boating restrictions	X	X
Paved Roads	1. PM-efficient vacuum sweeper	Weekly	Biweekly
	2. Switch from sand/cinders to deicers	X	X
	3. Pave unpaved roads at access points	X	X
Unpaved Roads	4. Pave road	X	
	5. Gravel for 50% of roads		X
	6. Speed restriction for 50% of roads		X
Construction Sites	7. Chemical suppressant	X[a]	X[b]
	8. Speed restriction		X
	9. Require > 12% soil moisture during earthmoving operations	X	X
Res. Wood Combustion	10. 50% curtailment	X	
	11. 20% curtailment		X

[a] For road and building construction projects
[b] For road construction projects only.

2.6. Analysis Methodology

This section describes the methodology employed to develop load reduction estimates and cost estimates for a series of control measures for atmospheric sources of pollutants. This section also provides details on the three intermediate steps needed to calculate load-reduction estimates: (1) emission inventory estimates by source category and by pollutant, (2) a simple conceptual model developed to reconcile emission estimates with the deposition budget, and (3) the spatial distribution of major source categories within the Basin.

Emission Inventory Estimates

Pollutant load reduction estimates are based on emission reduction estimates from implementing a package of PCOs. Many data sources were queried to obtain the inputs (i.e., source activity levels and emission factor input parameters) for generating an accurate emission inventory for the Basin. They include the following:

- CARB's 2005 emission inventory for the California portion of the Basin (CARB 2006a).
- Factors to scale emissions for the California portion of the Basin to the entire Basin (DRI 2004a).
- WRAP's fugitive dust handbook (CE 2006).
- EPA's Compilation of Air Pollutant Emission Factors, AP-42 (USEPA 2006).
- CARB's Emission Inventory Procedural Manual (CARB 2003).
- CARB's chemical source profile database for sources of phosphorus (Houck 1989).
- CE-CERT test results for prescribed fires and RWC in the Basin (CE-CERT 2004).
- Emission factors for RWC and campfires (Houck 2001; DRI 2004a).
- USFS's estimates of unpaved forest roads in the Basin (USFS 2007).
- U.S. Department of Transportation's (USDOT's) roadway classification guidelines (USDOT 2000)
- California DOT's estimates of VMT for unpaved roads in the Basin (CA DOT 2006).
- California Transportation Agency (CALTRANS)/Nevada Division of Transportation's (NDOT's) paved road maintenance schedule for the Basin (CALTRANS/NDOT 2006)
- Vehicle fleet mix and RWC activities for the Basin (CE-CERT 2004).
- Silt loading for highways and major roads in the Basin (DRI 2004a).
- TRPA's 1974–2004 Pathway Traffic Volumes for the entire Basin (TRPA 2007).
- TRPA's 2004 estimates of boating emissions for shore zone Lake Tahoe (Emmett 2007).
- Environ's estimates of ammonia emissions for California (ENVIRON 2002).

Emission Inventory Estimates by Source Sub-Category

The Lahontan Water Board's deposition budget for atmospheric sources of nitrogen is 218 MT/year. This estimate represents 148 MT/year of dissolved inorganic nitrogen species (NO_3^- and NH_4^+) with the balance (approximately one-third) as organic nitrogen species. Because there is no information available on organic nitrogen emission estimates for the Basin (let alone for other areas of the country), this report focuses on load reduction estimates for inorganic nitrogen species.

CARB's emission inventory for the California portion of the Basin provides the best available information for identifying the major sources of inorganic nitrogen species (NO_x and NH_3). Furthermore, the inventory can serve as a baseline against which estimates of the impact of PCOs can be assessed. Using the identified major sources coupled with PCOs, relative reductions of load can be determined. CARB's 2005 emission inventory for the California portion of the Basin was scaled to the entire Basin using land use and population-based factors (DRI 2004). These included multiplying the California emission estimates for paved and unpaved road dust, as well as emissions from on-road mobile sources, by 1.52 to account for differences in the VMT between the California portion of the air Basin and the entire air Basin. For all other sources, a scaling factor of 1.32 was used to account for differences in population (based on 2000 census data) between the California portion of the Basin and the entire Basin. Information on the source extent (i.e., activity level) for the major sources of fine sediments within the Basin was obtained to develop emission inventory estimates for the Basin that are more accurate than extrapolating CARB's emission inventory for the California portion of the Basin to the entire Basin. Emission estimates provided in this report represent annual average emissions, where the differences in emissions by season (e.g., lower resuspended dust from unpaved roads and construction sites during winter compared to summer) have been factored into the estimate.

Mobile Sources

CARB's 2005 emission inventory for mobile sources for the California portion of the Basin was scaled to the entire Basin by multiplying the California emission estimates by 1.52 to account for differences in the VMT between the California portion of the air Basin and the entire air Basin (DRI 2004a). Aircraft emissions were not extrapolated from the California portion of the Basin to the entire Basin since the only airport is on the California side of the Basin. TRPA's estimate of boating emissions was used in our analyses (Emmett 2007).

Paved Roads and Parking Areas

There are 113.4 miles of highways, 52 miles of secondary roads, and 704 miles of local roads in the Basin. The daily VMT estimates for paved roads in the Basin are 1.15 million for highways, 110,000 for secondary/collector roads and 164,000 for local roads (TRPA 2007). The peak VMT for highways occurs in August with an average daily VMT about 28 percent higher than the annual average day, and the minimum monthly average VMT is about 14 percent less than the annual average day (TRPA 2007). There are no reliable estimates of the source extent of paved parking lots or driveways in the Basin. However, their source extent is much less than that of paved roads. Furthermore, the speed of the vehicles driving on these surfaces is much less than that of vehicles traveling on paved roads. Thus, paved parking lots and driveways account for only a very small fraction of the resuspended dust emissions for this category. Consequently, the load reduction estimates presented in this report neglect these minor dust sources.

DRI measured the paved road dust emissions on state highway 28 from April through mid-July, 2003 (DRI 2004a). The PM10 emission factor (in units of grams per vehicle kilometers traveled, VKT) decreased by about a factor of three from 0.5 g/VKT in April to 0.17 g/VKT in July with the reduction associated with either a reduction in mud track-out onto the road surface and/or a cessation of traction control material on the roads. Based on EPA's AP-42 emission factor equation for PM10 (USEPA 2006), DRI's average PM10 emission rate of 0.23 g/VKT produces an average road surface silt loading for highway 28 of 0.05 g/m^2, which is almost 60 percent higher than CARB's default value of 0.032 g/m^2 for highways and major roads. The fugitive dust emission estimates provided below use a silt loading of 0.05 g/m^2 for both highways/major roads and collector roads and CARB's default silt loading value of 0.32 g/m^2 for local paved roads. Because the silt loading for highways/major roads and collector roads are the same, the TSP emission estimates for these two paved road categories can be combined. This will simplify any further analyses because there are differences in the paved road classification scheme used by the TRPA and by CARB that adopted the federal Highway Functional Classification System (USDOT 2000).

CE-CERT documented the vehicle fleet distribution by vehicle class during the summer of 2002 on different roadway types in the Basin (CE-CERT 2004). On the basis of this distribution (35 percent light duty vehicles, 37 percent light-duty trucks/SUVs, 24 percent medium-duty trucks, and the remaining 4 percent as heavy-duty trucks and buses) and EPA's published list of vehicle weights for different vehicle classes, the average vehicle weight of the fleet in the Basin is estimated to be approximately 3 tons. The fugitive dust emission estimates provided below use an average vehicle weight of 3 tons rather than CARB's default value of 2.4 tons.

Applying EPA's TSP emission factor equation together with the daily VMT value for each of the three paved road categories in the Basin provides the following fugitive dust emission estimates for paved roads: 4.01 tons TSP/day for highways and major streets, 0.38 tons/day for collector streets, and 2.01 tons TSP/day for local streets. This fugitive dust emissions estimate of 6.40 tons TSP/day (for an average day) for resuspended paved road dust is approximately double CARB's estimate extrapolated to the Basin of 3.18 tons TSP/day. There will be large seasonal variations in these emissions based on DRI's observations of silt loading and TRPA's observations of differences in monthly VMT. For example, DRI measured PM10 emission rates on highway 28 that ranged from 0.08 g/VKT to 0.56 g/VKT, which provides estimates of silt loading ranging from 0.02 g/m^2 to 0.12 g/m^2. Using this range of silt loadings for highways and major streets, the daily fugitive dust emission rate for this paved road category ranges from 1.43 tons TSP/day to 5.15 tons TSP/day.

Unpaved Roads

There are 185.3 miles of unpaved roads in the Basin (TRPA 2007) of which 67 miles are USFS roads (USFS 2007). The CA DOT estimates that there are 41.6 vehicle passes per average day for each mile of USFS roads in El Dorado County and 30 vehicle passes per average day for each mile of USFS roads in Placer County (CA DOT 2006), whereas CARB's default value for all unpaved roads is 10 vehicle passes per average day for each mile. Because many of the state-owned roads in the Tahoe air Basin are gated and have limited access (primarily for maintenance vehicles) and most of the unpaved roads at the higher elevations in the Basin have little or no traffic in winter, the number of vehicle passes per day on unpaved roads in the Basin will be lower than the CA DOT estimates for Placer and El Dorado Counties. Note that many of the vehicles driving on unpaved roads in the Basin are logging trucks. These heavy vehicles will produce significantly more resuspended soil dust than an automobile or pickup truck. Thus, it was assumed that that on an annual basis there are an average of 20 vehicle-passes per day for each mile of unpaved road in the Basin. Using TRPA's estimate of 185.3 miles of unpaved roads within the Basin and assuming an average of 20 vehicle passes per day for each mile of unpaved road, the average daily VMT for all unpaved roads in the Basin is estimated to be 3,706. Applying CARB's TSP emission factor for unpaved roads of 3.723 lb TSP/VMT results in an estimated 6.90 tons TSP per average day, which is approximately double the estimate of 3.54 tons per average day from scaling CARB's estimate for the California portion of the Basin to the entire Basin.

Paved Road Construction

The information provided by CALTRANS and by NDOT for road construction projects within the Basin in 2006 (primarily maintenance projects to repair pot holes and damaged roadways and erosion-control projects to keep sediments from entering the Lake) is not sufficiently detailed enough to estimate the source extent for this fugitive dust source category. Thus, CARB's 2005 fugitive dust emissions estimate for this source category extrapolated to the entire Basin was used to estimate the source extent for paved road construction. Using CARB's TSP emission factor for paved road construction of 0.17 tons/acre-month, an estimate of 132 tons TSP/year from paved road construction and an assumption that paved road construction projects last for 12 months, the source extent for this source category in 2005 was estimated to be 64.6 acres. On the basis of CARB's estimates that highway construction projects disturb 9.2 acres of land per mile of roadway and city/county road construction projects disturb 7.8 acres of land per mile of roadway, and CARB's assumptions that four-lane highways accounted for 10 percent of the new paved roads built in the Lake Tahoe region in 2005 and two-lane city/county roads accounted for 90 percent, produces a weighted average disturbed land factor for new road construction of 7.94 acres/mile. Thus, 64.6 acres of disturbed land represents 8.14 miles of new paved roads constructed in the Basin.

Building Construction

There are no independent estimates of the source extent for this fugitive dust source category. Thus, CARB's 2005 fugitive dust emissions estimate for this source category extrapolated to the entire Basin was used to estimate the source extent for building construction. The TSP emission estimate for the entire Basin is 283 tons TSP/year with 62 percent of these emissions from residential building projects and 38 percent from commercial building projects. Using CARB's TSP emission factor for building construction of 0.225 tons/acre-month and an assumption that building construction projects last for 12 months, the source extent in 2005 for this category is estimated to be 65.0 acres for residential buildings and 39.8 acres for commercial buildings.

Residential Wood Combustion

CE-CERT conducted a survey in the Lake Tahoe region in 2003 to quantify the amount of RWC activity in the Basin (CE-CERT 2004). DRI used CE-CERT's survey results together with emission factors for inorganic nitrogen species (NO_x plus NH_3) and elemental carbon developed by DRI (DRI 2004a) for RWC sources within the Basin to estimate the annual inorganic nitrogen and elemental carbon emissions generated by 21,000 housing units with wood stoves and fireplaces in the Basin. DRI estimated that RWC in the Basin produces 97 tons of inorganic nitrogen per year (from an emission factor of 3.26 lb/ton of fuel burned for wood stoves and fireplaces) and 104 tons of elemental carbon per year (based on an emission factor of 3.12 lb/ton of fuel burned for wood stoves and an emission factor of 6.96 lb/ton of fuel burned for fireplaces) assuming that each residence burns 2.83 tons of wood per year (DRI 2004a).

Emission Inventory Estimates by Pollutant

Inorganic Nitrogen Species

The annual inorganic nitrogen (NO_x plus NH_3) emission inventory for the Basin (based on extrapolating CARB's 2005 emission inventory for the California portion of the Basin to the entire Basin) is presented in Table 2-3. The emission estimates presented in Table 2-3 indicate that mobile sources account for about 87 percent of the total inorganic nitrogen emissions in the Basin. The annual daily average inorganic nitrogen emissions estimate for the Basin is 8.96 tons/day. The summer daily average estimate is 8.53 tons/day and the winter daily average estimate is 9.20 tons/day. The winter increase is primarily due to home heating, along with an increase in mobile source emissions attributable to winter recreation activities. The bulk of the mobile-source ammonia emissions come from catalyst-equipped vehicles traveling in the Basin. The emission inventory presented in Table 2-3 does not take into account the effect of altitude or grade on mobile source emissions. Bishop et al. (2001) observed that heavy-duty diesel trucks operating at an altitude of 2 km (similar to the elevation of the Lake Tahoe air Basin) would have approximately 50 percent higher NO_x emissions than the same vehicles operating at sea level. Gertler et al. (1996) and Pierson et al. (1996) observed differences of as much as 55 percent for NO_x emissions for vehicles operating on different grades. NO_x emissions were higher for vehicles being driven uphill compared to vehicles on level ground with the opposite being true for vehicles being driven downhill. Overall, the net effect on NO_x emissions for vehicles operating on different grades could be to cancel each other out compared to vehicles being driven on level surfaces. Because mobile sources account for almost 90 percent of the inorganic nitrogen species in the Basin, underestimating the absolute inorganic nitrogen emissions from mobile sources will not have a major impact on the load reduction estimates for inorganic nitrogen.

Table 2-3. Annual inorganic nitrogen emission inventory for the Basin

Source	$NO_x + NH_3$ (tons/yr)	Percent of total $NO_x + NH_3$
On-road vehicles	1,406	43.0
Other mobile*	784	24.0
Boats	581	17.8
Other Area	196	6.0
Stationary	138	4.2
RWC	97	3.0
Aircraft	69	2.1
Total	3,271	

*Primarily off-road equipment

Fugitive Dust

The annual fugitive dust emission inventory for the Basin using the revised emissions estimates for paved and unpaved roads presented above is shown in Table 2-4. As mentioned earlier, there will be large seasonal variations in fugitive dust emissions from paved and unpaved roads. For example, fugitive dust emissions from unpaved roads during winter months when the roads are snow covered will drop to zero. Fugitive dust emissions from paved roads will be significantly higher during periods when the silt loading on the roadway increases such as after the application of traction control material or after rains have increased the amount of track-out of soil onto the road surface.

Table 2-4. Annual fugitive dust (FD) emission inventory for the Basin

Fugitive dust source	Source extent (miles)	Daily VMT	FD (tons/year)	Percent of total fugitive dust
Unpaved Roads	185.3	3,706	2,518	47.6
Paved Roads	–	–	2,334	44.1
Highways	113.4	1,150,000	–	–
Secondary paved roads	52	110,000	–	–
Local paved roads	704	164,000	–	–
Paved Road Construction	8.14	–	132	2.5
Building Construction	104.8*	–	283	5.3
Other	–	–	26	0.5
TOTAL	–	–	5,293	–

*Source extent of disturbed bare soil for building construction projects is assumed to be 104.8 acres.

Elemental Carbon

The annual elemental carbon emission inventory for the Basin using the revised emissions estimates for RWC presented above is shown in Table 2-5. RWC and mobile sources account for about 42 percent and 26 percent of the annual elemental carbon emissions, respectively.

Table 2-5. Annual elemental carbon (EC) emission inventory for the Basin

Combustion source	EC (tons/year)	Percent of total EC
RWC, Stoves	83.4	33.3
Mobile, Diesel	52.8	21.1
Paved Roads	45.5	18.2
RWC, fireplaces	20.7	8.3
Mobile, Gasoline	19.4	7.8
Unpaved Roads	12.3	4.9
Prescribed Burning	8.6	3.4
Other Combustion	3.2	1.3
Campfires	2.0	0.8
Other	2.2	0.8
Total	250.3	

Inert Species

The annual inert species inventory (fugitive dust plus elemental carbon) for the Basin using the revised emission estimates for paved and unpaved roads and RWC presented above is shown in Table 2-6. The major sources of inert species are unpaved roads (46 percent) and paved roads (43 percent). The annual emissions estimate of inert species for the Basin is 5,543 tons/year with fugitive dust accounting for about 96 percent of these emissions and elemental carbon accounting for the balance.

Table 2-6. Annual inert species emission inventory for the Basin

Source	Inert species (tons/year)	Percent of total inert species
Unpaved Roads	2,530	45.6
Paved Roads	2,380	42.9
Building Construction	284	5.1
Paved Road Construction	132	2.4
Residential Wood Combustion	104	1.9
Mobile	72	1.3
Other	40	0.7
Total	5,543	

Phosphorus

The annual phosphorus emission inventory for the Basin is shown in Table 2-7. The source profiles measured by CE-CERT for RWC and prescribed burning sources within the Basin (CE-CERT 2004) were used to estimate the phosphorus emissions for these two sources plus campfires. Professor Cahill's source profiles measured at the South Lake Tahoe site (Cahill 2004) were used to estimate the phosphorus emissions for the fugitive dust sources (paved and unpaved roads, construction, and windblown dust) within the Basin and CARB's source profile database was used to estimate the phosphorus emissions for mobile sources (Houck 1989). The phosphorus content (by weight) ranged from 0.012 percent for mobile sources, to 0.11 percent for campfires and prescribed burning, to 0.17 percent for RWC, to 0.3 percent for all other sources of phosphorus included in Table 2-7. The major sources of phosphorus are unpaved roads (44 percent) and paved roads (40 percent). The annual emissions estimate of phosphorus for the Basin is 17.4 tons/year with fugitive dust accounting for about 92 percent of these emissions and combustion sources accounting for the balance.

Table 2-7. Annual phosphorus emission inventory for the Basin

Source	Phosphorus (tons/year)	Percent of total phosphorus
Unpaved Roads	7.6	43.5
Paved Roads	7.0	40.3
Residential Wood Combustion	1.2	7.1
Building Construction	0.85	4.9
Paved Road Construction	0.40	2.3
Prescribed Burning/Campfires	0.19	1.1
Windblown Dust	0.11	0.6
Mobile	0.02	0.1
TOTAL	17.4	

Pollutants of Interest

The major sources of the three pollutants of interest within the Basin – inorganic nitrogen (as a surrogate for total nitrogen), phosphorus, and inert species (as a surrogate for fine sediment) are presented in Table 2-8.

Table 2-8. Annual average percent contribution of sources of pollutants in the Basin

	Percentage of pollutant from a specific source		
Source	Inorganic nitrogen	Phosphorus	Inert species
Mobile	87	<1	1
Stationary (non-RWC)	10	< 1	< 1
RWC	3	7	2
Unpaved Roads	–	44	46
Paved Roads	–	40	43
Building Construction	–	7	5
Paved Road Construction	–	5	2

Reconciling Emission Estimates with Deposition Budget

The annual emissions estimate of inert species for the Basin of 5,543 tons/year is approximately 5.9 times the annual fine sediment deposition budget of 850 MT/year for atmospheric sources. This indicates that a large fraction of the fugitive dust emissions for sources within the Basin deposit out before reaching the Lake. The annual phosphorus emissions estimate for the Basin of 17.35 tons/year is approximately 2.6 times the annual total phosphorus deposition budget of 6 MT/year for atmospheric sources. Because a large fraction of the fugitive dust from sources within the Basin does not reach the Lake, a large fraction of the phosphorus associated with fugitive dust emissions will not reach the Lake either. Combustion sources account for about 8 percent of the total phosphorus emissions from atmospheric sources within the Basin. It is expected that a large fraction of this phosphorus in the fine size mode (< 1µm in diameter) will make it to the Lake.

The total annual inorganic nitrogen (NO_x and NH_3) emission estimate for the Basin of 3,271 tons/year is approximately 20 times the annual inorganic nitrogen deposition budget of 148 MT/year for atmospheric sources. Thus, only a small fraction (~0.05) of the gas phase species NO_x and NH_3 form secondary aerosol species and nitric acid in the atmosphere that are deposited into the Lake.

Data sources used to develop a simple conceptual model to reconcile emission estimates with the pollutant load budget to account for deposition losses between the emission source and the Lake include the following:

- EPA's estimates of the transportable fraction of fugitive dust emissions (Pace 2005).
- Lake Tahoe TMDL Phase 1 final report (Lahontan and NDEP 2007).
- CARB's Lake Tahoe Atmospheric Deposition Study (CARB 2006b).

Transportable Fraction

For a number of years, air quality scientists have recognized that the ambient impact of fugitive dust sources is substantially lower than emissions inventories would suggest. It was concluded that substantial dust removal processes including impaction on vegetation and structures occur within several hundred meters of the source. In 2005 EPA developed a *limiting cases* conceptual model for particles smaller than 10 µm in diameter (PM10) as a way to bound the dust removal potential by surfaces near the source of emissions (Pace 2005). An unpaved road in the forest would represent one extreme or limiting case whereby most, if not all, of the road dust would be captured within the vegetation canopy. At the other extreme or limit, road emissions in barren areas would not be subject to capture or removal because of vegetation. Other surface characteristics would fall between these two limits. EPA refers to the fraction of a source's mass emissions captured by the vegetation (or other surface obstructions) as the *Capture Fraction* (CF) with $0 \leq CF \leq 1$, where CF = 0 for a barren landscape and for water and CF = 1.0 within a dense forest. The term *Transportable Fraction* (TF) is used to describe those particles remaining airborne and available for transport away from the vicinity of the source after localized removal has occurred, where TF = 1 – CF.

Estimation of CF for specific geographic areas requires use of a land cover database such as the Biogenic Emission Land-cover Database (BELD). BELD is a compendium of surface cover (mainly vegetation) characteristics used by the Biogenic Emission Inventory System biogenic emission model (USEPA 2003). It contains data on several hundred species of vegetation at a 1-km cell size. EPA used the land cover information contained in the BELD database and grouped the results into five cover types with a specific TF value assigned to each group as follows: 1.0 for barren and water; 0.75 for agricultural; 0.75 for grasses, scrub and sparsely wooded; 0.50 for urban; and 0.0 for forested. EPA calculated a county average TF for every county in the United States using the fraction of land area assigned to each land cover type for each county in the BELD database and the TFs for each land cover group. The average TF for fugitive dust particles smaller than 10 µm in diameter for the Lake Tahoe air Basin, from each county's contribution to the total surface area of the Basin, is 0.216. A TF of 0.216 signifies that about 80 percent of the fugitive dust particles smaller than 10 µm in diameter generated within the Basin will deposit within several hundred meters from their source. Particles emitted by combustion sources or formed in the atmosphere are primarily in the fine particle size range below 1 µm diameter and will have a substantially larger TF than 10 µm particles, whereas the TF for fugitive dust particles between 10 µm and 30 µm in diameter will be less than that for 10 µm particles.

Lake Tahoe Dust Deposition Experiment

To understand dispersion and loss as a function of distance from a dust source, CARB conducted the SOLA Dust Experiments in March 2004 (CARB 2006b). The SOLA ambient monitoring site in South Lake Tahoe is ~50 feet from Highway 50 (also known as Lake Tahoe Boulevard in that stretch of the highway) and ~100 feet away from the beach on the south shore of the Lake. CARB placed optical particle counters at increasing distances from the road and recorded the particle counts at each site as a function of particle size. For particles smaller than 30 µm in diameter, there was approximately an 80 percent loss in the number of particles within 100 feet of the highway due to dispersion, deposition, and interactions with tree canopies between the roadway and the beach. Thus, the transportable fraction of fugitive dust smaller than 30 µm in diameter is estimated to be 0.20 approximately 100 feet from the emissions source.

Conceptual Model for Deposition Losses of Fugitive Dust within the Basin

To reconcile the inert species emissions estimates for the Basin with the fine sediment deposition budget for the Lake, a simple conceptual model was developed to account for loss of inert species before they reach the Lake and to account for the fact that pollutant sources close to the Lake will have a larger impact on the Lake than distant sources. To a first approximation, the transportable fraction for fugitive dust is estimated by solving the following equation that represents the relationship between emissions of inert species and deposition of fine sediments:

$$FD_E \times TF_{FD} + EC_E \times TF_{EC} = FS_D \qquad (2\text{-}1)$$

where,

FD_E and EC_E = emission estimates for fugitive dust and elemental carbon (tons/year)
TF_{FD} and TF_{EC} = transportable fractions for fugitive dust and elemental carbon
FS_D = deposition budget estimate for atmospheric sources of fine sediments (tons/year)

Plugging the fugitive dust and elemental carbon emission estimates from Tables 2-1 and 2-2 and the deposition budget estimates into equation 2-2 produces the following equation:

$$5{,}293\ (TF_{FD}) + 250\ (TF_{EC}) = 935 \text{ tons/year} \qquad (2\text{-}2)$$

Assuming the transportable fraction for fine mode elemental carbon is 1.0, produces the following estimate for the transportable fraction of fugitive dust for sources within the Basin: $TF_{FD} = 0.13$. This estimate of the transportable fraction of fugitive dust is of key importance in understanding the relative importance of different pollutant sources contributing to the Lake's deposition budget. On the average, only 13 percent of the fugitive dust (as well as the phosphorus associated with fugitive dust) generated in the Basin actually reach the Lake, whereas a much larger percentage of the fine mode aerosol species from combustion sources (elemental carbon and phosphorus) will reach the Lake.

Spatial Distribution of Source Extent for Fugitive Dust Sources

Because fugitive dust sources closer to the Lake have a higher probability that their emissions will reach the Lake compared to sources distant from the Lake, the distance from the Lake for different road categories within the Basin was examined using the Arc View software program. Discrete zones at a prescribed distance from the Lake shoreline were established as follows: 0–100 m, 100–200 m, 200–500m, 0.5 km to 1 km, and then in 0.5 km increments to the outer boundary of the Basin. Figure 2-2 presents the cumulative distribution of VMT for three paved roadway categories (highways, secondary roads, and local roads) and unpaved roads as a function of distance from the Lake. The actual traffic counts provided by the TRPA were used for highways and some of the secondary paved roads. On the basis of discussions with the TRPA, the balance of the secondary roads were assigned a traffic count of

2,000 vehicles per mile per day, all local paved roads were assigned a traffic count of 233 vehicles per mile per day, and all unpaved roads were assigned a traffic count of 20 vehicles per mile per day (i.e., for an annual average day).

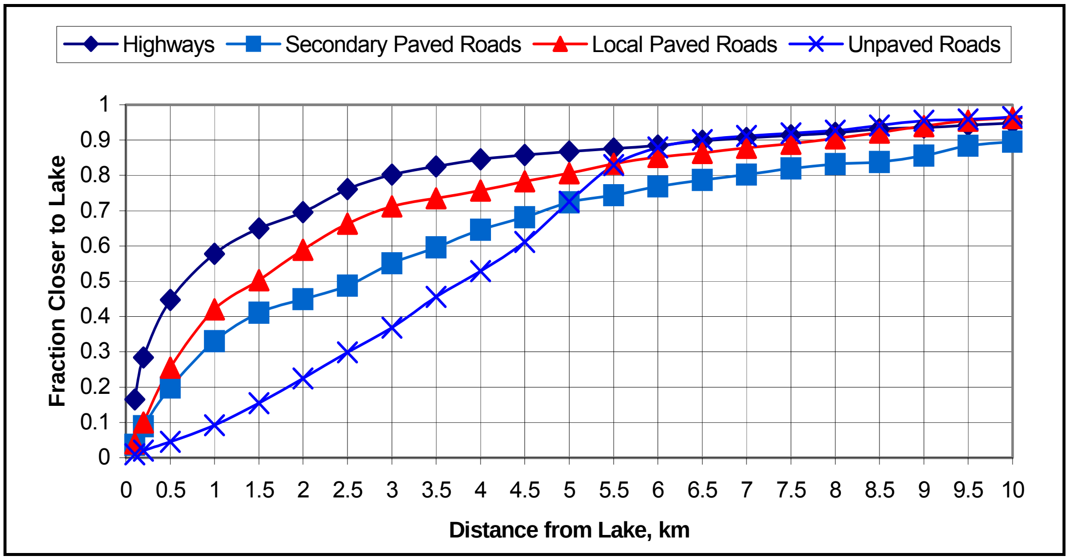

Figure 2-2. Cumulative distribution of VMT for paved and unpaved roads in the Basin

The Arc View software program was also used to examine the spatial distribution of new construction activities in the Basin as a function of distance from the Lake. Figure 2-3 presents the cumulative distribution of disturbed area associated with proposed new building construction projects within the Basin as a function of distance from the Lake. Estimates of disturbed area for each construction project were obtained from grading permits on record with the TRPA (personal communication with Gene Lohrmeyer, May 2, 2007). Figure 2-4 presents the cumulative distribution of disturbed area associated with existing building and road construction projects in the Basin as a function of distance from the Lake. It is obvious from comparing Figure 2-3 with Figure 2-4 that a larger portion of the proposed new building projects are closer to the Lake than existing buildings.

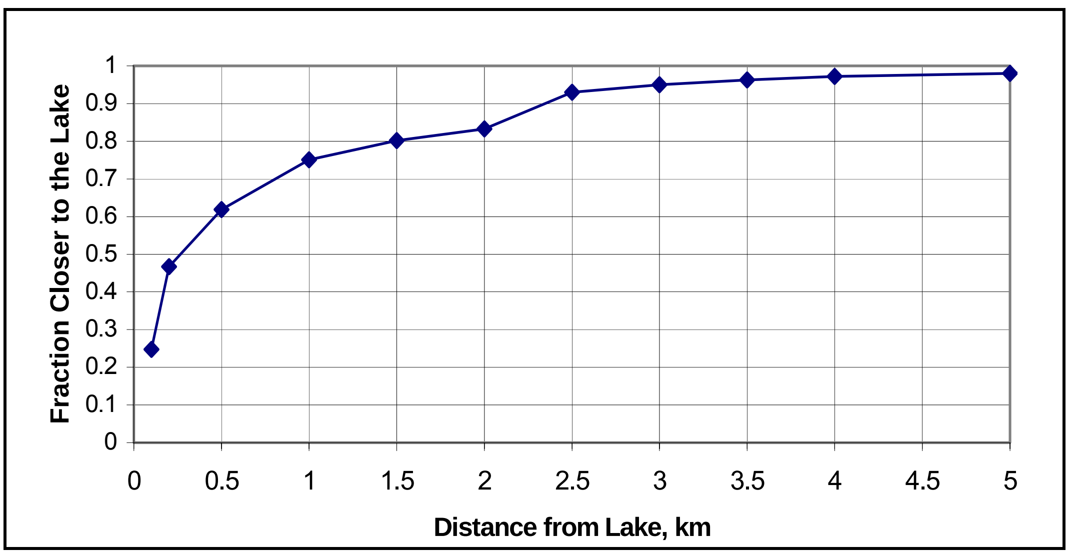

Figure 2-3. Cumulative distribution of proposed building construction projects

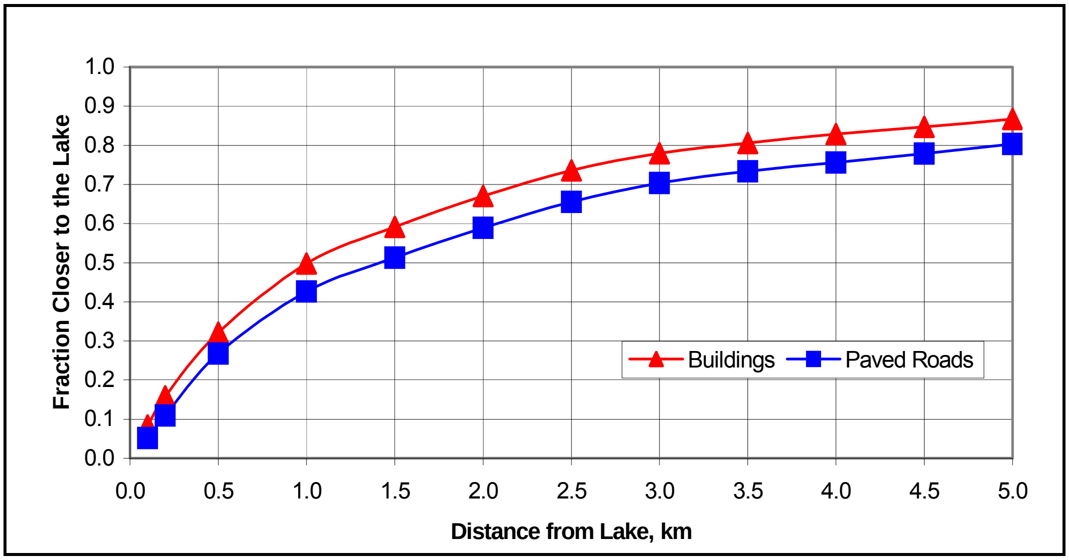

Figure 2-4. Cumulative distribution of existing buildings and paved roads in the Basin

The results presented in Figure 2-2 and Figure 2-4 are summarized in Table 2-9, indicating that there are large differences in the spatial distribution of vehicle activity for the different road categories. There are a greater number of vehicles traveling on highways and major roads close to the Lake compared to the other two paved road categories and the unpaved roads.

Table 2-9. Fraction of fugitive dust source activity versus distance from the Lake

Setting	Distance from Lake (km)	Highways & major roads	Secondary roads	Local roads	Unpaved roads	Existing buildings
1	0.2	0.284	0.089	0.100	0.104	0.158
2	1.0	0.577	0.330	0.420	0.450	0.498
3	3.0	0.802	0.551	0.663	0.737	0.780
4	Entire Basin	1.000	1.000	1.000	1.000	1.000

The spatial distribution of existing buildings within the Basin was used to assign emissions from RWC, stationary source and other area sources to the different settings within the Basin. The spatial distribution of proposed new building projects was used to assign emissions from new building projects to the different settings within the Basin. The spatial distributions for proposed new building projects and existing paved roads were averaged to assign emissions from new paved road construction projects to the different settings within the Basin.

Transportable Fraction as a Function of Distance from the Lake

Table 2-10 and Figure 2-5 present a first approximation estimate for the transportable fraction for fugitive dust as a function of distance from the Lake. These TF estimates are based on the conceptual model developed to reconcile inert species emission estimates with the fine sediment deposition budget estimate for the Lake, that indicated that the Basin-wide transportable fraction of fugitive dust species (TF_{FD}) was about 0.13, and the results of CARB's Lake Tahoe dust deposition experiment, which indicated that the transportable fraction of fugitive dust is 0.20 approximately 100 feet from the emissions source. Note: The TF estimates only assume that the material will be transported to the Lake, not end up depositing into the Lake

Table 2-10. Transportable fraction of fugitive dust versus distance from Lake

Distance from Lake (km)	Percent of fugitive dust emissions	Cumulative percent	Estimated TF_{FD}
0.1	10.0	10.0	0.197
0.2	8.4	18.3	0.190
0.5	16.1	34.4	0.175
1	16.1	50.5	0.150
3	4.4	77.1	0.080
0–16.5	100.0	100.0	0.129

The average fugitive dust TF for the four different settings being considered for the Basin are 0.194 for Setting 1 (within 0.2 km of the Lake), 0.174 for Setting 2 (within 1 km of the Lake), 0.151 for Setting 3 (within three kilometers of the Lake), and 0.129 for Setting 4 (the entire Basin). On the basis of these estimates, implementing a control measure for a source of fugitive dust within Setting 1 would be about 50 percent more effective in reducing the atmospheric deposition of fine sediments to the Lake on a per unit basis than the same control measure applied to all fugitive dust sources within the Basin. On the other hand, because the transportable fraction of fine mode aerosol and gas phase nitrogen species associated with emissions from mobile sources and RWC is close to unity, control measures applied to these pollutant sources are expected to have equal effectiveness for sources throughout the Basin.

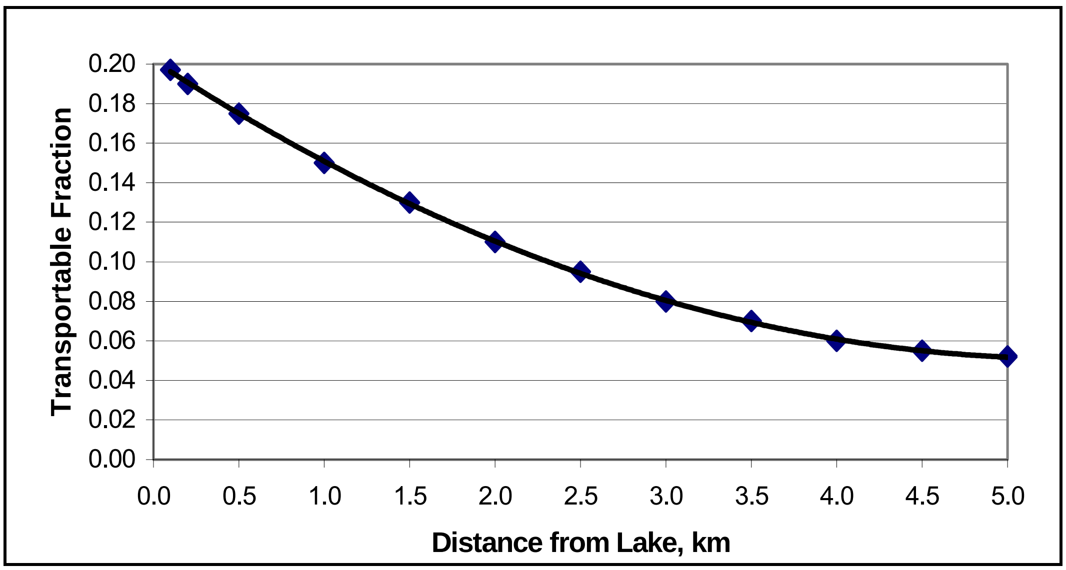

Figure 2-5. Transport fraction of fugitive dust versus distance from Lake

Sample Load Reduction Calculation

A sample calculation for estimating the Tier 3 for a specific control measure for one of the fine sediment source categories is presented below for illustrative purposes.

Assuming that the emission inventory for the Basin indicates that paved roads account for 41 percent of the total inert species generated by sources within the Basin, 41 percent of the annual fine-sediment pollutant load from atmospheric sources (850 MT/year) is from resuspended paved road dust. Implementing the PCO with the highest published control efficiency for controlling resuspended paved road dust for all paved roads in the Basin, namely weekly vacuum sweeping with a control efficiency of 45 percent for particles less than 30 μm in diameter (CE 2006), will reduce the fine sediment load by 157

MT/year (850 MT/year x 0.41 x 0.45). There will also be a simultaneous reduction in the phosphorus load from implementing this PCO since paved road dust contains 0.3 percent phosphorus by weight (Houck 1989).

Cost Estimates

The cost of each control measure includes both the initial capital costs as well as the annual O&M costs and is a function of the source extent or activity level for each source category. For several proposed control measures there are no costs (e.g., mandatory reduction in residential wood burning); for other proposed control measures, the costs may be offset by fees or may result in no additional costs (e.g., switching from sand and cinders as traction material on ice- and snow-covered roads to deicers).

The cost-effectiveness of a specific control measure is calculated by dividing the annualized cost of the control measure by the load reduction estimate expressed in tons of pollutant reduced. The total annualized cost is equal to the annualized capital investment cost plus the annual O&M costs, where the annualized capital investment cost is the product of the capital cost multiplied by the capital recovery factor (CRF). The CRF is calculated as follows:

$$\text{CRF} = [\, i\,(1 + i\,)^{n}\,] \,/\, [(1 + i)^{n} - 1] \qquad (2\text{-}3)$$

where

i = annual interest rate (fraction)
n = number of payment years (i.e., useful, economic life of control measure)

Cost-effectiveness has been calculated on an annual cost per MT of pollutant reduced basis as well as an annual cost per mile basis for roads and an annual cost per acre of disturbed land basis for building construction projects.

2.7. Results

This section provides load reduction estimates (based on the emission inventory developed for the Basin) as well as cost and cost-effectiveness estimates from implementing the proposed package of control measures for atmospheric sources of inorganic nitrogen, fine sediment, and phosphorus; a discussion of the SCG's confidence in these estimates; and conclusions and recommendations for future efforts to improve the accuracy of the estimates.

First, several caveats are in order:

- CARB's Lake Tahoe Atmospheric Deposition Study (LTADS) monitoring program in 2003 covers a single year, and the pollutant budget derived from this study might not be representative of long-term average conditions.
- Actual emissions of the atmospheric pollutants vary seasonally and from year to year.
- Although there might be differences in activities on the California and Nevada sides of the air Basin such as deicing practices, the analysis presented in this report assumes identical practices throughout the region.
- The load reduction for inert species such as fugitive dust, elemental carbon, and phosphorus linked to fugitive dust is proportional to the emission reduction of these pollutants. However, the same might not be true for nitrogen species formed from chemical reactions within the atmosphere.

- Because there are limited records on the source extent or location of active construction projects within the Basin, the load reduction estimates used CARB's estimates of source activity for new paved roads and buildings for the California portion of the Basin that were scaled to the entire Basin.
- The annual average load reduction estimates have uncertainties that are in part related to the inherent uncertainties associated with the pollutant budget for Lake Tahoe and in part related to the inherent uncertainties associated with the emission inventory for the Basin and the estimated transportable fraction for pollutants.

Load Reduction Estimates

Load-reduction estimates were derived from pollutant emission reduction estimates on the basis of implementing the proposed PCOs for atmospheric sources of pollutants for both treatment tiers. Load reduction estimates (with units of MT/year) for the entire Basin as well as for three different settings within the Basin for both Tiers are presented below.

Maximum Analyzed Emission Reduction Estimates

The Tier 3 estimates represent the highest load reduction analyzed from implementing a package of control measures with the highest control efficiencies. Load reduction estimates are based on emission reduction estimates. To illustrate the steps employed to calculate the maximum emission reduction for sources of inert species (the source of fine sediment), phosphorus and inorganic nitrogen, a series of tables (Tables 2-11 through 2-14) were generated for the Basin-wide setting. These four tables, representing maximum emission reductions calculations, include information on the source category, activity data, emission factors, emission rates before control, control efficiency, emission rates after control, and emission reduction with references to the source(s) of information for the emission estimates. Table 2-11 presents the maximum emission reduction estimates of inert species (fugitive dust and elemental carbon) for paved and unpaved roads, Table 2-12 presents the maximum emission reduction estimates of inert species for construction sites, Table 2-13 presents the maximum analyzed emission reduction estimates of elemental carbon and inorganic nitrogen for RWC, and Table 2-14 presents the maximum analyzed emission reduction estimates of inorganic nitrogen for mobile sources.

Table 2-11. Maximum emission reduction of inert species from roads in the Basin

Road category	Highways	Secondary	Local	All paved	Unpaved
Activity Data[a]					
Source extent (miles)	113.4	52	704	869.4	185.3
Vehicle count (VMT/day)	1,146,694	110,289	164,057	1,421,040	3,706
TSP Emission Factor					
TSP EF Equation[b] (lb/VMT)	$E = 0.082\ (sL/2)^{0.65}\ (W/3)^{1.5} - 0.00047$				
SL[c]—silt loading (g/m^2)	0.05	0.05	0.32		
W[c]—average vehicle weight (tons)	3	3	3		
TSP Emission Factor (lb/VMT)	0.00699	0.00699	0.02445		3.723[d]
TSP Emissions Before Control (t/y)	1,462	141	732	2,334	2,518
Control Efficiency (%)				45	99
TSP Emissions After Control (t/y)				1,284	25
TSP Emission Reduction (t/y)				1,050	2,493
EC/TSP Ratio				0.0195[e]	0.0049[f]
EC Emission Reduction (t/y)				20	12
Inert Species Emis. Red'n (t/y)				1,070[d]	2,505[d]

[a] TRPA (2007)
[b] USEPA (2006)
[c] DRI (2004a)
[d] CARB (2003)
[e] MRI (1992)
[f] CE (2006)
[d]There will be a simultaneous reduction of phosphorus emissions of 3 tons/year from paved roads and 7 tons/year from unpaved roads.

Table 2-12. Maximum emission reduction of inert species from construction in the Basin

Construction category	Paved roads	Buildings	Roads & buildings
Activity Data[a]			
New paved roads per year (miles)	8.14		
Disturbed land each year (acres)	64.6	104.8	169.4
TSP Emission Factor[b] (tons/acre-month)	0.17	0.225	
TSP emissions before control (tons/year)	132	283	415
TSP emissions after control (tons/year)	21	45	66
TSP emissions reduction (tons/year)	111	238	349
EC/TSP Ratio			0.049[c]
EC Emission Reduction (t/y)			14[d]
Inert Species Emis. Red'n (t/y)			296[e]

[a] CARB (2006a)
[b] CARB (2003)
[c] CE (2006)
[d] DRI (2004a)
[e] There will be a simultaneous reduction of phosphorus emissions of 1 ton/year.

Table 2-13. Maximum EC and IN emission reduction from RWC in the Basin

RWC category	Wood stoves	Fireplaces	All
Activity Data[a, b]			
Source extent (residences)	18,900	2,100	21,000
Wood burned (tons/year/residence)	2.83	2.83	
Emission Factors[b]			
EC Emission Factor (lb/ton of fuel)	3.12	6.96	
IN Emission Factor (lb/ton of fuel)	3.26	3.26	
EC Emissions			
Before control (tons/year)	83.4	20.7	104.1
After control (tons/year)	41.7	10.3	52.1
Emission Reduction (tons/year)	41.7	10.3	52.1
IN Emissions			
Before control (tons/year)	87.3	9.7	97.0
After control (tons/year)	43.6	4.8	48.5
Emission Reduction (tons/year)	43.6	4.8	48.5

[a] CE-CERT (2004)
[b] DRI (2004a)

Table 2-14. Maximum IN emission reduction for mobile sources in the Basin

IN emissions	On-road	Other	Boats	Aircraft	Total
Before Control (t/y)	1,410	821	583	70	2,884
After Control (t/y)	1,057	616	437	70	2,180
Reduction* (t/y)	353	205	146	0	704

*There will be a simultaneous reduction of elemental carbon emissions of 18 tons/year.

Tier 3 Load Reduction Estimates

The Tier 3 estimates from implementing the proposed package of control measures for four different Settings that account for changes in the transportable fraction of fugitive dust as a function of distance from the Lake as well as the different spatial distributions for atmospheric sources of pollutants within the Basin are presented in Table 2-15. Rather than showing load-reduction estimates for different discrete portions of the Basin, the results presented in Table 2-15 (and again in Table 2-16) indicate a progressive increase in load reduction as one implements control measures for portions of the Basin moving outwards from the shoreline of the Lake: Setting 1, Setting 2, Setting 3, and finally Setting 4.

Table 2-15. Tier 3 load reduction estimates for different Settings

		Load reduction for different settings (MT/year)			
Pollutant	Source	Setting 1 (≤0.2 km from Lake)	Setting 2 (≤1 km from Lake)	Setting 3 (≤3 km from Lake)	Setting 4 (entire Basin)
Fine Sediment	Unpaved Roads	47	183	262	305
	Paved Roads	44	95	124	143
	Construction	22	30	35	43
	Combustion Sources	12	33	55	65
	TOTAL (MT/year)	**125**	**340**	**476**	**555**
	TOTAL (% of budget)*	**15%**	**40%**	**56%**	**65%**
Phosphorus	Unpaved Roads	0.26	1.02	1.45	1.68
	Paved Roads	0.23	0.49	0.63	0.71
	Construction	0.12	0.16	0.19	0.23
	Combustion Sources	0.16	0.52	0.82	1.05
	TOTAL (MT/year)	**0.78**	**2.19**	**3.09**	**3.67**
	TOTAL (% of budget)*	**13%**	**36%**	**52%**	**61%**
Inorganic Nitrogen	Mobile	12.7	19.9	25.6	31.4
	RWC	0.4	1.1	1.7	2.2
	TOTAL (MT/year)	**13.1**	**21.0**	**27.3**	**33.6**
	TOTAL (% of budget)*	**9%**	**14%**	**19%**	**23%**

*Percentage of atmospheric deposition budget for this treatment tier option.

The Tier 3 estimate from implementing the proposed package of PCOs for the entire Basin is 555 MT of fine sediment per year, 3.67 MT of phosphorus per year, and 33.6 MT of inorganic nitrogen per year. These reductions represent 65 percent of the annual atmospheric deposition budget for fine sediments, 61 percent of the annual atmospheric deposition budget for phosphorus, and 23 percent of the annual atmospheric deposition budget for inorganic nitrogen. Table 2-15 indicates that implementing the proposed package of PCOs for this treatment tier in Setting 1 will reduce the atmospheric deposition of fine sediment and phosphorus by about 14 percent and inorganic nitrogen by about 9 percent. The corresponding reductions in the atmospheric deposition of fine sediment and phosphorus from implementing the same package of PCOs in Setting 2 and in Setting 3 are estimated to be about 38 percent and 54 percent, respectively, whereas the reductions in the atmospheric deposition of inorganic nitrogen are estimated to be about 14 percent and 19 percent, respectively.

The Tier 3 estimates for the major sources of fine sediment as a function of source extent for all settings within the Basin are calculated to be the following:

- 1.64 MT/mile for unpaved roads
- 0.16 MT/mile for paved roads
- 1.6 MT/mile for paved road construction projects
- 0.28 MT/acre of disturbed area for building construction projects

Summary

Implementing the proposed package of PCOs in a phased approach, starting with the sources closest to the Lake and moving outwards from the shoreline of the Lake to include additional sources will achieve the following load reductions represented as a percentage of the total Basin-wide load reduction for the maximum treatment tier option:

- Setting 1 (i.e., within 0.2 km of the Lake): about 22 percent for fine sediment and phosphorus, and 39 percent for inorganic nitrogen
- Setting 2 (i.e., within 1 km of the Lake): about 61 percent for fine sediment and phosphorus, and 63 percent for inorganic nitrogen
- Setting 3 (i.e., within 3 km of the Lake): about 86 percent for fine sediment and phosphorus, and 82 percent for inorganic nitrogen

Tier 2 Estimates

The Tier 2 estimates from implementing the proposed package of control measures for four different settings that account for changes in the transportable fraction of fugitive dust as a function of distance from the Lake are presented in Table 2-16.

The load-reduction estimate from implementing the proposed package of PCOs for this treatment tier for the entire Basin is 221 MT of fine sediment per year, 1.46 MT of phosphorus per year, and 13.5 MT of inorganic nitrogen per year. These reductions represent 26 percent of the annual atmospheric deposition of fine sediment, 24 percent of the annual atmospheric deposition of phosphorus, and 9 percent of the annual atmospheric deposition of inorganic nitrogen to the Lake. Table 2-16 indicates that implementing a package of PCOs for this treatment tier in Setting 1 will reduce the atmospheric deposition of fine sediment and phosphorus by about 6 percent and inorganic nitrogen by about 4 percent. The corresponding reductions in the atmospheric deposition of fine sediment and phosphorus from implementing the same package of PCOs in Setting 2 and in Setting 3 are estimated to be about 15 percent and 21 percent, respectively, whereas the reductions in the atmospheric deposition of inorganic nitrogen are estimated to be about 5.5 percent and 7 percent, respectively.

Table 2-16. Tier 2 Estimate for different Settings

Pollutant	Source	Load reduction for different settings (MT/year)			
		Setting 1 (≤0.2 km from Lake)	Setting 2 (≤1 km from Lake)	Setting 3 (≤3 km from Lake)	Setting 4 (Entire Basin)
Fine Sediment	Unpaved Roads	14	54	77	89
	Paved Roads	23	49	63	73
	Construction	16	21	26	33
	Combustion Sources	5	13	22	26
	TOTAL (MT/year)	**56**	**136**	**188**	**221**
	TOTAL (% of budget)*	**6%**	**16%**	**22%**	**26%**
Phosphorus	Unpaved Roads	0.08	0.30	0.42	0.49
	Paved Roads	0.12	0.25	0.32	0.36
	Construction	0.08	0.12	0.14	0.18
	Combustion Sources	0.07	0.21	0.33	0.42
	TOTAL (MT/year)	**0.35**	**0.87**	**1.21**	**1.46**
	TOTAL (% of budget)*	**6%**	**14%**	**20%**	**24%**
Inorganic Nitrogen	Mobile	5.1	8.0	10.3	12.6
	RWC	0.2	0.4	0.7	0.9
	TOTAL (MT/year)	**5.3**	**8.4**	**11.0**	**13.5**
	TOTAL (% of budget)*	**4%**	**5.5%**	**7%**	**9%**

*Percentage of atmospheric deposition budget for this treatment tier option.

The TIER 2 estimates for the major sources of fine sediment as a function of source extent for all settings within the Basin are calculated to be the following:

- 0.47 MT/mile for unpaved roads
- 0.08 MT/mile for paved roads
- 1.6 MT/mile for paved road construction projects
- 0.08 MT/acre of disturbed area for building construction projects

Summary

Implementing the proposed package of PCOs in a phased approach, starting with the sources closest to the Lake and moving outwards from the shoreline of the Lake to include additional sources will achieve the following load reductions represented as a percentage of the total Basin-wide load reduction for the realistic treatment tier option:

- Setting 1 (i.e., within 0.2 km of the Lake): about 23 percent for fine sediment and phosphorus, and 39 percent for inorganic nitrogen
- Setting 2 (i.e., within 1 km of the Lake): about 62 percent for fine sediment, phosphorus, and inorganic nitrogen
- Setting 3 (i.e., within 3 km of the Lake): about 85 percent for fine sediment and phosphorus, and 82 percent for inorganic nitrogen

Summary of Load Reduction Estimates for the Basin

The Tier 3 and Tier 2 estimates for the entire Basin are summarized in Table 2-17.

Table 2-17. Tier 3 and Tier 2 estimates for the Basin

	Inorganic nitrogen (MT/year)		Fine sediment (MT/year)		Phosphorus (MT/year)	
Category	Tier 3	Tier 2	Tier 3	Tier 2	Tier 3	Tier 2
Mobile	31.4	12.6	17	7	0	0
Paved Roads			143	73	0.71	0.36
Unpaved Roads			305	89	1.68	0.49
Construction			43	33	0.23	0.18
Res. Wood Comb.	2.2	0.9	48	19	1.05	0.42
Total	**33.6**	**13.5**	**555**	**221**	**3.67**	**1.46**
Percent of atmospheric deposition budget	**23%**	**9%**	**65%**	**26%**	**61%**	**24%**

Cost Estimates

The estimated inorganic nitrogen load reductions from implementing the proposed package of PCOs for mobile sources for the Tier 3 and Tier 2 options are coupled with the cost estimates to implement these PCOs to derive an estimate of the cost/ton reduction in inorganic nitrogen load. Methods to determine costs, as well as predicted costs for the two scenarios, and cost/ton estimates for inorganic nitrogen load reduction are presented in this section.

Because fugitive dust sources account for more than 92 percent of the fine sediment and phosphorus load (with combustion sources contributing the balance) and mobile sources account for more than 90 percent of the inorganic nitrogen load, this section focuses on PCOs for fine sediments and phosphorus from fugitive dust sources and PCOs for inorganic nitrogen from mobile sources. As stated in Section 2.3 there are a number of programs in place to reduce mobile source emissions. Because the results of their implementation are not available, an analysis of their effectiveness has not been included in the analyses.

There are no costs associated with the proposed PCOs for the mandatory curtailment of RWC. Annualized cost estimates are based on the useful life of the control measure and a CRF assuming an interest rate of 5 percent. The source of the data used to estimate the annualized costs for each PCO is the WRAP fugitive dust handbook (CE 2006).

Cost

Cost of PCOs for Mobile Sources of Inorganic Nitrogen

Without performing the surveys identified in Section 2.7 Recommendations, only preliminary cost estimates are possible for control measures addressing mobile sources. Preliminary cost estimates for the proposed control measures for on-road mobile sources (PCOs M1 and M2) on the basis of information provided by Shaw (2007) and preliminary cost estimates for controlling emissions from commercial boating activities (PCO M3) are presented below. Inherent in the estimates for on-road mobile sources are a number of assumptions (Shaw 2007), namely

- Peak daily VMT in the Basin of 1,580,000 miles/day
- Average trip length of 4.91 miles
- Average vehicle occupancy of 1.82

- 57,000 vehicles per day driven by visitors arriving at the access points to the Basin
- Average of 15 passengers per transit vehicle per hour
- Shuttle bus service that is in operation 10 hours per day, 365 days per year
- Total cost of shuttle bus service is $90/hour
- Cost of new diesel electric hybrid bus is $300,000
- Useful life of new buses is 10 years
- Bus storage facility will accommodate 8.13 buses per acre
- Park-and-ride lots will accommodate 125 automobiles per acre
- Cost of bus storage facility and park-and-ride lots is $180,000 per acre
- Useful life of bus storage facility and park-and-ride lots is 25 years

To provide a diesel electric hybrid bus shuttle service in the Basin for both residents and visitors that will accommodate the peak daily VMT will require 1,076 buses for the Tier 3 option (25 percent reduction in VMT of 395,000 miles/day) or 430 buses for the Tier 2 option (10 percent reduction in VMT of 158,000 miles/day). These estimates assume 10 percent additional buses as spares.

Estimate of Fees Generated by PCO #M1

The percentage of tourists that would potentially use a shuttle service could be as high as 25 percent (Tier 3) but is more likely to be 10 percent (Tier 2). Assuming 10 percent usage of the shuttle system for Tier 2 and an entrance fee of $10/day for the other 90 percent of the 57,000 tourists' vehicles that enter the Basin each day that decide not to use the free park-and-ride service, annual revenue would be $187M. If the entrance fee were raised to $30 per day, annual revenue income would be $562M.

Assuming 25 percent usage of the shuttle system for Tier 3 and an entrance fee of $10/day for the other 75 percent of the 57,000 tourists' vehicles that enter the Basin each day that decide not to use the free park-and-ride service, annual revenue would be $156M. If the entrance fee were raised to $30 per day, annual revenue would be $468M. The revenue generated by the fees from those visitors electing not to use the free park-and-ride facilities at access points to the Basin could be used to offset the cost of the PCOs.

Estimate of Costs for Park-and-ride Facilities (PCO #M1)

A total of 114 acres will be needed for the park-and-ride facilities for the high Treatment Tier option to accommodate 14,250 visitors' vehicles arriving each day. The capital cost for the park-and-ride facilities would be $20.5M, and the annualized capital cost would be $1.5M/year based on a useful life of 25 years. The capital cost for the park-and-ride facilities for the realistic Treatment Tier option would be $8.2M, and the annualized capital cost would be $0.6M/year. Adding in the annual O&M costs estimated to be $1M/year for the Tier 3 option and $0.4M/year for the Tier 2 option produces annual cost estimates of $2.5M/year and $1.0M/year, respectively for the two treatment tier options

Estimate of Cost of Diesel Electric Hybrid Buses for Residents and Visitors (PCO #M2)

The annual O&M costs of operating the shuttle bus service for the Treatment tier 3 option are estimated to be $321M. The capital cost required every 10 years for the fleet is estimated to be $323M. This results in an annualized cost of $363M/year. The capital cost for the fleet facility to store 1,076 buses would be $24M (annualized cost of $1.7M/year based on a useful life of 25 years for the facility). Adding in the annual O&M costs estimated to be $1M/year produces an annual cost estimate of $2.7M/year for the bus storage facility. The cost estimates for the Treatment tier 2 option would be 40 percent of the cost estimates for the Treatment Tier 3 option.

Estimate of Costs Associated with a Reduction of Commercial Boating Activities (PCO #M3)

There are no available figures for the value of commercial boating activities on the Lake. The SCG assumed an upper limit of $10M/year generated by commercial boating activities. Hence, a 25 percent reduction in commercial boating activity that directly scales with income will reduce commercial boating income by $2.5M/year. A 10 percent reduction in activity will reduce commercial boating income by $1M/year.

Summary

Table 2-18 summarizes preliminary cost estimates for implementing the proposed package of control measures for mobile sources of inorganic nitrogen for both the Tier 3 and Tier 2 treatment tier options.

Table 2-18. Cost estimates for PCOs for mobile sources of inorganic nitrogen

Treatment tier option	PCO #	Capital cost ($)	Annual O&M costs ($/y)	Useful life (y)	Annualized cost ($)
Tier 2	M1 (parking lots)	8.2M	0.4M	25	1.0M
	M2 (buses)	129M	128M	10	145M
	M2 (bus facility)	9.6M	0.4M	25	1.1M
	M3	N/A	1M	N/A	1M
	M1, M2, & M3				**148M**
Tier 3	M1 (parking lots)	20.5M	1M	25	2.5M
	M2 (buses)	323M	321M	10	363M
	M2 (bus facility)	24M	1M	25	2.7M
	M3	N/A	2.5M	N/A	2.5M
	M1, M2, & M3				**371M**

Charging a fee of $10/day for visitors not using the free park-and-ride service from the major access points to the Basin would generate annual revenue estimated to be $156M/year for the Tier 3 option and $187M/year for the Tier 2 option. Raising the daily fee to $30/day would generate annual revenue estimated to be $468M/year for the Tier 3 option and $562M/year for the Tier 2 option. At $10/day, these fees would offset part of the cost of implementing the proposed control measures for mobile sources. At $30/day, these fees would offset the entire cost of implementing the proposed control measures for mobile sources with enough left over to offset the cost of the proposed control measures for non-mobile sources of pollutants.

Cost of PCOs for Sources of Fine Sediment and Phosphorus

Cost estimates for the proposed package of PCOs for fine sediment and phosphorus for both the Tier 3 option and the Tier 2 option are presented in Table 2-19. The source of these cost estimates is the WRAP fugitive dust handbook (CE 2006).

Table 2-19. Cost estimates for PCOs for fine sediment and phosphorus

Category	PCO #	Capital cost	Annual O&M cost	Life year	Annualized cost	Total annualized cost for the Basin
Paved Roads	1	$152,000/unit	$40,000/unit	8	$63,518/unit	$762,213[a] (Tier 3) $381,106[b] (Tier 2)
	2	Assume same as current control measure using sand and cinders				
	3	$6,500/access	NA	25	$461/access	$92,200[c]
Unpaved Roads	4	$290,000/mile	$270/mile	25	$20,846/mile	$3,862,803
	5	$53,000/mile	$300/mile	5	$12,542/mile	1,161,985
	6	$200/sign	NA	15	$39/sign	$3,370
Construction	7	$5,000/acre	$1,000/acre	1	$6,250/acre[d]	$1,058,948[e] (Tier 3) $403,948 (Tier 2)
	8 & 9	$200/acre	$80/acre	15	$99/acre	$10,403

[a] 12 PM-efficient vacuum sweeper units required for weekly sweeping
[b] 6 PM-efficient vacuum sweeper units for required for bi-weekly sweeping
[c] Assumes 200 access points from unpaved surfaces onto paved roads in the Basin
[d] $6,250/acre is equivalent to $49,623/mile for paved road construction
[e] This estimate represents $403,948 for road construction and $655,000 for building construction

The total annualized cost for 12 PM-efficient vacuum sweepers is $762,212 or $877/mile, whereas the total annualized cost for 6 units is $381,106 or $438/mile. The total annualized cost of applying a 3" layer of gravel for 50 percent of the unpaved roads in the Basin (PCO #5) is about 40 percent of the total annualized cost estimate of paving all the unpaved roads in the Basin (PCO #4).

Cost-Effectiveness

Estimates of the cost-effectiveness on a dollar per MT of pollutant load reduction basis for the proposed package of PCOs are presented below.

Mobile Sources

On-road mobile sources and commercial boating activities account for 43 percent and 14 percent, respectively, of the local in-Basin inorganic nitrogen emissions (See Table 2-3). Thus, these two sources are assumed to account for 43 percent and 14 percent, respectively, of the inorganic nitrogen budget of 148 MT/year. The cost-effectiveness of PCOs M1 and M2 for controlling emissions from on-road mobile sources is estimated to be $23,000,000 per MT of inorganic nitrogen load reduction for both treatment tier options. The cost-effectiveness of PCO M3 for controlling emissions from commercial boating activities is estimated to be $500,000 per MT of inorganic nitrogen load reduction for both treatment tier options.

Non-mobile Sources

The cost-effectiveness estimates for PCOs addressing fine sediment are presented in Table 2-20, and those for phosphorus in Table 2-21.

Table 2-20. Cost-effectiveness of PCOs for reducing fine sediment load

Category	PCO #	Cost-effectiveness ($/MT-year) Tier 3	Tier 2
Paved Roads	1	5,300	N/A
	2	–	–
	1 & 3	NA	6,500
Unpaved Roads	4	12,700	N/A
	5 & 6	N/A	13,100
Construction	7	24,600	N/A
	7, 8 & 9	N/A	12,600

Table 2-21. Cost-effectiveness of PCOs for reducing phosphorus load

Category	PCO #	Cost-effectiveness ($/MT-year) Tier 3	Tier 2
Paved Roads	1	1,100,000	N/A
	2	–	–
	1 & 3	N/A	1,300,000
Unpaved Roads	4	2,300,000	N/A
	5 & 6	N/A	2,400,000
Construction	7	4,600,000	N/A
	7, 8 & 9	N/A	2,300,000

Assumptions

This load reduction report includes the following assumptions:

- The atmospheric deposition pollutant budget is assumed to be accurate.
- The source activity for each atmospheric deposition source subcategories is assumed to be accurate.
- The parameters used to estimate emissions (e.g., silt loading for paved roads, average vehicle weight) are assumed to be correct.
- EPA's and CARB's emission factors are assumed to be correct.
- DRI's multiplication factors to scale CARB's emission inventory estimates for the California portion of the Basin to the entire Basin are assumed to be correct.
- CARB's 2005 emission inventory for the California portion of the Basin is assumed to be representative of 2007 emissions.
- The source profile test results providing the estimates of the content of elemental carbon and phosphorus are assumed to be accurate.
- The published control efficiencies of different control measures are assumed to be accurate.
- The list of control measures that are in force is assumed to be accurate.
- The cost estimates for non-mobile sources obtained from published reports are assumed to be accurate.

- The cost estimates for mobile sources obtained from Gordon Shaw of TRPA's Transportation Working Group are assumed to be accurate.
- The control efficiency from implementing multiple PCOs simultaneously for a specific source is underestimated and is assumed to be equal to the control efficiency of the PCO with the largest control efficiency.
- The estimates of the transportable fraction of fugitive dust emissions as a function of distance from their source are assumed to be correct.
- It is assumed that the impact on the Lake's clarity due to pollutants from sources outside the Basin is minor compared to in-Basin sources.
- The spatial distribution of pollutants within the Basin obtained from the TRPA is assumed to be accurate.
- The spatial distribution of new paved road construction projects is assumed to be the average of the spatial distribution for new building projects and existing paved roads.
- The spatial distribution of emissions from RWC, stationary sources and other area sources are assumed to be the same as the spatial distribution of existing buildings.
- The load-reduction estimates are assumed to be proportional to emission-reduction estimates adjusted for the transportable fraction for different pollutants.
- The inorganic nitrogen load reduction estimates assume a 25% reduction of emissions for off-road equipment for treatment Tier 3 and 10% reduction for treatment Tier 2 from the implementation of EPA's non-road diesel emission regulations.
- The load-reduction estimates represent an average day on an annual basis without consideration for seasonal differences.

Confidence in Results

Overall, the results presented in this report are sound having been based on source data obtained for the Lake Tahoe air Basin and research conducted by nationally respected research organizations. However, there are numerous uncertainties in the estimates presented in this document. One source of uncertainty is the emissions inventory. The inventory described in this document was derived from the CARB emission inventory for the Basin, which, although it has certain deficiencies such that the absolute values for the emissions are highly uncertain, the relative contributions are considered accurate. Thus, the SCG was able to identify and rank the atmospheric sources of pollutants that deposit directly to the Lake; for example, mobile sources are the dominant source of inorganic nitrogen in the Basin.

There is a large uncertainty in the load-reduction estimates presented in this report that is associated with the inherent uncertainty in EPA's emission factors, the uncertainty in the pollutant budget estimates, and the variability of published source profile test results. EPA recently released a report prepared by RTI International, which states that the uncertainty in the emission estimate for a specific source based on the emission factors published in AP-42 is ± 50 percent (RTI 2007). Uncertainty in the context here refers to an uncertainty at the 95th percentile.

The load-reduction estimate for phosphorus is based on source profile test results that have an uncertainty of ± 50 percent. The other term used to estimate load reduction is source extent (i.e., activity level) that has an uncertainty of ± 25 percent. However, the uncertainty associated with the assumed source extent for unpaved roads and construction sites is much larger. The amount of vehicle traffic on unpaved roads and the extent of road and building construction projects in the Basin must be quantified by independent sources.

Assuming that the uncertainty in the pollutant budget is ± 25 percent, the fine sediment and inorganic nitrogen load reduction estimates are estimated to have an uncertainty of ± 61 percent, and the phosphorus load reduction estimates an uncertainty of ± 79 percent. The uncertainty in the cost estimates is ±25 percent. Thus, the overall uncertainty in the cost-effectiveness estimates for fine sediment and inorganic nitrogen is estimated to be ± 66 percent, and the overall uncertainty in the cost-effectiveness estimates for phosphorus is ± 83 percent.

There are also a number of areas of uncertainty associated with the estimates of PCO cost and cost-effectiveness. These include the following:

- The lack of Tahoe-specific surveys to assess usage/impacts
- A lack of quantitative, tested, and reliable means to predict effectiveness of PCOs, as designed, as constructed, and as maintained
- A lack of information on how the PCOs will change in time and their variable performance over life span
- Failure to address changes associated with cycles in weather and climate

In spite of these deficiencies, the reduction in a parameter such as VMT would lead to an absolute reduction of the load to the Lake. Therefore, the reduction confidence is high, while the cost-effectiveness confidence is low. One further point that needs to be mentioned is the impact of in- Basin versus out-of-Basin sources. The SCG has focused on in-Basin controls to reduce inorganic nitrogen, while ignoring out-of-Basin sources. If a significant fraction of the inorganic nitrogen came from out-of-Basin sources, the proposed PCOs would not be effective. Fortunately, studies have shown that the majority of pollutants come from in-Basin sources on an annual basis (Cahill and Cliff 2000). Thus, the proposed PCOs should be very effective. However, it should be pointed out that during summer months, prevailing winds from the west can carry nitrogen primarily as particulate nitrate into the Basin. This can affect the nitrogen deposition to the Lake regardless of local emissions. While overall, this influence is likely low on an annual basis, it should not be ignored. This would have the effect of slightly overstating the degree of load reduction from local controls and correspondingly underestimating the cost-effectiveness values related to inorganic nitrogen. Similarly, during summer months, prevailing winds from the west could carry nitrogen emissions (primarily from motor vehicles on the east side of the Lake) out of the air Basin without ever affecting the Lake. Thus, there are local emissions that would have no bearing on nitrogen deposition to the Lake, and accordingly, the relationship between nitrogen emissions reductions and reduction of nitrogen load to the Lake is a very complex issue.

The situation described above for the transport of nitrogen species, also applies to inert species, but more appropriately to elemental carbon, which because of its finer particle size, stays airborne longer than crustal fugitive dust, and can be affected by strong winds. There are a number of days, for example during winter wind and storm events, when wood smoke emissions can be ventilated out of the Basin. There is also the potential transport of elemental carbon into the Basin from wildfires external to the Basin such as the major Oregon fire that occurred several years ago.

Relative confidence ratings (on a scale of 1 to 5 with the lower numbers denoting less confidence) of the load reduction estimates for each Setting and Tier combination are presented in Table 2-22. The ratings for the two different Treatment Tiers are identical because they both rely on the same assumptions. The ratings for the first three Settings were assigned a rating one lower than that for the entire Basin because the load reduction estimates for these settings rely on the accuracy of the spatial distribution of pollutant sources within the Basin. The ratings for the phosphorus (P) load reduction estimates were assigned a rating one lower than that for the fine sediment (FS) and inorganic nitrogen (IN) load-reduction estimates because the former estimates rely on the accuracy of source profile tests.

Table 2-22. Relative confidence ratings of load-reduction estimates

	Tier 3			Tier 2		
Setting	FS	IN	P	FS	IN	P
1 (within 0.2 km of Lake)	3	3	2	3	3	2
2 (within 1 km of Lake)	3	3	2	3	3	2
3 (within 3 km of Lake)	3	3	2	3	3	2
4 (Entire Basin)	4	4	3	4	4	3

Conclusions

Implementing the proposed package of control measures for Tier 3 for the major atmospheric sources of pollutants within the Lake Tahoe air Basin is estimated to provide the following annual load reductions:

- 33.6 MT (36.9 tons) of inorganic nitrogen/year representing a 23 percent reduction in inorganic nitrogen load from atmospheric sources at an annualized cost of $371 million for control measures addressing on-road mobile sources and commercial boating. The cost of reducing the inorganic nitrogen load from off-road mobile sources affected by the EPA's 2004 non-road regulations has not been addressed.
- 555 MT (610 tons) of fine sediments/year representing a 65 percent reduction in fine sediment load from atmospheric sources and 3.7 MT (4.0 tons) of phosphorus/year representing a 61 percent reduction in phosphorus load from atmospheric sources at an annualized cost of $6 million.

Implementing the proposed package of control measures for Tier 2 for the major atmospheric sources of pollutants within the Basin is estimated to provide the following load reductions:

- 13.5 MT (14.8 tons) of inorganic nitrogen/year representing a 9 percent reduction in inorganic nitrogen load from atmospheric sources at an annualized cost of $148 million for control measures addressing on-road mobile sources and commercial boating. The cost of reducing the inorganic nitrogen load from off-road mobile sources affected by the EPA's 2004 non-road regulations has not been addressed.
- 221 MT (243 tons) of fine sediments/year representing a 26 percent reduction in fine sediment load from atmospheric sources and 1.5 MT (1.6 tons) of phosphorus/year representing a 24 percent reduction in phosphorus load from atmospheric sources at an annualized cost of $2 million.

The atmospheric deposition pollutant load reduction estimates for the two treatment tier options for the entire Basin are summarized in Table 2-23. A preliminary ballpark load-reduction estimate for organic nitrogen species can be obtained by multiplying the load-reduction estimates for inorganic nitrogen species by 50 percent from the fact that the organic nitrogen load estimate is approximately one-half that of the inorganic nitrogen load estimate for atmospheric sources (Lahontan and NDEP 2007).

Table 2-23. Atmospheric pollutant load reduction estimates

Treatment Tier	Inorganic nitrogen (MT/y)	Fine sediment (MT/y)	Phosphorus (MT/y	Annual cost ($)
Tier 2	13.5	221	1.5	150M
Tier 3	33.6	555	3.7	377M

The cost-effectiveness of implementing the proposed package of control measures for on-road mobile sources and commercial boating activities of inorganic nitrogen in the Basin is estimated to be $18,000,000 per MT of inorganic nitrogen reduced per year for both the Tier 3 option and the Tier 2 option. The cost-effectiveness of implementing the proposed package of control measures for the major atmospheric sources of fine sediment and phosphorus in the Basin is estimated to be $11,000 per MT of fine sediment load reduced per year and $2,000,000 per MT of phosphorus load reduced per year for both the Tier 3 option and the Tier 2 option.

Recommendations

There are a number of recommendations for additional work that can be performed to reduce the uncertainty in the emission inventory estimates, the load reduction estimates, and the cost-effectiveness results presented in this report. In terms of the emissions inventory, improvements include the following:

- Accounting for all off-road sources and their activity
- Estimating mobile source emissions on grades and at the altitude of the Basin
- Using more accurate vehicle model year and class distribution data for mobile source emission factor models
- Using Basin-specific source activities
- Conducting additional source tests in the Basin to obtain emission factors for elemental carbon, phosphorus, and nitrogen species
- Measuring resuspended fugitive dust emission rates for sources in the Basin rather than relying on EPA’s AP-42 emission factors

For the load-reduction estimates, improvements include the following:

- Conducting demonstration projects in the Basin to evaluate the effectiveness of specific control measures
- Conducting field studies to quantify the transportable fraction of the pollutants of interest generated in different parts of the Basin that reach the Lake

For the cost estimates, improvements include the following:

- Developing and applying of Tahoe-specific surveys (See below)
- Studying the effect of PCOs on the behavior of population and the effectiveness of various PCOs
- Developing Tahoe-specific cost estimates for PCO implementation
- Determining the impact of weather and climate on PCOs

To obtain an estimate of the costs for implementing the proposed control measures for mobile sources, the following steps are needed:

- Obtain an estimate of the number of vehicles entering the Basin along with a count of the number of passengers per vehicle.
- Administer a survey to tourists driving into the Basin addressing how a fee (different cost options) would affect their behavior regarding the park-and-ride services.
- Administer a survey to tourists driving in the Basin addressing whether a shuttle service between resorts would affect their travel behavior.
- Administer a survey to tourists and permanent residents in the Basin addressing how these control options would affect their activities.

- Administer a survey to employees in the Basin addressing if an employer-sponsored shuttle program would affect the usage of their vehicles.
- Contact employers in the Basin to see how many would participate in an employer-sponsored shuttle service for employees.
- Obtain the number of employees for work places that agree to participate in an employer-sponsored shuttle service.
- From the survey results, calculate the number of passengers that would use the shuttle system and use this information to calculate the amount of hybrid buses/vans that would need to be purchased, along with the frequency of service.
- Calculate the difference in the fuel consumption using hybrid vehicles versus gasoline and diesel fueled cars to estimate the change in emissions.
- Obtain information on operation and maintenance costs and useful life of the shuttle service vehicles.
- From the survey results, calculate the cost of informing the public about benefits of the new regulations.
- Estimate the reduction in on-road and commercial boating activities.
- Obtain estimates of the costs for law enforcement officials to administer the new regulations as well as estimates of income from fines.

2.8. References

Bishop, G. A., Morris, J. A., Stedman, D. H., Cohen, L. H., Countess, R. J., Countess, S. J., Maly, P. and Scherer, S., 2001. The Effects of Altitude on Heavy-Duty Diesel Truck On-Road Emissions. *Environ. Sci. Technol.* 35:1574–1578

CA DOT (California Department of Transportation), 2006. *2005 California Public Road Data, report prepared by the* California Department of Transportation, Sacramento, CA.

Cahill, T.A., 2004. *Size, Time, and Compositionally Resolved Aerosols at South Lake Tahoe*, report prepared for the Tahoe Regional Planning Agency, South Lake Tahoe, CA by University of California-Davis, Davis, CA.

Cahill, T. A., and Cliff, S. S., 2000. *Air Quality in the Lake Tahoe Watershed Assessment*, report prepared for the Tahoe Regional Planning Agency, South Lake Tahoe, CA by University of California-Davis, Davis, CA.

CALTRANS (California Transportation Department) and NDOT (Nevada Department of Transportation), 2006. *2006 Tahoe Basin [Road] Construction Activities*, report downloaded from CALTRANS website (www.dot.ca.gov/dist3/tahoe.const).

CARB (California Air Resources Board). 1997. *Entrained Dust from Paved Road Travel: Emission Estimation Methodology Background Document*, report prepared by California Air Resources Board, Sacramento, CA, July.

CARB (California Air Resources Board). 2002. *Evaluation of Air Quality Performance Claims for Soil-Sement Dust Suppressant,* report prepared by California Air Resources Board, Sacramento, CA.

CARB (California Air Resources Board). 2003. *Emission Inventory Procedural Manual Volume III: Methods for Assessing Area Source Emissions*, report prepared by California Air Resources Board, Sacramento, CA.

CARB (California Air Resources Board). 2006a. *2005 Emissions Inventory for the Lake Tahoe Air Basin*., EXCEL spreadsheet downloaded from CARB website (www.arb.ca.gov/ei).

CARB (California Air Resources Board), 2006b. *Lake Tahoe Atmospheric Deposition Study (LTADS)*, report prepared by California Air Resources Board, Sacramento CA.

CE (Countess Environmental), 2004. *Cost Effectiveness of Fugitive Dust Control Measures*, report prepared for the Western Governor's Association, Denver, CO by Countess Environmental, Westlake Village, CA.

CE (Countess Environmental), 2006. *WRAP Fugitive Dust Handbook*, report prepared for the Western Regional Air Partnership, Denver, CO by Countess Environmental, Westlake Village, CA.

CE-CERT (College of Engineering - Center for Environmental Research and Technology), 2004. *Improvement of the PM Emission Inventory for the Lake Tahoe Region*, report prepared for California Air Resources Board, Sacramento, CA, by College of Engineering - Center for Environmental Research and Technology, Riverside, CA for Contract 01-733.

Countess, R. J., 2001. *Methodology for Estimating Fugitive Windblown and Mechanically Resuspended Road Dust Emissions Applicable for Regional Air Quality Modeling*, paper presented at the U.S. EPA Emissions Inventory Conference, Denver, CO, April.

Cowherd, C., 1991. *Best Available Control Measures (BA CM) for Fugitive Dust Sources: Revised Draft Guidance Document*, report prepared for the USEPA by Midwest Research Institute, Kansas City, MO.

DRI (Desert Research Institute). 2004a. *Lake Tahoe Source Characterization Study*, report prepared for California Air Resources Board, Sacramento, CA by Desert Research Institute, Reno, NV for Contract 01-734.

DRI (Desert Research Institute), 2004b. *International Workshop on Organic Speciation in Atmospheric Aerosols Research*, Las Vegas, NV, April 5–7, 2004.

Emmett, C., 2007. *Lake Tahoe 2004 Boating Emissions Analysis for Shorezone EIS*, report prepared by the Tahoe Regional Planning Agency, South Tahoe, CA.

ENVIRON, 2002. *California Regional PM10/PM2.5 Air Quality Study Ammonia Emissions Improvement Projects in Support of CRPAQS Aerosol Modeling and Data Analyses: Draft Ammonia Inventory Development*, report prepared for California Air Resources Board, Sacramento, CA.

Gertler, A. W., 1996. On-Road Chassis Dynamometer and Engine-Out Dynamometer Measurements of Heavy-Duty Vehicle Emission Factors. In *Proceedings of the A&WMA Conference on the Emission Inventory: Programs & Progress*, Research Triangle Park, NC, October.

Houck, J. 1989. *Determination of Particle Size Distribution and Chemical Composition of Particulate Matter for Selected Sources in California*, report prepared for California Air Resources Board, Sacramento, CA, by OMNI Environmental, Portland, OR.

Houck, J. 2001. *Review of Wood Heater and Fireplace Emission Factors,* paper given at USEPA Emission Inventory Conference, Denver, CO, April.

Lahontan (California Regional Water Quality Control Board, Lahontan Region) and NDEP (Nevada Department of Environmental Protection), 2006. *Draft Lake Tahoe TMDL Source Category Group Work Plan*, report prepared by California Regional Water Quality Control Board Lahontan Region, South Tahoe CA, and Nevada Department of Environmental Protection, Carson City, NV.

Lahontan (California Regional Water Quality Control Board, Lahontan Region) and NDEP (Nevada Department of Environmental Protection), 2007. *Lake Tahoe TMDL Technical Report*, report prepared by California Regional Water Quality Control Board Lahontan Region, South Tahoe, CA, and Nevada Department of Environmental Protection, Carson City, NV.

Langston, R., 2005. *Control Measures for Unpaved Roads*, paper presented at the Western Regional Air Partnership Dust Control Conference, Palm Springs, CA., May.

MRI (Midwest Research Institute), 1992. *Fugitive Dust Background Document for BACM*, report prepared for the U.S. EPA by Midwest Research Institute, Kansas City, MO.

MRI (Midwest Research Institute), 1999. *Estimating Particulate Matter Emissions from Construction Operations*, report prepared by Midwest Research Institute, Kansas City, MO for the USEPA, September.

MRI (Midwest Research Institute), 2001. *Particulate Emission Measurements from Controlled Construction Activities*, report prepared for the U.S. EPA by Midwest Research Institute, Kansas City, MO.

MRI (Midwest Research Institute), 2006. *Background Document for Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Emission Factors*, report prepared for the Western Regional Air Partnership, Denver, CO by Midwest Research Institute, Kansas City, MO.

Pace, T. G., 2005. *Methodology to Estimate the Transportable Fraction (TF) of Fugitive Dust Emissions for Regional & Urban Scale Air Quality Analyses*, report published by U.S. Environmental Protection Agency, Washington, DC.

Pierson, W., 1996. *Real-World Automotive Emissions - Summary of Studies in the Fort McHenry and Tuscarora Mountain Tunnels*. *Atmos. Environ*. 30:2233-2256.

Reuter, J. E., 2007. *Atmospheric Deposition*, Chapter 4.5 prepared for the Lake Tahoe TMDL Phase 1 Report by UC-Davis, Davis, CA.

RTI (Research Triangle Institute), 2007. *Emissions Factor Uncertainty Assessment*, report prepared for the U.S. Environmental Protection Agency, Washington, DC by RTI International, Research Triangle Park, NC.

Shaw G., 2007. Personal correspondence, April.

Sierra Research, 2003. *Final BACM Technological and Economic Feasibility Analysis,* report prepared for the San Joaquin Valley Unified Air Pollution Control District by Sierra Research, Sacramento, CA.

SCAQMD (South Coast Air Quality Management District), 1997. *Air Quality Management Plan, Appendix IV-A: Stationary and Mobile Source Control Measures*, report prepared by South Coast AQMD, Diamond Bar, CA.

TRPA (Tahoe Regional Planning Agency). 2002. *Master List of Compliance Measures, Appendix A of TRPA 2001 Threshold Evaluation Draft Report*, prepared by Tahoe Regional Planning Agency, South Tahoe, CA

TRPA (Tahoe Regional Planning Agency), 2007. Personal communication with Keith Norberg, March.

USDOT (U.S. Department of Transportation). 2000. *Federal Highway Administration (FHWA) Functional Classification Guidelines: Concepts, Criteria and Procedures*, report prepared by U.S. Department of Transportation, Washington, DC, April.

USEPA (U.S. Environmental Protection Agency), 2003. *Biogenic Emissions Inventory System (BEIS) Modeling*, report prepared by U.S. Environmental Protection Agency, Washington, DC, November 17.

USEPA (U.S. Environmental Protection Agency), 2006. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary and Area Sources (AP-42)*, report prepared by U.S. Environmental Protection Agency, Washington, DC.

USFS (U.S. Forest Service), 2007. *Draft Three Year Forest Road BMP Upgrade Monitoring Report (2003-2005)*, report prepared for the Lake Tahoe Basin Management Unit, South Tahoe, CA, by the U.S. Forest Service.

Walsh, M., 2007. *A Brief History of Motor Vehicle Pollution Control in the United States,* EM Magazine, published by the Air and Waste Management Association, Pittsburgh, PA, June.

3. Urban Uplands & Groundwater Sources

3.1. Source Discussion

The Urban Uplands and Groundwater Source Category Group (UGSCG) assessed pollutant loading associated with urban storm water runoff, including infiltration to groundwater, for the Lake Tahoe Basin. Reduction of pollutant loads associated with storm water is a focus of Lake Tahoe Basin regulations and programs, including major water quality improvement projects implemented by local governments and agencies. Current practices for water quality improvement and protection in the Lake Tahoe Basin include implementation of best management practices (BMPs) on private and public lands and in public rights-of-way. Water quality is affected by improvements constructed both at the parcel scale (generally private-property BMPs) and at the scale of urban catchments (generally public projects associated with the Environmental Improvement Program [EIP]). Storm water quality improvement projects typically combine many types of improvements intended to reduce pollutant loads, but their cumulative effects for reducing pollutant loading in storm water runoff are not well quantified. Additionally, potential loads to groundwater from infiltration of urban storm water are not well quantified.

The pollutants of concern for Lake Tahoe are primarily related to Lake clarity and include nitrogen (N), phosphorus (P), and fine sediment. The Total Maximum Daily Load (Lake Tahoe TMDL) Phase One Lake Tahoe pollutant budget highlights the importance of the urban upland/groundwater source categories for addressing pollutants of concern. According to the pollutant budget, roughly 30 percent of the mass load of fine sediment in the < 63 µm range to Lake Tahoe is generated from urban upland runoff. However, roughly 70 percent of the total number of fine particles (< 20 µm) considered critical to Lake clarity come from urban upland runoff. Furthermore, the combined pollutant loading from urban uplands and groundwater accounts for roughly 40 percent of the total nitrogen (TN) and roughly 55 percent of the total phosphorus (TP) input to Lake Tahoe (Lahontan and NDEP 2007).

The primary sources influencing pollutant loading in urban uplands and groundwater are from the following:

1. Modification of natural hydrologic processes caused by impervious surfaces that result in erosion of slopes, gullies and road shoulders, and alteration of natural features such as wetlands that contribute to water quality protection
2. Addition of anthropogenic sources of pollutants such as fertilizers and road abrasives

Modifications to natural hydrologic processes in a watershed are caused by impervious surfaces associated with urban development. During storm runoff events, precipitation that falls directly on impervious surfaces is sometimes routed to pervious surfaces, typically focusing flow in roadside ditches, gullies, and other pervious pathways. These hydrologic modifications result in accelerated loss of native soils and increases in the erosive power of runoff. Road cuts and other modifications can create localized areas of accelerated erosion. Research conducted by Grismer and Hogan (2005) in the Tahoe Basin suggests that erosion from road cuts on steep slopes is nearly an order of magnitude greater than erosion from native, undisturbed soils.

Anthropogenic pollutant sources in Lake Tahoe include application of fertilizers to enhance vegetation growth in naturally nutrient-poor Tahoe soils and application of road abrasives to increase motorist safety in the winter. These annual applications are constant additions to the pollutant budgets for N, P, and fine sediment.

3.2. SCG Analysis Overview

The UGSCG has developed a range of Pollutant Control Options (PCOs), and analyzed and defined Lake Tahoe Basin Settings where these PCOs are applicable. The PCOs and Settings have then been used to define Treatment Tiers to represent two levels of potential pollutant load reduction. Additionally, a specialized Treatment Tier has been developed that might be applied in specific geographic areas for a storm water collection, conveyance, and mechanized treatment system (Pump and Treat Tier or P&T Tier). The potential impacts of infiltrating urban upland storm water to groundwater are also assessed, including application of PCOs before infiltration and advanced *in situ* treatment for groundwater.

This section provides an overview of the UGSCG work to develop the Settings, Treatment Tiers, and a set of Input Tables for the Watershed Model (Input Tables) that will be used in Tahoe Basin-scale estimation of pollutant load reductions. Input Tables contain several Reference Tables that are designed for direct application to the Watershed Model. Simulations in the Watershed Model use the intermediate results developed in this report to estimate pollutant load reductions for urban uplands at the Tahoe Basin-wide scale.

Pollutant Control Options

A very large number of BMPs are applicable to the urban upland and groundwater source category, and these are typically applied in various combinations, configurations, and sizes depending on the characteristics of the development and site conditions. For this analysis, PCOs were defined that represent groups of typical BMPs with similar functions. This consolidation was necessary to avoid analysis of an unmanageable number of alternatives and relies on defining expected performance in terms of primary function for a group of BMPs rather than for a particular BMP. While the performance of individual BMPs or individual storm water quality improvement projects could vary from these estimates, the UGSCG considers this approach reasonable for the purpose of estimating average expected load reductions by Setting and for extrapolation to the Tahoe Basin-wide scale.

PCOs were grouped into three major load reduction elements for the purpose of estimating performance by function—Pollutant Source Controls (PSCs), Hydrologic Source Controls (HSCs), and Storm Water Treatment (SWT). Pollutant load reductions can be associated with each of these major elements—this organization is consistent with current Tahoe Basin practice (e.g., Preferred Design Approach and Formulating and Evaluating Alternatives [SWQIC 2004]) for implementation of storm water quality improvement projects in the Lake Tahoe Basin.

PCOs are generally applied in combinations of the major load reduction elements, and their performance is interdependent (e.g., HSC increases SWT effectiveness by reducing runoff volumes). Therefore, an evaluation of overall performance requires consideration of combinations of PSCs, HSCs, and SWT in various Settings. For the purpose of this evaluation, the UGSCG developed a conceptual model that treats PSCs, HSCs, and SWT sequentially and tracks inputs to groundwater at the HSC and SWT steps. Although in practice, specific BMPs might serve more than one function, this conceptual model provides a simple means to estimate interactions among the major load-reduction elements and to facilitate development of Input Tables for the Watershed Model.

Settings

Settings were developed as the basis for defining PCO applications, considering typical physical and land use characteristics and constraints. Setting classifications are based on two key physiographic characteristics: (1) impervious area configuration (Concentrated or Dispersed), and (2) land slope (Steep or Moderate). These physiographic characteristics were identified as the most important factors for the Setting analysis because they indicate typical physical and land-use constraints that most strongly influence the spatial application of PCOs and the feasibility of implementing different types of PCOs.

Geographic information system (GIS) analysis was used to define Setting characteristics and to classify subwatersheds into Settings. Because 184 subwatersheds will be used as the basis for estimates of load reduction at the Tahoe Basin-wide scale in the Watershed Model, resolution of Settings finer than the 184 subwatershed scale will not be useful in the simulations. Therefore, each of the 184 subwatersheds simulated in the Watershed Model for the urban uplands source category was classified into one of the four Settings.

The four Settings used for the analysis are the following:

- Concentrated-Steep
- Concentrated-Moderate
- Dispersed-Steep
- Dispersed-Moderate

Concentrated Settings generally have urban development that has little available aboveground space within or downstream of the development where large-scale, centralized storm water treatment BMPs (e.g., water quality basins) can be implemented and development is frequently near the Lake margin. Dispersed Settings are significantly less constrained in this respect.

Within a subwatershed classified as any of the above Settings, multiple land uses are present. The mixture of land uses in a subwatershed plays a key role in computation of pollutant loads.

Treatment Tiers

Treatment Tiers are defined as conceptual combinations of PCOs applicable to a Setting. Pollutant loads associated with existing conditions were estimated in Watershed Model runs in Phase One of the Lake Tahoe TMDL and provide the baseline for load reduction estimates (Lahontan and NDEP 2007). Existing condition loads are estimated by computing runoff (considering impervious area) and using average Event Mean Concentrations (EMCs) by land use. This baseline and the methods used to estimate loads in the Watershed Model guided the UGSCG definition of Treatment Tiers for pollutant load reduction. Two standard Treatment Tiers were defined for each Setting, representing steps or levels in expected water quality performance and cost. The existing practice load reduction Treatment Tier (Tier 1) represents current practice in the Lake Tahoe Basin, considering typical constraints that affect water quality improvement design and implementation. The maximum analyzed load reduction Treatment Tier (Tier 2) represents comprehensive application of PCOs and more advanced and intensive practices for storm water management. Tier 2 places reduced emphasis on typical constraints such as land acquisition, operations and maintenance (O&M), and cost.

Tier 1 and Tier 2 are defined by their application of specific PCOs to land uses or land-use groups. For Tier 1, the assumptions include application of PCOs to only a portion of the area within each land-use group. This reflects current practice, which generally prioritizes improvements according to the significance of pollutant sources and is strongly influenced by constraints of land availability, cost, maintenance and operation capabilities, and other factors. Tier 2 was defined by not only more advanced practice, but more complete spatial application of PCOs within the project area.

The specialized Treatment Tier, referred to as the P&T Tier, represents collection and pumping of storm water to a regional treatment plant and is applicable to areas of relatively densely developed land, typically involving contiguous areas in more than one adjacent subwatersheds.

Analysis Methodology

Treatment Tiers provide the conceptual basis for estimating overall pollutant load reductions and costs. The analysis methodology translates the combination of PCOs that define a Treatment Tier to a Load Input Table for each Setting. The Input Table defines the routing of runoff from specific urban upland land uses through PCOs. For PCOs associated with each major load reduction element (i.e., PSC, HSC, and SWT), performance characteristics are specified by the Input Table that can be used in Watershed Model simulations.

In each Input Table, the performance of PSCs for improving the quality of runoff is defined in terms of reduced EMCs by land use. After taking into account PSCs, the performance of HSCs for runoff reduction is specified using storage and infiltration parameters on a unit impervious area basis. The total volume of runoff captured by HSCs in a Treatment Tier and Setting will vary by subwatershed in the Watershed Model, but performance in terms of total runoff volume (% capture, or capture ratio) should be relatively uniform. After routing through HSCs, runoff is routed to SWT. SWT performance is defined by achievable effluent concentrations for the portion of the runoff treated. Bypassed flows for SWT are assumed to discharge to surface waters at influent concentrations. SWT inputs in the Input Table include storage and infiltration parameters that affect capture ratio. HSC inputs are very similar.

The baseline condition for groundwater loading to Lake Tahoe (Lahontan and NDEP 2007) is the groundwater evaluation conducted by the U.S. Army Corps of Engineers (ACOE 2003a). Estimated changes to groundwater loads are computed independent of Watershed Model simulations. Groundwater inputs from infiltration in HSCs and SWT are estimated using a mass balance approach. Estimated concentration decreases due to PSCs, soil filtration and adsorption, and advanced treatment of infiltrated flows in SWT are represented in the mass balance load computations.

Results and Uncertainty

Load reduction results for urban uplands are simulated in the Watershed Model. The UGSCG reviewed the results from these runs to assess the reasonableness of output for various Settings and Treatment Tiers.

Confidence in the results of the load-reduction computations is affected by various factors. Primary factors reducing confidence include the following:

- Modeling assumptions include static concentrations with variable flow rates. Lack of sufficient understanding regarding the variability of pollutant loads with flow rates, seasons, and other factors could affect overall PCO performance on an annual average basis.
- Defining the effectiveness of pollutant source control implementation is difficult and minimal supporting data exists, both in Tahoe and elsewhere, on a BMP or land-use basis.
- Results are sensitive to hydrologic computations that affect capture ratios of PCOs, where the capture ratio is sensitive to variability of physical parameters that affect runoff at smaller scales than simulated.
- The accessibility of data sets for Lake Tahoe treatment BMP (SWT) performance is limited and difficult to assess in a statistically robust manner.

- Defining the spatial extent of PCO application in Tier 1 is based on best professional judgment.
- Very limited data exists on the effects of maintenance on PCO performance.
- Efforts to date for estimating O&M costs do not include validation and comparison with existing storm water utilities.

Primary factors that improve confidence are the following:

- Relative confidence in hydrologic computations (compared to those involving pollutant concentrations) and confidence that overall pollutant load performance is heavily influenced by hydrologic performance
- Multiple levels of pollutant control (PSCs, HSCs, SWT), which because of redundancy, probably provide robust performance across a range of conditions
- Reasonably high confidence that effluent concentrations reflected in the Lake Tahoe data sources and International BMP Database should be achievable in Lake Tahoe with sound design and adaptation of designs over time; and recognition that effluent concentrations in SWT strongly influence overall performance in Tier 2
- Relatively high confidence in estimates for treatment performance of particulates in the P&T Tier on the basis of measured performance for potable water treatment and for storm water treatment plants in other locations.
- Emphasis on relative performance of Tier 1 and Tier 2 in comparison to existing conditions (as opposed to absolute values for pollutant loads)

3.3. Pollutant Control Options

A large number of both structural and nonstructural BMPs are applicable to urban upland sources of pollutants in Lake Tahoe. To reduce the number of potential BMPs to be evaluated, the UGSCG has grouped BMPs according to function and process in reducing pollutant loads. Each of these groups of BMPs is referred to as a PCO. Note that there could be several BMPs or variations on a BMP design that fit in a single PCO.

PCOs for the urban upland and groundwater source category are further organized into the following major load reduction elements: PSC, HSC, and, SWT. Within each of these major elements, several PCOs (groups of functionally similar BMPs) could be identified. Pollutant load reductions can be associated with each of these major elements—this organization is consistent with current Tahoe Basin practice (e.g., *Preferred Design Approach and Formulating and Evaluating Alternatives* [SWQIC 2004]) for implementation of storm water quality improvement projects in the Lake Tahoe Basin. The following definitions are used for the major load reduction elements in the UGSCG analyses.

- **Pollutant Source Controls (PSCs):** PSCs reduce the mobilization and transport of pollutants of concern at their sources. This includes sources that could be widely distributed in a catchment (e.g., land surface erosion, fertilizer applications, animal waste) and those that are more concentrated specific sources (e.g., gully erosion).
- **Hydrologic Source Controls (HSCs):** HSCs reduce runoff volumes and rates through runoff interception, infiltration, and disconnection of impervious surfaces. HSCs primarily function to increase infiltration, which routes precipitation or surface runoff to groundwater.
- **Storm Water Treatment (SWT):** SWT removes pollutants after they have entered concentrated storm water runoff flow paths. This might include treatment of flows to be infiltrated to groundwater as well as those to be discharged to surface waters.

In practice, the distinction between these groups might be blurry for particular BMPs (e.g., site restoration and revegetation could be both a PSC and HSC, or a BMP can function in different groups depending on application). However, this difficulty in definition is not particularly relevant to the problem of estimating load reductions for PCOs, where performance of a group of BMPs can be defined by representative changes in runoff concentrations or runoff volumes without focusing on the function of a particular BMP.

In a typical storm water quality improvement project, PSCs, HSCs, and SWT work together to reduce pollutant loads. The UGSCG developed a conceptual model for how these categories of PCOs interact to reduce pollutant loads in storm water management improvements in the Tahoe Basin. PCOs might be implemented in various combinations, and the effects of PSCs, HSCs, and SWT are interdependent. For example, PSCs could affect influent concentrations or HSCs could affect runoff volumes to SWT, thereby changing treatment effectiveness.

Figure 3-1 illustrates the conceptual model for evaluation of load reductions by combinations of PCOs. Because the effectiveness of PSCs, HSCs, and SWT are interdependent and because they vary with subwatershed land use and hydrologic characteristics, overall load reductions are computed by the Watershed Model. Information developed in this study and provided to the Watershed Model for each major load reduction element is indicated in **red**. The conceptual model tracks relative changes in infiltration loading as a result of PCO implementation using a simple urban infiltration mass balance (indicated in **grey**). The conceptual linkage to groundwater PSCs and potential *in situ* treatment is also represented in Figure 3-1 (*black italics*).

The conceptual model places the first opportunity for pollutant control on the application of PSCs. The anticipated benefits of PSCs are accounted for by revised EMCs for each land use. The revised land use EMCs are inputs into the Watershed Model, resulting in revised runoff EMCs for individual land uses. Although in practice some HSCs could operate at this first step in the runoff process, a parallel PSC-HSC model would be considerably more complex, and the UGSCG considers the sequential representation in Figure 3-1 adequate for estimating load reductions.

Runoff with revised EMCs is routed to the HSCs, which reduce the total storm water runoff volume through increased infiltration. In this report, the UGSCG provides sizing parameters for HSCs for use in the Watershed Model to simulate the quantities of runoff infiltrated in subwatersheds. The remainder of runoff is either discharged to surface waters or routed to SWT, which typically has both a treatment and infiltration component. When flows exceed the design capacity of SWT (also provided in this report for use in the Watershed Model), the excess flow is bypassed to discharge to surface waters.

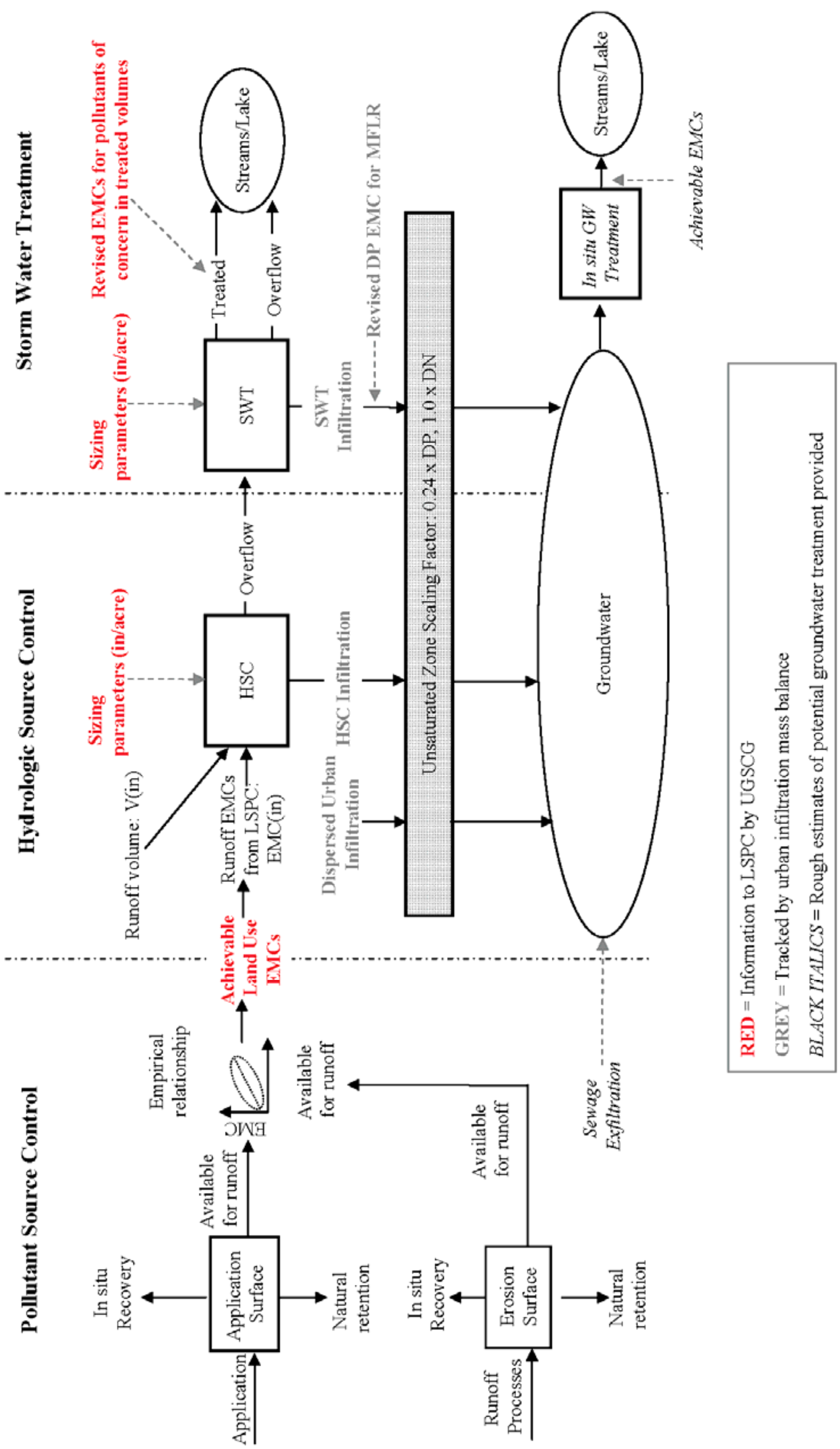

Figure 3-1. Conceptual model for PCO combination.

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Surface Water

The following section presents the urban uplands analysis of PCOs for each major load-reduction element (i.e., PSC, HSC, and SWT) associated with surface water runoff in urban uplands. The majority of PCOs in this section were developed at two levels of expected performance to provide the building blocks for formulation of two standard Treatment Tiers.

The two standard Treatment Tiers represent two levels in expected water quality performance and cost. Tier 1 represents current practice in the Lake Tahoe Basin, considering typical constraints that affect water quality improvement design and implementation. PCOs developed for Tier 1 reflect these assumptions. Tier 2 represents comprehensive application of PCOs and more advanced and intensive practices for storm water management, and places reduced emphasis on typical constraints such as land acquisition, O&M, and cost. PCOs developed for Tier 2 reflect these assumptions. On the basis of these assumptions, the estimated water quality performance of PCOs developed for Tier 1 is expected to be lower than PCOs developed for Tier 2. This section describes the development of PCOs and the basis for estimating their effectiveness. The combined use of PCOs to formulate Treatment Tiers by Setting is described in Section 3.5.

Pollutant Source Controls

The left-hand side of Figure 3-1 illustrates the conceptual approach to estimate pollutant load reductions associated with PSC. Working within the context of informing the Watershed Model, the UGSCG devised an approach to reduce the existing conditions land use EMCs shown in Table 3-1 (Lahontan and NDEP 2007) to reflect anticipated water quality performance from application of PSCs. PCOs were defined as combinations of source reduction or recovery PSCs to reduce the mass of each of the pollutants of concern available for transport. The approach considers the opportunities for PSC to be primarily the following:

- A reduction in the mass of soil and particulate materials mobilized in storm water.
- A reduction in the mass of anthropogenic pollutants applied to surfaces.
- *In situ* recovery of pollutants following erosion and mobilization of particulates or anthropogenic application. *In situ* recovery applies to activities such as street sweeping and cleaning of sediment traps to recover road abrasives and sediments that accumulate before mobilization from storm water runoff.

Table 3-1. Existing conditions EMC values for urban upland land uses

Land use category	TN (mg/L)	DN (mg/L)	T (mg/L)	DP (mg/L)	TSS (mg/L)	Fine sediment < 63 micron (% TSS)
Residential_SFP	1.752	0.144	0.468	0.144	56	76%
Residential_MFP	2.844	0.42	0.588	0.144	150	88%
CICU_Pervious	2.472	0.293	0.702	0.078	296	85%
Veg_Turf	4.876	0.487	1.5	0.263	12	63%
Residential_SFI	1.752	0.144	0.468	0.144	56	76%
Residential_MFI	2.844	0.42	0.588	0.144	150	88%
CICU_Impervious	2.472	0.294	0.702	0.078	296	85%
Roads_Primary	3.924	0.72	1.98	0.096	952	85%
Roads_Secondary	2.844	0.42	0.588	0.144	150	85%

Note: DN = dissolved nitrogen; DP = dissolved phosphorus; TSS = total suspended solids

Existing Conditions

The UGSCG identified primary processes that result in the mobilization and transport of pollutants in urban storm water to Lake Tahoe. The primary processes considered in this evaluation that mobilize sediment and nutrients are the following:

- Erosion of land surfaces such as slopes, gullies and road shoulders

The primary anthropogenic sources of pollutants considered in this evaluation are the following:

- Fertilizer applications
- Road abrasive applications and secondary pollutant accumulation (i.e., buildup/wash-off)

Opportunities exist for pollutant source reductions of both land surface and anthropogenic sources within the Lake Tahoe Basin. The rate and magnitude of erosion of Tahoe soils has been accelerated by the presence of roads and other impervious surfaces. Slopes, gullies, and road shoulders with high erosion potential can be physically stabilized to reduce total and fine sediment loading to the Lake. In addition, particles from roadways can be removed before transport in urban storm water through road sweeping activities or capture by roadside sand trap devises. Application reductions of fertilizers and road abrasives can decrease the load of nutrients and sediment generated in urban areas readily available for storm water mobilization and transport to the Lake.

The summary below describes the main urban pollutant sources that might be reduced by PSC (For more details, See Appendix UGSCG-A). Appendix UGSCG-A reviews major pollutant sources, typical current practices, opportunities for increased load reduction, and primary BMP implementation constraints on a land use basis.

Erosion of Land Surfaces and Soils

Natural hydrologic processes are modified by impervious surfaces in urban areas. During storm runoff events, precipitation that falls directly on impervious surfaces is sometimes routed to pervious surfaces, typically focusing flow in roadside ditches, gullies, and other pervious pathways. These hydrologic modifications result in accelerated particulate loss of native soils and the runoff's erosive power is increased with increasing slope of the pervious surface. Road cuts and other natural surface modifications can create localized areas of accelerated erosion. Research conducted by Grismer and Hogan (2005) in the Tahoe Basin suggests that erosion from road cuts on steep slopes (28-78 percent) yields nearly an order of magnitude greater sediment than native, undisturbed soils. Significant capital improvement efforts in Lake Tahoe urban uplands have focused upon stabilizing locations of high erosion potential and improving hydrologic routing to minimize the particulate loss at the impervious/pervious boundaries.

Fertilizer Applications

The Groundwater Framework Study for Lake Tahoe conducted by the U.S. Army Corps of Engineers (ACOE 2003a) documented fertilizer as one of the primary anthropogenic sources of nutrients to Lake Tahoe. ACOE (2003a) used existing literature and Lake Tahoe-specific land use information to estimate the annual N and P loading as a result of residential and public fertilizer applications. Aggregating all land uses where fertilizer is applied, the ACOE (2003a) estimated between 143 metric tons (MT) to 294 MT of N and 45 to 429 MT of P were applied each year within the Lake Tahoe Basin, with the greatest annual applications occurring on residential properties. The ACOE (2003a) compared these estimates to Basin-wide fertilizer applications in the 1970s by Mitchell and Reisenauer (1972) and found a steady increase. On the basis of estimates from Mitchell and Reisenauer (1972) and ACOE (2003a) of annual applications of fertilizer, the ACOE (2003a) estimates an increase in annual N application of 230 percent and an increase in annual P application on the order of 400 percent over the past 35 years.

Road Abrasive Applications

The alpine climate of Lake Tahoe requires road abrasive applications to increase motorist safety. The majority of available information reviewed by the UGSCG on winter road maintenance and roadway storm water quality data was from the California Department of Transportation (CALTRANS), Nevada Department of Transportation (NDOT), City of South Lake Tahoe, and Desert Research Institute (DRI). Though local municipalities within the Lake Tahoe Basin also provide various levels of road sanding, road sweeping, and roadway maintenance each year, the roadway maintenance records and typical practices from all local public works departments were not reviewed by the UGSCG.

Typical roadway safety techniques employed include the application of deicing salt and road abrasives during freezing and snowy conditions to reduce ice coverage and ice persistence while increasing overall automobile traction. In the 10-year period from the 1995–1996 winter to the 2004–2005 winter, the average annual application rates on California highways was 10,400 MT/yr of road abrasive and 1,180 MT/yr of deicing salt (CALTRANS 2005). While the exact amount of road abrasives ultimately transported into Lake Tahoe has not been quantified, the amount applied (10,400 MT/yr) is approximately 60 percent of the total annual suspended sediment load from urban and non-urban upland runoff. (Lahontan and NDEP 2007).

Applications are generally limited to 600 lbs (0.27 MT) of road abrasive per lane mile during each storm event, though up to 1,000 lbs (0.45 MT) are applied on particular sections or under unusual conditions (CALTRANS 2005). Both deicing salt and road abrasives are applied before and during the storm event. After the storm event, CALTRANS has employed BMPs, such as road and shoulder sweeping and sand trap placement and cleaning, to recover applied materials and reduce the water quality impact on the Lake. CALTRANS has reported an average annual sand and sediment recovery of 68 percent since 1995–1996. The recovery estimate is not limited to applied particles but likely includes native sediments as well.

The seasonal application of sediment and particles to high-traffic roadway surfaces is an anthropogenic and potentially controllable source of TSS and fine sediment. Preapplication grain size distribution studies (CALTRANS 2005) indicate that 2–3 percent of the road abrasive applied is smaller than 75 µm in diameter. However, storm water monitoring data (Table 3-1) indicates that on average, 85 percent of TSS as mass per unit volume in runoff from primary roads is smaller than 63 µm in diameter—presumably caused by pulverization of road abrasives from vehicles. Particles < 20 µm have been determined to have the greatest influence on Lake Tahoe clarity (Swift et al. 2006). While little roadway–specific, particulate grain size data for the < 20 µm size fraction exists, the 85 percent mass per unit volume estimate is likely disproportionately skewed by the heavier particles (> 20 µm).

In Situ Recovery

The primary opportunities for *in situ* recovery include the containment and removal of particulate pollutants, including the sediment fraction (< 63 µm) before the mobilization into urban storm water systems. Impervious surface PCOs include well-distributed and well-maintained sediment traps, rigorous street and road-shoulder sweeping and other particulate-recovery activities to minimize the load of particulates that can be transported in subsequent runoff events to the Lake.

PCOs for Pollutant Source Control

A variety of BMPs are applicable to the sources described above. Application of particular BMP designs is highly variable because of land use characteristics, space and slope constraints, political jurisdictions, and non-water quality objectives (e.g., traffic safety) associated with BMP implementation. Because of high variability in BMP application, consideration of individual BMPs or BMP types in this evaluation was not considered effective. Instead, PCOs are identified mainly by function in addressing particular sources, and their performance is estimated in *lumped* fashion for groups of BMPs applied to particular land uses.

The UGSCG identified PCOs that directly address opportunities to

- Reduce the risk of pollutant generation and mobilization by land surface erosion
- Reduce the contribution of anthropogenic pollutants to the natural Lake Tahoe budget
- Increase the recovery of particulate pollutants before introduction into the urban storm water runoff

Table 3-2 presents the four PCOs developed by the UGSCG for PSCs, where each PCO consists of a group of typical BMPs. The PCOs presented in Table 3-2 are categorized according to the land uses where they most generally apply. This categorization by groups of land uses facilitates incorporation into the Watershed Model (Section 6) with other PCOs that apply to similar land uses. PCOs are identified for each land use group with two levels of expected performance (indicated by Tier 1 and Tier 2; for details, See Section 5). This organization facilitates later use to formulate Treatment Tiers by combining PSCs, HSCs, and SWT in particular Settings (Section 4). The estimated confidence the UGSCG has in determining achievable EMC values for each PCO are provided in Table 3-2. (Confidence scale: 1 = low confidence, 5 = high confidence)

Table 3-2. PSCs included in UGSCG analyses

PCO	Example BMPs	Applicable urban upland land uses	Confidence
PSC-1 Tier 1	a. Road drainage system stabilization, sand trap installation, slope stabilization, and revegetation b. Minimal change in abrasive application rates c. Particulate recovery strategies focused on inter-storm removal in locations with greatest accumulation of particulates.	Roads_Primary; Roads_Secondary; CICU_Impervious	3
PSC-1 Tier 2	a. Road drainage system stabilization, sand trap installation, slope stabilization, and revegetation b. Advanced deicing strategies c. Rigorous and advanced particulate recovery strategies including sweeping, vacuuming and sand trap vactoring d. High performance is assumed for the above measures—increased enforcement or incentives might be needed as an integral part of the PSC.	Roads_Primary; Roads_Secondary; CICU_Impervious	3
PSC-2 Tier 1	a. Encourage P application reductions/elimination, suggest fertilizer management plans. Assume 10% increase in compliance. b. Slight increase in management and educational involvement	Veg_Turf	4
PSC-2 Tier 2	a. Advance turf management strategies and education direction to turf managers. b. Targeted and informed reductions in annual N and P fertilizer applications	Veg_Turf	3

PCO	Example BMPs	Applicable urban upland land uses	Confidence
	c. High performance is assumed for the above measures—increased enforcement or incentives could be needed as an integral part of the PSC.		
PSC-3 Tier 1	a. Private BMP implementation including soil stabilization, driveway paving, and so on as currently defined by TRPA.	Residential_SFP; Residential_SFI; Residential_MFP; Residential_MFI; CICU_Pervious	3
PSC-3 Tier 2	a. Private BMP implementation including soil stabilization, driveway paving, and so on, as currently defined by TRPA.		3
	b. Control of over-the-counter fertilizer sales.		
	c. Control of nonnative plant sales in the Basin and public education regarding Lake Tahoe-friendly landscaping.		
	d. Increase in individual stewardship of all private land owners.		
	e. High performance is assumed for the above measures—increased enforcement or incentives could be needed as an integral part of the PSC.		

Note: TRPA = Tahoe Region Planning Agency

PSC-1 through PSC-3 span one or more urban land use categories and apply directly to urban storm water load generation. Separate PCOs were created for private and public property based on differences in opportunities for implementation and funding. For publicly owned land, separate PCOs were developed for pervious surfaces and impervious surfaces because of different implementation opportunities and pollutants of concern. PCOs for roadways and Commercial/Institutional/Communications/Utilities (CICU) impervious surfaces are assumed to be similar in function and include BMPs focused on reducing particulate pollutant mobilization from impervious surfaces. In contrast, land uses such as vegetated turf and golf courses include BMPs focused on reducing nutrient pollution to downstream resources. On private properties, BMP implementation and pollutant load reduction efforts on pervious and impervious surfaces are often integrated, with the exception being the reduction of residential and CICU fertilizer application on pervious surfaces.

Quantification of Performance

The Watershed Model uses land-use-based EMCs for pollutants of concern. The UGSCG approach assumes that the implementation of PCOs for pollutant source control (PSC) will equate to sustainable land use based EMCs that are lower than the characteristic EMCs for the existing conditions of urban upland land uses (See Table 3-1). The UGSCG used storm water quality data from the Lake Tahoe Basin and data from outside the Lake Tahoe Basin (where appropriate), to estimate achievable land use EMCs on the basis of assumed PCO application to a specific urban upland land use. This approach was selected because it allows for future revision and refinement through additional performance monitoring and additional literature review of achievable EMCs for the pollutants of concern.

The UGSCG began the PCO performance analysis by qualitatively documenting and evaluating existing storm water quality conditions and current general land use activities. On the basis of existing conditions, the UGSCG identified opportunities and constraints for increasing PSC efforts, and then qualitatively defined the collection of BMPs and management strategies that compose each of the PCOs contained in Table 3-2. The qualitative descriptions of PSC-1, PSC-2, and PSC-3 pertain to urban upland storm water and are provided below. Recommended control options for groundwater (e.g., PSC-4) are presented in the Groundwater section.

The revised land-use-based EMCs for each Treatment Tier are presented in Table 3-3. The goal of the EMC adjustments was to use existing data and best professional judgment to estimate achievable EMC values for each pollutant of concern within each land use category given the implementation of PCOs. The achievable EMC values presented in Table 3-3 are based on the aggregated implementation of all the BMPs and management actions in a PCO for each land use. Appendix UGSCG-A provides more detail on the procedure, data sources, assumptions, and technical information used to generate the achievable EMC values provided in Table 3-3. Nutrient and TSS values are reported as mg/L in Table 3-3. Fine sediment is reported as the fraction (%) of TSS smaller than 63µm.

Table 3-3. EMCs for existing conditions, Tier 1, and Tier 2

PSC	Applicable urban upland land use category	Pollutant of concern	Existing conditions EMC	Tier 1	Tier 2
PSC-1	Roads_Primary	TN	3.924	2.962	2.00
		DN	0.72	0.705	0.600
		TP	1.98	1.173	0.367
		DP	0.096	0.061	0.021
		TSS	951.6	538	124
		Fine Sed. (%TSS)	85%	85%	85%
	Roads_Secondary	TN	2.844	2.322	1.80
		DN	0.420	0.420	0.378
		TP	0.588	0.407	0.225
		DP	0.144	0.120	0.096
		TSS	150	100	50
		Fine Sed. (%TSS)	85%	85%	85%
	CICU_Impervious	TN	2.472	2.136	1.80
		DN	0.294	0.195	0.096
		TP	0.702	0.536	0.37
		DP	0.078	0.050	0.022
		TSS	296.4	204	112
		Fine Sed. (%TSS)	85%	85%	85%
PSC-2	Veg_Turf	TN	4.876	4.388	2.38
		DN	0.487	0.438	0.350
		TP	1.5	1.350	0.363
		DP	0.263	0.263	0.237
		TSS	12	12	10.8
		Fine Sed. (%TSS)	63%	63%	63%
PSC-3	Residential_SFP	TN	1.752	1.577	0.467
		DN	0.144	0.130	0.055
		TP	0.468	0.421	0.199
		DP	0.144	0.130	0.028
		TSS	56.4	38	38

PSC	Applicable urban upland land use category	Pollutant of concern	Existing conditions EMC	Tier 1	Tier 2
		Fine Sed. (%TSS)	76	76	76
	Residential_MFP	TN	2.844	2.560	1.598
		DN	0.42	0.378	0.289
		TP	0.588	0.529	0.437
		DP	0.144	0.130	0.07
		TSS	150	56.4	56.4
		Fine Sed. (%TSS)	88%	88%	88%
	CICU_Pervious	TN	2.472	2.136	1.800
		DN	0.293	0.195	0.096
		TP	0.702	0.536	0.37
		DP	0.078	0.050	0.022
		TSS	296.4	204	112
		Fine Sed. (%TSS)	85	85	85
	Residential_SFI	TN	1.752	1.577	0.467
		DN	0.144	0.130	0.055
		TP	0.468	0.421	0.199
		DP	0.144	0.130	0.028
		TSS	56.4	38	38
		Fine Sed. (%TSS)	76%	76%	76%
	Residential_MFI	TN	2.844	2.560	1.598
		DN	0.42	0.378	0.289
		TP	0.588	0.529	0.437
		DP	0.144	0.130	0.07
		TSS	150	56.4	56.4
		Fine Sed. (%TSS)	88%	88%	88%

The UGSCG approached the quantification of the PSC performance as follows:

- A combination of existing data, geochemical fate and transport assumptions, and best professional judgment were used to assign achievable EMC values assuming PCO implementation as outlined in this report.
- Existing storm water data from a variety of sources was used to estimate achievable EMCs for each urban upland land use given the implementation of the relevant PCO. Existing reports, data and information compiled and reviewed included Tahoe-specific and statewide data from CALTRANS, NDOT, DRI, Tahoe Environmental Research Center (TERC), and 2NDNATURE.
  - Land-use-specific storm water quality data from 2NDNATURE (2006a) is a synthesis of 25 different Lake Tahoe BMP quantitative performance evaluations from which storm water quality influent to the respective BMPs across land-use types were employed.
  - Effluent water quality data from roadway BMP evaluations by NDOT and DRI were used to determine achievable Tier 2 values for roadway BMPs. Data from outside the Lake Tahoe Basin, including CALTRANS and the National BMP Inventory Database, were

also reviewed in an effort to quantify achievable EMC values for each land use following the implementation of PCOs.

- Achievable EMC values for Tier 2 were determined on the basis of a variety of applicable data sources (See Table A-2 in Appendix UGSCG-A). The main data sources used, in order of priority were (1) Tahoe-specific storm water monitoring data representing from specific urban upland land uses; (2) statewide or other applicable storm water monitoring data; and (3) existing conditions EMCs from other land uses representing desired pollutant generation conditions. When multiple applicable data sources were available, the lowest value observed was assigned for Tier 2. For example, PSC-3 Tier 2 assumes complete implementation of the residential BMPs on 100 percent of all the Residential properties within the Lake Tahoe Basin. Using a collection of Lake Tahoe specific storm water quality observations in runoff emanating from land uses designated Residential, the minimum annual EMC value from all sites (up to eight) for each pollutant was assumed to be achievable as a result of PCO implementation in Tier 2.
- Achievable EMC values for Tier 1 are assumed to improve water quality relative to existing conditions (Table 3-1) but provide less pollutant reduction than Tier 2. To estimate achievable EMCs from PCO implementation in Tier 1, achievable EMCs developed for Tier 2 were considered *book-end values*. Using this assumption, the Tier 1 achievable EMCs were estimated to be between existing conditions EMCs and Tier 2 EMCs on the basis of the assumed efficacy of current practices (See Table A-3 in Appendix UGSCG-A).
- Existing EMC values express fine sediment as a percent of TSS (See Tables 3-1 and 3-3). Given the minimal amount of existing data and research regarding the fate and transport of fine sediment, the UGSCG assumed the relative fraction of fine sediment to TSS does not change from the existing condition estimate.

A summary of the main data sources and rationale for EMC adjustment within each PCO are discussed below.

PSC-1: Land Uses—Roads_Primary; Roads_Secondary; CICU_Impervious

Achievable EMCs were estimated primarily on the basis of roadway storm water monitoring and BMP performance evaluations conducted by CALTRANS, NDOT, TERC, and DRI within the Tahoe Basin. Achievable storm water quality conditions were also considered using CALTRANS roadway water quality monitoring conducted in areas devoid of deicing needs throughout California. Additional data sources included commercial land use runoff pollutant EMCs from Gunter (2005).

The UGSCG assumed that implementation of PSC-1 in Tier 2 (Table 3-2) would significantly reduce pollutant generation from road abrasive application/transport and road shoulder erosion. To represent this performance, the UGSCG used average effluent EMCs from roadway BMPs (NDOT and DRI studies), average Tahoe summer thunderstorm runoff EMCs, and average California statewide nonurban runoff EMCs. Multiple data sources were often available for each pollutant of concern. Therefore, the lowest average values were chosen to represent the achievable EMCs under Tier 2. Caution was used in estimating EMC reductions for DN on impervious surfaces, and to a lesser extent TN, because of the likelihood that PSC-1 might have a small impact on N generation and accumulation on impervious surfaces. Additional DN and TN reductions on impervious surfaces are expected to result from the Atmospheric SCG, which targets atmospheric reductions in vehicular and fire loading to TN and DN.

The CICU impervious land use category is included in PSC-1 because pollutant load-reduction opportunities and PCO application are assumed similar to primary and secondary roads (e.g., decreased road abrasive application, increased fine sediment recovery via sweeping and sand trap installation and maintenance). Therefore, achievable EMCs for the CICU impervious land use were adjusted using both

Gunter (2005) data and CALTRANS data to represent anticipated performance following PCO implementation.

PSC-2: Land Use—Veg_Turf

The primary local data source for evaluating the impact of fertilizer management on surface water nutrient concentrations is a study conducted by 2NDNATURE on the Village Green ballfield in Incline Village, Nevada (2NDNATURE 2007). The report provides five years of water quality monitoring data down gradient of a 100 percent vegetated turf land use. Observations compare conditions during significant application of fertilizer containing P followed by three seasons where P applications were eliminated. Achievable EMCs for TN, DN, and TP were set to the 25th percentile of all turf runoff concentrations from the Village Green vegetated turf surface for Tier 2. The existing conditions TSS and DP EMCs were determined to approach the achievable EMC values and were reduced by 10 percent under Tier 2.

Under Tier 1, the UGSGC assumed that only minimal decreases in achievable EMCs could be accomplished through continued use of non-mandatory turf management strategies on public pervious surfaces.

PSC-3: Land Use—Residential_SFP; Residential_SFI; Residential_MFP; Residential_MFI; CICU_Pervious

The existing conditions EMCs do not differentiate the water quality of runoff from impervious and pervious surfaces on residential and commercial land uses (Tables 3-1 and 3-3). For consistency with Phase One and recognizing a lack of sufficient data to reasonably differentiate between impervious and pervious runoff concentrations in these land uses, the UGSCG adjusted all pervious and impervious achievable EMCs similarly for Residential_SFP, Residential_MFP, and CICU_Pervious land uses.

Gunter (2005) is the primary source of storm water monitoring data used to estimate achievable EMCs emanating from residential properties in the Tahoe Basin, though other Tahoe-specific residential data sources were also reviewed. Sites evaluated in Gunter (2005) were divided between low-density residential (Residential_SFP/SFI), high-density residential (Residential_MFP/MFI), and CICU_Pervious on the basis of the land-use contribution to the water quality monitoring site. For each land-use category and pollutant of concern, the site with the minimum mean EMC observed over 2 years of monitoring was assumed to represent achievable EMCs for each pollutant of concern under Tier 2.

Confidence in Performance Estimates

The most significant limitation of confidence in the UGSCG determination of achievable EMCs is the lack of data integration and robust assessment tools to analyze the extensive storm water quality monitoring data that has been collected in Lake Tahoe over the past few decades. The majority of land-use-based storm water quality data was extracted from summary tables presented in individual evaluation reports, as well as mean, minimum, and maximum EMC values from specific monitoring sites. Future efforts to statistically integrate Tahoe-specific, storm water monitoring data will improve the confidence in land use based achievable EMC values for each pollutant of concern. The ability to statistically integrate water quality observations according to the subwatershed conditions, drainage characteristics, and the intensity of BMP implementation across similar land-use types will increase confidence in the existing conditions as well as predicted, achievable EMC values.

A number of the general limitations associated with the confidence in the quantification of achievable EMCs are described below. However, regardless of the current limitations associated with accurate quantification of achievable EMCs and load reductions as a result of PCO implementation of PSC, the UGSCG has very high confidence (ranking of 5) that committed, diligent, and sustained implementation of the PCOs presented in Table 3-2 will result in measurable, long-term reductions in the annual pollutant loads to the budgets of all of the six pollutants of concern.

1. Pollutants of concern are inconsistent across many existing storm water quality reporting efforts, and fine sediment (the primary pollutant of concern with respect to Lake Tahoe clarity) data is extremely sparse. In addition, minimal water quality data exists on pollutant EMC values from areas containing 100 percent coverage of a specific land-use category. Given the existing data, best professional judgment was a primary factor in determining achievable land use EMC values from PCO implementation.

2. The EMCs potentially necessary to achieve water quality objectives for Lake Tahoe are fairly low relative to what typical municipalities are trying to achieve. Therefore, the majority of data sources outside the Tahoe Basin are not extremely useful for this effort. In some cases, the existing low levels of certain nutrient and sediment EMC values observed in Lake Tahoe could be close to achievable storm water quality, given the presence of human activities. The Tahoe Basin community will need to be an innovator of advanced storm water practices and monitoring of advanced practices.

3. The UGSCG used a very limited, but reasonably representative, set of data sources to best approximate achievable EMC values for each urban upland land use assuming successful implementation and rigorous maintenance of PCOs. However, very limited data is available on the effects of maintenance on PCO performance.

4. There is an extremely limited amount of accessible and applicable fine sediment distribution data from the Tahoe Basin and elsewhere. The Lake Tahoe TMDL EMC existing conditions characterize fine sediment as a fraction of TSS, resulting in an inherent reduction in fine sediment load as the EMC of TSS is adjusted due to PCO application. Because of the lack of available data, the relative distributions of fine sediment were unchanged for PCO application. Because fine sediment has recently been considered the most critical pollutant of concern for Lake clarity, future focused investigations addressing the fine sediment generation and PSC impacts on fine sediment loading is advisable to improve load-reduction estimates.

5. The structure of the Watershed Model, which characterizes specific EMC values for unique land-use types to generate area-weighted pollutant loading, provides future hypothesis testing opportunities for storm water monitoring efforts. Many opportunities exist to improve the accuracy of the land use EMC values for existing and anticipated future conditions by (1) standardizing water quality data collection, (2) developing and maintaining a functional water quality storm water database, (3) prioritizing future water quality monitoring to constrain sites that represent a specific land use category, and (4) defining rigorous statistical methods to consistently reduce large data sets and identify representative land use EMC values. Future monitoring efforts can be designed to focus on specific land use characteristics to better constrain existing conditions EMC values, as well test specific pre- and post-PSC implementation storm water quality monitoring to continue to refine our estimates of *achievable* EMC values for PCO implementation of PSC.

Hydrologic Source Controls

Existing Conditions

Major sources of urban upland runoff are generated from impervious areas associated with the following urban upland land uses: roads, single-family residential (SFR), multifamily residential (MFR), and CICU. Impervious area has altered the hydrologic function of urban uplands in the Tahoe Basin by changing physical processes associated with infiltration, runoff collection, and runoff routing. The typical result from modifications to these physical processes is an increase in surface runoff peak flows, total surface runoff volumes, and flow durations capable of producing erosion downstream. The changes in runoff characteristics could lead to any of the following effects that are water quality concerns: (1) increased erosion in a drainage system; (2) increased erosion in streams downstream; (3) increased delivery of pollutants collected on impervious surfaces, and (4) decreased efficiency for storm water treatment because of high hydraulic loading rates or bypasses of significant runoff volumes or peak flows.

PCOs for Hydrologic Source Control

The UGSCG considered a range of PCOs to address runoff from impervious area associated with the land-use-based sources described above. This range included PCOs for (1) redirecting runoff between drainage catchments, (2) decreasing runoff generated, (3) decreasing runoff reaching the catchment outlet, and (4) implementing private-property BMPs to detain and infiltrate runoff.

The PCO for redirecting runoff between drainage catchments was excluded from the UGSCG analysis because quantifying this opportunity is very site-specific and was not practical for the UGSCG to estimate within the context of this broader, Basin-wide analysis. Additionally, the HSC effects from decreasing runoff generated and the HSC effects from decreasing runoff reaching the catchment outlet were combined because of the similar function these processes serve. Ultimately, this led to two specific types of PCOs included in the UGSCG analysis of HSC: (1) decreasing runoff reaching the catchment outlet, and (2) implementing private-property BMPs to detain and infiltrate runoff.

HSCs were categorized by similar function and by application to urban upland land uses. This approach was taken to simplify the assessment of HSCs and to provide reasonable tools to estimate performance in subsequent steps for simulations in the Watershed Model. The UGSCG has defined three specific HSCs, as shown in Table 3-4. Examples of typical BMPs that accomplish the intended function of the HSC, as well as the land uses where the HSC generally applies are shown in Table 3-4. HSC-1 and HSC-2 accomplish the same function but are included as separate PCOs to provide a varying degree of performance. HSC-1 and HSC-2 are applied to impervious surfaces associated with roads. HSC-3 is applied to impervious surfaces associated with SFR, MFR, and CICU. HSC-3 captures the function of private property BMPs in the Tahoe Basin, assuming most of the CICU coverage is associated with private enterprise.

Table 3-4. HSCs included in UGSCG analyses

PCO		Example BMPs	Applicable urban upland land uses	Confidence
HSC-1	Decrease runoff reaching catchment outlet on moderate slopes	a. Impervious area and soft coverage removal b. Routing impervious runoff to pervious area c. Pervious pavement	Impervious surfaces associated with Secondary Roads and Primary Roads	3

PCO		Example BMPs	Applicable urban upland land uses	Confidence
HSC-2	Decrease runoff reaching catchment outlet on steep slopes	a. Impervious area and soft coverage removal b. Routing impervious runoff to pervious area c. Perforated piping d. Infiltration trenches	Impervious surfaces associated with Secondary Roads and Primary Roads	3
HSC-3	Private BMPs to detain and infiltrate runoff	a. Percolation trench b. Slotted drain c. Drywell d. Pervious pavement e. Prefabricated infiltration system	Impervious surfaces associated with SFR, MFR, and CICU	4

Quantification of Performance

The quantification of HSC performance is dependent on the specific PCO, but it is relatively simple conceptually, as illustrated in Figure 3-1. Calculations of long-term HSC effectiveness are simulated in the Watershed Model, where runoff (and infiltration in HSCs) can be computed over long periods in a series of short time steps. Runoff from impervious surfaces is routed to an HSC with a specified storage volume and infiltration rate. Runoff is infiltrated on a continuous basis in the simulation unless runoff exceeds the storage volume of the HSC. In this case, the calculated infiltration is routed to groundwater, and overflow is routed as surface flow.

The following key assumptions were made by the UGSCG and apply to the performance of all HSCs and the incorporation of HSCs into the analyses:

- HSCs are applied only to the impervious land uses within urban uplands. The significant fraction of runoff generated in urban uplands is from impervious land uses. Applying HSCs on a fraction of the pervious land uses within the urban uplands is not within the resolution of the current Watershed Model and is not likely to generate substantial changes in total computed runoff volume.
- HSCs create pollutant load reductions in surface water through reduction in volumes of runoff. To simplify the analysis and facilitate representation in the Watershed Model, HSCs do not alter concentrations in surface storm water runoff and do not reduce pollutant source generation downstream.
- HSCs increase the volume of storm water infiltrated to groundwater and can reduce concentrations in the infiltrated storm water through soil filtration and adsorption.
- Design criteria developed for each HSC are based on storage and infiltration of runoff from one acre of impervious area. This unit area assumption provides a scalar approach to simulating HSCs in the Watershed Model.
- Infiltration in HSCs is a represented by a constant rate and is based on relatively conservative hydraulic conductivity values (James and James 2000). This approach was taken to account for non-ideal conditions during the continuous simulations, such as frozen soils and decreased infiltration capacity over time.

Table 3-5 lists specific design assumptions for each HSC. HSC-1 and HSC-2 represent the disconnection and distribution of impervious runoff to pervious surfaces for subsequent infiltration. HSC-1 and HSC-2 were separated on the basis of the severity of slopes at the point of application. The rationale for this approach is based on two assumptions that affect storage and infiltration: (1) moderate slopes promote more distributed flow paths, ponding, and temporary storage of runoff relative to steeper slopes; and (2) moderate slopes convey runoff at lower velocities allowing for slightly longer hydraulic residence times across pervious surfaces. Both of the assumptions were used to develop design criteria for infiltration and storage of HSC-1 and HSC-2. Data sources for infiltration were consulted (e.g., 1974 & 2006 NRCS Soil Surveys, local county design manuals), however, the spatial variability of infiltration is too great and site specific to incorporate into the broad-scale analyses performed by the UGSCG. Consequently, the design assumptions for HSC-1 and HSC-2 include relatively conservative values for hydraulic conductivity for a water quality assessment.

Table 3-5. Design assumptions for HSC influencing performance

PCO	PCO description	Design assumptions
HSC-1	Decrease runoff reaching catchment outlet on moderate slopes	Routing = 0.1 acre of pervious land receives and infiltrates runoff from 1 acre of impervious area
		Depth of overland flow = 0.1 feet
		Hydraulic Conductivity = 0.3 inch/hr
HSC-2	Decrease runoff reaching catchment outlet on steep slopes	Routing = 0.1 acre of pervious land receives and infiltrates runoff from 1 acre of impervious area
		Depth of overland flow = 0.05 feet
		Hydraulic Conductivity = 0.2 inch/hr
HSC-3	Private BMPs to detain and infiltrate runoff	Storage = 1 inch/impervious acre
		Hydraulic Conductivity = 0.3 inch/hr

HSC-3 represents the detention and infiltration of runoff associated with impervious surfaces for predominantly private land uses (i.e., SFR, MFR, and CICU). HSC-3 is the hydrologic reduction component or private property BMP implementation. Unlike HSC-1 and HSC-2, HSC-3 is associated with a regulatory requirement and thus a design standard is available, which lends itself to a simple quantification of performance. The specific regulation (TRPA 2004) Chapter 25 – Best Management Practice Requirements) requires containment, at a minimum, of the storm water runoff volume generated by a 20-year return period, 1-hour duration *design storm* from impervious surfaces. The calculation of runoff volume is made by multiplying the intensity of the 20-year, 1-hour design storm (generally taken as 1 inch of rain in 1 hour) by the impervious surface area. Therefore, the design assumption for HSC-3 is storage of 1 inch of runoff per impervious acre. Data sources consulted include TRPA regulations and the BMP sizing worksheet available at http://www.tahoebmp.org/documents.aspx. The use of this design criterion for HSC-3 is a reasonable approach for storm water management in the Basin. Geosyntec Consultants (2005) estimated that more than 85 percent of the runoff volume can be captured on an average annual basis using this design criterion.

Figure 3-2 illustrates the estimated PCO performance of each HSC according to the design assumptions described above. Figure 3-2 displays the estimated volume of runoff that can be detained or infiltrated in a 1-hour time step during model simulations. The volume is presented in inches for an impervious acre, which is the format that is used by the Watershed Model to extrapolate the effects of PCO application for HSCs to the urbanized portions of the Tahoe Basin.

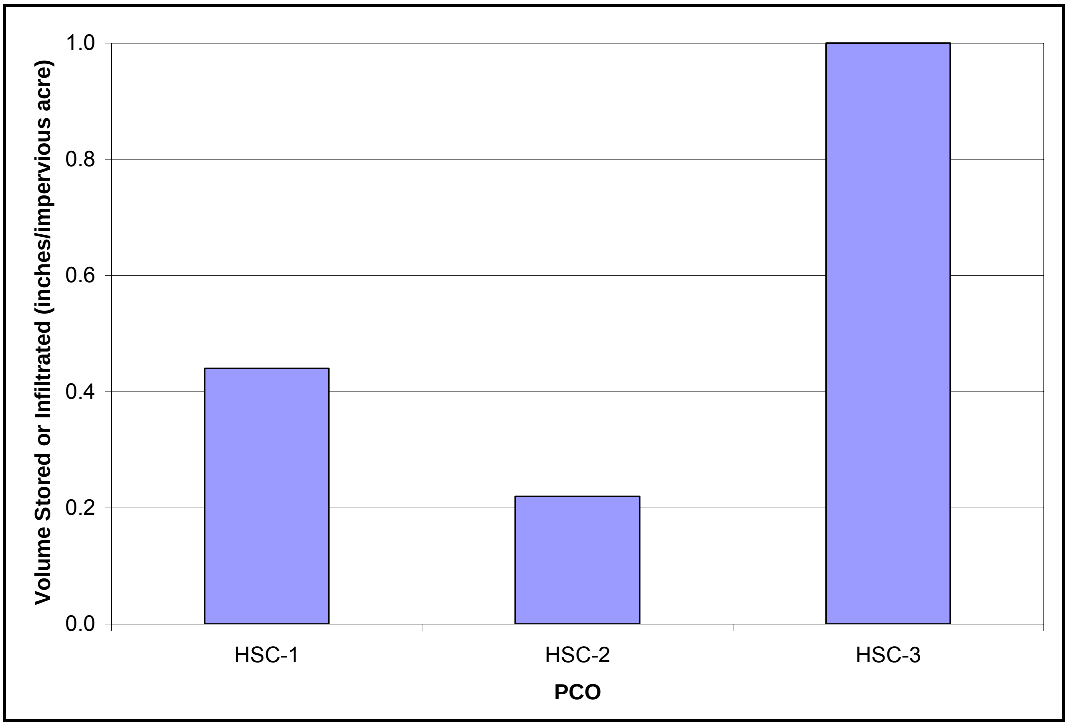

Figure 3-2. Volume of runoff stored or infiltrated in a 1-hour time step.

Confidence in Performance Estimates

The confidence associated with estimating the performance of HSCs is relatively high because the primary function of an HSC (storage/infiltration) is relatively simple to simulate in runoff models compared to the highly variable pollutant loads associated with PSCs or the chemical and biological processes associated with SWT. Although uncertainty in hydrologic estimates is considered relatively low compared to the many factors affecting PSC or SWT, considerable uncertainty can be associated with infiltration properties of the soil and effects of shallow groundwater. When HSCs are intensively loaded hydraulically with tributary impervious area, performance uncertainty increases because of limitations in estimating long-term soil infiltration capacity in relationship to runoff volumes.

A necessary modeling assumption made by the UGSCG is a constant infiltration rate for each HSC. However, infiltration rates are highly variable depending on localized conditions and temporal effects such as a high seasonal groundwater table. Confidence ratings for each HSC were listed in Table 3-2. A rating of 3 was assigned to HSC-1 and HSC-2 because assumptions for infiltration and storage were based primarily on professional judgment. A rating of 4 was assigned to HSC-3 because design assumptions are based on a regulatory standard that typically ensures consistent performance.

Storm Water Treatment

N, P, and fine sediment have been identified as the primary pollutants of concern affecting Lake clarity in the Tahoe Basin. The treatability of these pollutants in storm water BMPs is highly dependent on the phase and species present in the runoff, as well as the unit treatment processes provided by the BMP. N is often present in storm water as dissolved species that can effectively be removed only by biological denitrification and vegetative uptake processes, which is largely the reason wetland systems and wet ponds have been shown to provide effective treatment. P is often highly particulate-bound in storm water, and the dissolved fraction can be readily adsorbed or precipitated. However, surface complexation reactions can be reversed in variable redox environments (such as seasonally wet meadows), which can lead to the release of previously captured P species. Even in the runoff water itself, the concentrations of

DP are buffered by a chemical equilibrium with the particulate-P fraction (Froelich 1988). While some fine sediment can be removed by physical sedimentation processes, generally particles smaller than 25 µm require coagulation/flocculation or filtration (Geosyntec Consultants 2005).

Existing Conditions

In addition to more spatially distributed PCOs (PSCs and HSCs) that have been implemented in the Tahoe Basin, many different treatment BMPs such as detention basins, wet ponds, wetlands, sand filters, underground vaults, and hydrodynamic devices have also been used to improve the quality of storm water runoff (Geosyntec Consultants 2005; 2NDNATURE 2006a; NTCD 2005). Available monitoring data indicate that the best performing BMPs in terms of effluent quality are wet pond/wetland basin type treatment systems for TSS and N and media filters for P (Geosyntec Consultants 2005). Detention basins, sediment retention ponds, and hydrodynamic separators, which are perhaps the most widely implemented structural BMPs in the Tahoe Basin for removing sediment, do not typically remove dissolved nutrients significantly below influent concentrations (2NDNATURE 2006a). The use of coagulants/flocculants or filtration media specifically engineered to sorb dissolved nutrients could be necessary to meet discharge targets for these constituents (Heyvaert et al. 2006a; Bachand et al. 2006a, 2006b; CALTRANS 2007).

Selecting a BMP for a location is generally based on the land use being treated, agency-accepted practices, and site-specific constraints. There does appear to be a preference for surface detention on the California portion of the Lake Tahoe Basin as opposed to underground vaults on the Nevada portion (NTCD 2005), which could be from a number of factors such as cost, space availability, differences in land forms, or typical engineering practice. The Nevada portion of the Basin generally has steeper slopes in the urbanized areas, which places constraints on the construction of surface impoundment basins.

PCOs can include one or more BMPs designed to remove pollutants via physical (e.g., sedimentation), biological (e.g., vegetative uptake), or chemical (e.g., coagulant dosing) treatment processes. These BMPs are generally placed at the downstream end of a significant drainage catchment or subwatershed but could also be somewhat distributed within the primary urban drainage system to capture and treat impervious area runoff before mixing with natural streams and channels. For example, hydrodynamic devices could be installed at multiple outfalls to a stream in the subwatershed.

On the basis of the pollutants of concern and the treatment processes needed to address these, all PCOs must, at a minimum, include sedimentation or filtration processes. Treatment BMPs typically implemented in existing practice include these minimum treatment options, but to adequately and consistently achieve effluent quality targets, BMPs that provide biological or chemical processes in addition to more advanced physical treatment mechanisms might be necessary. A storm water treatment train that uses several BMPs or BMP components to first reduce flow rates and volumes and then successively reduce smaller and smaller particles until all pollutants of concern are adequately addressed is the preferred conceptual design (Strecker et al. 2005). The steps of this approach are summarized as follows:

1. Minimize flow rates or volume of runoff from the urbanized drainage area (HSC).
2. Remove bulk solids (pretreatment: > 5 mm)
3. Remove settleable solids and liquid floatables (coarse primary conventional treatment: >75 µm; fine primary conventional treatment TSS: >10 µm)
4. Remove suspended and colloidal solids (secondary conventional treatment: > 0.1–25 µm)
5. Remove colloidal, dissolved, volatile, and pathogenic constituents (enhanced treatment)

As discussed above, existing engineering practice for BMP implementation in Lake Tahoe does not necessarily follow this conceptual treatment train approach. While many advanced treatment BMPs are being implemented and evaluated in Tahoe (e.g., Tahoe City Wetland Treatment System; Heyvaert et al. 2006b), current practice regarding BMP selection and design, in general, seems to be driven more by design storm criteria (i.e., 1-hour, 20-year storm) and physical constraints (e.g., steep slopes, space limitations) than by the unit treatment processes needed to address the pollutants of concern. Therefore, selecting PCOs for Basin-wide evaluation of urban upland BMP implementation should not only take into account site constraints, but also whether existing practices or a more advanced treatment train approach that takes into account the pollutants of concern and relevant unit processes should be considered. For example, existing practice BMPs include extended detention basins, sediment traps, underground vaults, and hydrodynamic separators. More advanced BMPs can include media filters, vegetated filters, wet ponds, wetland systems, or a combination of these.

PCOs for Storm Water Treatment

Because site-specific conditions and constraints cannot be adequately characterized for the evaluation of BMP implementation at a Basin-wide scale, storm water BMPs are grouped into PCOs for SWT. Four different PCOs were developed on the basis of categorizing conventional storm water treatment BMPs according to their primary treatment mechanisms and the level of treatment provided. Table 3-6 identifies PCOs by each primary treatment function, the bypass mechanism for each PCO, typical BMPs that accomplish the intended function, and the confidence related to estimating the performance of the PCO. Unlike PSCs and HSCs described above, SWTs are generally not land-use based, being more often applied to combined runoff from many different land uses.

Table 3-6. SWTs included in UGSCG analyses

PCO		Bypass mechanism	Example BMPs	Confidence
SWT-1A	Surface detention and sedimentation	Vstored > Vmax	Detention basin Sediment basin	4
SWT-1B	Surface detention and sedimentation with biological/chemical treatment processes	Vstored > Vmax	Retention pond Infiltration basin Wetland Basin	3
SWT-2A	Mechanical separation	Qin > Qmax	Prefabricated vault Hydrodynamic device	4
SWT-2B	Mechanical separation with media filtration	Qin > Qmax	Media filter Sand filter	2

Quantification of Performance

SWT performance is based primarily on (1) the quantity of runoff captured and (2) the achievable effluent quality for the captured volume. The quantity of runoff captured is a direct function of the design treatment capacity, which includes both storage volume and discharge rate. The current design standard for Lake Tahoe is the runoff volume from a 20-year, 1-hour rainfall event, which is approximately a 1-inch rainfall depth (Geosyntec Consultants 2005).

For volume-based PCOs, a recommended extended detention drawdown time is approximately 48 hours to maximize sedimentation of fine particulates without providing conditions that promote mosquito breeding. For most regions of the Tahoe Basin, if a PCO is sized to store 1-inch of runoff (0.08 acre-foot per acre) with a 48-hour drawdown rate, Geosyntec Consultants (2005) estimated that more than 85 percent of the runoff volume can be captured and more than 50 percent of fine sediment could be removed through settling. For flow-based PCOs, Geosyntec Consultants (2005) estimated that a flow rate of approximately 0.07 cfs/impervious acre could achieve greater than 85 percent runoff volume capture. However, the project team has noted that this design flow rate might not be adequate for many areas of the Lake during rain-on-snow events. A cursory investigation of runoff hydrology using 8 years of rainfall and temperature data from the Marlette SnoTel weather station (John Riverson, personal communication 2007) indicates that a design flow of approximately 0.1 cfs/impervious acre could capture 90 percent of the runoff. On the basis of this assessment of treatment capacity, volume-based PCOs (SWT-1A and SWT-1B) are assumed to be designed for a 1-inch of rainfall over the impervious area of the watershed, and drawdown time will be 48 hours. Flow-based PCOs (SWT-2A and 2B) are assumed to be designed for 0.1 cfs/impervious acre.

The achievable effluent quality of treatment BMPs is a function of numerous environmental conditions and specific design characteristics that must be known to adequately model individual unit treatment processes such as settling, adsorption, nutrient uptake, and biological degradation. An alternative to modeling individual unit treatment processes is to use an effluent quality approach that groups BMPs into categories and evaluates the observed effluent concentrations for each BMP group. For this Basin-wide analysis, two primary sources of BMP effluent field data were used: Tahoe-specific data and the International BMP Database (www.bmpdatabase.org). For the Tahoe-specific data, Geosyntec Consultants (2005), with data from Reuter et al. (2001), summarized effluent concentration data from 23 BMP studies in the Tahoe Basin and 2NDNATURE (2006a) summarized effluent concentration data from 15 BMP studies. The BMPs summarized in these studies primarily included dry-detention basins, underground vaults, hydrodynamic devices, and wetlands. These BMPs adequately represent the PCOs developed and defined as SWT-1A, 1B, and 2A. However, because only one media filter study was summarized (2NDNATURE 2006a), there are inadequate data to represent SWT-2B. CALTRANS (2007) has recently been researching the effectiveness of advanced filter media, and the BMP Database includes a recent summary of media filter effluent concentrations (Geosyntec Consultants and Wright Water Engineers 2006). On the basis of these data sources, median effluent concentrations for each of the four PCOs were developed as summarized below in Table 3-7.

Table 3-7. Estimated achievable effluent quality for SWTs

PCO	BMP Assumptions	TN (mg/L)	DN (mg/L)	TP (mg/L)	DP (mg/L)	TSS (mg/L)
SWT-1A	Median Effluent from Dry Detention Ponds from Tahoe Data Only	1.1	0.12	0.16	0.05	25
SWT-1B	25th Percentile from Dry Detention Ponds from Tahoe Data Only	1	0.07	0.14	0.04	19
SWT-2A	Median Effluent from Underground Mechanical Devices from Tahoe Data Only	1.42	0.28	0.18	0.09	47.5
SWT-2B	Lowest Median Effluent Between Media Filters and Hydrodynamic Devices in ASCE BMP Database and Mechanical Devices and Media Filters from Tahoe Data	0.64	0.28	0.13	0.03	15

Note: ASCE = American Society of Civil Engineers

Confidence in Performance Estimates

A number of factors influence the relative confidence rating assigned to each PCO shown in Table 3-6. A few of the major factors are discussed below.

Grouping of BMPs into PCOs

Because of the scale of the analysis and the general application of storm water treatment options, grouping BMPs into PCOs was necessary. Groupings were based on common treatment mechanisms and pollutant removal effectiveness. However, subtle differences in BMP design (and thus performance) are lost in the groupings. For example, some BMP types would be expected to infiltrate more runoff than others depending on the specific design and underlying soils, but average infiltration rates had to be assumed for each PCO.

Dependence on Hydrology and Hydraulics

While there is generally a relatively high confidence in the accuracy of hydrologic simulation as compared to water quality modeling, there is a heavy dependence of pollutant removal on hydraulic loading rates to storm water BMPs. Assumptions regarding BMP size and outlet structure design are necessary to provide the required input to the Watershed Model. However, expected hydrologic/hydraulic response might differ from the performance estimated by the Watershed Model.

Effluent Quality Data

The majority of the data used to estimate median effluent concentrations for each PCO are based on BMP studies in the Tahoe Basin. Therefore, the confidence that the data accurately represent the BMPs implemented in Tahoe is relatively high. However, since the BMP data sets are relatively small from a statistical standpoint and the scope of work did not allow for a rigorous compilation and statistical evaluation of the raw BMP data sets, there is still uncertainty in the estimated median effluent concentrations. Also for SWT-2B, data from the International BMP Database (Geosyntech 2006) and a CALTRANS pilot study were used to fill in the data gap for media filters. Because of the use of this outside data, as well as the fact that the performance of engineered filter media has not been widely studied, the relative confidence in the estimated median effluent quality for SWT-2B is lower than for the other PCOs.

Groundwater

Unlike the urban uplands analysis, which is dependent on Watershed Model simulations to estimate pollutant load reductions, the groundwater analysis estimates changes to groundwater loads independent of Watershed Model simulations. The groundwater analysis estimates loads from infiltration of runoff using a mass balance approach, and represents potential load reductions in concentration associated with PSCs, soil filtration and adsorption, and more advanced treatment of infiltrated flows in SWT. Output from the UGSCG groundwater analysis is compared to the *Groundwater Framework Study for Lake Tahoe* conducted by the U.S. Army Corps of Engineers (ACOE 2003a) as the basis for estimates of load reductions relative to baseline conditions. The UGSCG took this approach because the data provide by the ACOE report is the estimate of groundwater loading for the baseline condition in Phase One (Lahontan and NDEP 2007). The groundwater evaluation conducted by ACOE is regarded as the most thorough synthesis of existing knowledge on the groundwater discharge and nutrient water quality in the Lake Tahoe Basin.

Because of the differences in approach between the urban upland analysis and the groundwater analysis for estimating pollutant load reductions, the UGSCG felt that including the groundwater analysis entirely within the following section would provide a more concise discussion for the reader to follow.

The main goals of the groundwater analysis by the UGSCG were to

- Identify the main sources of dissolved nutrients to groundwater
- Identify and explore opportunities to reduce existing groundwater nutrient loads to Lake Tahoe
- Estimate the expected DN and DP load reductions to the Lake as a result of PCOs
- Prioritize PCO strategies to reduce groundwater dissolved nutrient concentrations and subsequent loading to Lake Tahoe

Existing Conditions

The primary pollutants of concern in groundwater are limited to the dissolved inorganic nutrient species, DN and DP, because of the relative immobility of particulate material in the subsurface environment. The geochemical behavior of DN and DP in the unsaturated and saturated zones are very different. DN is composed of nitrate and ammonia, which are considered to be conservative pollutants, possessing a high solubility constant, particularly for nitrate, and a low affinity to adhere to soil particles. Typical groundwater DN concentrations in Lake Tahoe urban areas range from 0.06 to 0.90 mg/L (ACOE 2003a). The South Tahoe Pubic Utility District (STPUD) water quality database, containing more than 440 samples over a 15-year period, reports the mean DN concentration of all STPUD wells as 0.39 mg/L (I. Bergsohn, STPUD, personal communication 2007).

In contrast, DP—also known as phosphate, orthophosphate, or soluble reactive P—will preferentially adhere to hydroxide and clay particles and, therefore, can be removed from solution because of soil/water interactions. The slow transport of DP in the subsurface is referred to as retardation, as phosphate ions can adsorb/desorb from to clay particles over time, greatly reducing the rate of travel of DP. Typical groundwater DP concentrations in Lake Tahoe urban areas range from 0.02 to 0.09 mg/L (ACOE 2003a). STPUD reports the mean DP concentration of all STPUD wells as 0.045 mg/L (I. Bergsohn, STPUD personal communication 2007). Groundwater sampling results from various Lake Tahoe groundwater studies surrounding existing BMPs have yielded DP concentrations as low as 0.001 mg/L, with median values at or above 0.03 mg/L (USGS 2005; 2NDNATURE 2006b; 2NDNATURE 2007).

The ACOE (2003a) Groundwater Framework Study for Lake Tahoe presents estimated annual loads of total dissolved nitrogen and total dissolved phosphorus, equating to 50 MT and 6.8 MT, respectively (Table 3-8). The Watershed Model and Lake Tahoe TMDL define DN and DP as the inorganic species contained in the dissolved fraction, and using the ACOE (2003a) estimate, the annual load of DN and DP to the Lake via groundwater are 35.7 MT and 4.9 MT, respectively. These values represent 18 percent and 36 percent of the biologically available DN and DP loads delivered annually to Lake Tahoe.

The ACOE (2003a) groundwater evaluations specifically addressed the relative contribution of urban land uses to the groundwater DN and DP levels in five regions around the Lake. Using groundwater nutrient data from wells upgradient of areas of human development, the ACOE estimated the ambient groundwater concentrations of all DN and DP species. With these ambient nutrient concentrations, the ACOE was then able to estimate the anthropogenic contribution to groundwater nutrient concentrations and the eventual flux of anthropogenic nutrients to the Lake. To remain consistent with the pollutants of concern, the UGSCG adjusted the ACOE ambient values to reflect DN and DP (inorganic species only) and estimated an ambient DN concentration of 0.16 mg/L and an ambient DP concentration of 0.034 mg/L. The difference between total and ambient annual DN and DP loading to the Lake reported by the ACOE suggests Basin-wide anthropogenic loading (loads in excess of ambient natural conditions) estimates to the Lake via groundwater for DN and DP of 24 MT/yr and 2.6 MT/yr, respectively.

Table 3-8. Summary of annual groundwater loading s as presented by ACOE (2003a)

	TDN	TDP	DN	DP
Annual Loads	**Values presented in MT/yr**			
Ambient	17	3.1	12	2.3
Anthropogenic	33	3.6	24	2.6
Total annual load to Lake Tahoe	50	6.8	35.7	4.9
Concentrations	**Values presented in mg/L**			
Ambient	0.27	0.049	0.16	0.034

Anthropogenic	0.44	0.04	0.262	0.029
Basin-wide mean	0.78	0.11	0.56	0.076

Notes: TDN: total dissolved nitrogen = NOx + DKN, inorganic + organic dissolved; TDP: total dissolved phosphorus = SRP (inorganic) + organic dissolved P; DN = dissolved inorganic nitrogen: NOx + NH4; DP = dissolved inorganic nitrogen: SRP

The local hydrogeology and associated hydraulic conductivity of Lake Tahoe aquifers was evaluated Basin-wide by Thodal (1997) and regionally by the ACOE (2003a) using available monitoring well log information. The average Basin-wide horizontal permeability value is estimated to be 23 ft/day, with values ranging from 2 to 70 ft/day throughout the Basin. These values agree well with detailed site-specific hydraulic conductivity measurements made by the U.S. Geological Survey (USGS) in South Lake Tahoe, California (USGS 2005). Using the Basin average, groundwater migrates horizontally more than 1.5 miles in one year. While spatial variability certainly exists, the groundwater contributions to the Lake Tahoe's annual nutrient budgets are expected to decline if sources of excess nutrients to the groundwater reservoir are controlled.

The UGSCG identified two priority sources of dissolved nutrients to the groundwater reservoir of Lake Tahoe: infiltration of urban storm water and sewage exfiltration.

Infiltration of Urban Storm Water

Infiltration of water potentially influenced by urban activities can be categorized as the following:

- Dispersed infiltration on pervious surfaces
- Induced localized infiltration as a result of HSC or SWT

Dispersed, or nonpoint source, infiltration on pervious surfaces is difficult to quantify and occurs throughout the Basin. ACOE (2003a) suggested that dispersed locations with elevated loading of dissolved nutrients per unit area are directly related to land use activities where fertilizer applications can occur. As stated in Section 3.1, the ACOE (2003a) estimated that between 143 MT to 294 MT of N and 45 MT to 429 MT of P are applied each year within the Lake Tahoe Basin among all land uses that include pervious Residential_SFP, pervious Residential_MFP, CICU_pervious and Veg_Turf. ACOE (2003a) estimated that residential land uses have the greatest potential loading of anthropogenic fertilizer due to the large surface area occupied by this land use and the unregulated application of fertilizer. For simple evaluation, fertilized pervious surfaces within 1,500 ft of the Lake Tahoe shore likely pose a greater risk of contributing nutrients to the Lake via groundwater than fertilized surfaces that are at greater distances inland. A GIS land use analysis suggests that 3,917 acres, or 30 percent of the land uses within 1,500 ft of the Lake are one of the four land uses above, that are most likely to receive fertilizer applications. The relative influence of dispersed infiltration in urban areas on groundwater nutrient loading is evaluated later in this report.

Localized urban infiltration is a common practice in Lake Tahoe to reduce runoff volumes and provide storm water treatment. Key components of the UGSCG storm water PCOs include HSC and SWT features that are assumed to provide sustainable surface water load reductions in DN and DP via increased infiltration of urban storm water. However, little information and data exist on the impacts of urban infiltration on groundwater quality and the fate of infiltrated nutrients originating in urban storm water. Preliminary surface water and groundwater nutrient monitoring data at existing Lake Tahoe SWTs suggest relatively lower DN and DP concentrations are observed in the shallow groundwater in comparison to the surface water concentrations (2NDNATURE 2006b, 2NDNATURE 2007). Soil/water interactions, geochemical processes, and dilution of infiltrated waters with the existing groundwater reservoir all contribute to these observed differences.

Sanitary Sewage Exfiltration

The other primary source of DN and DP to urban groundwater is from the transfer or storage of sewage, which is nutrient-enriched and commonly results in the eutrophication of downstream resources throughout the world. In an effort to protect Lake Tahoe, the Basin sewage system was constructed, and all waste was pumped outside of the Basin beginning in 1968. While the potential impact of sewage has been significantly reduced through export, the ACOE (2003b) has identified sewage exfiltration, or the overflow or leakage of sewage through joints or cracks in sewage pipes, as a continuous anthropogenic source of nutrients to Lake Tahoe. Many sewage lines are in close proximity to the Lake's shore, limiting the distance that these nutrients must travel to the Lake if exfiltration is occurring, and thus reducing their exposure to potential natural retention processes.

The ACOE (2003b) estimated an average annual sewage system leakage rate of 15.4 million gallons (58,295 m^3), equating to an estimated annual leakage of 1.75 MT of N and 0.47 MT of P to Lake Tahoe groundwater each year. ACOE (2003b) prioritized the potential risk of sewage overflow/release locations throughout the Basin and developed a risk reduction action plan with associated cost estimates for each local sewage district. In 2003 the majority of the Lake Tahoe sewage system was estimated to be 30–40 yrs old, with more than 95 percent of the original sewage line still existing (placed in the 1960s). While current annual exfiltration rates might be relatively stable because of maintenance improvements, the Basin's sewage system is nearing its expected lifespan of 50 years.

According to the ACOE (2003b), existing practices in the sewage districts throughout the Basin do not include aggressive monitoring, maintenance, rehabilitation, and replacement programs, with some districts conducting sewage system inspections only every 3–5 years. The potential for a major sewage leak or overflow to the Lake from portions of the sewage system that have been identified to have a high risk of failure might increase over time without active, system-wide capital improvements (ACOE 2003b). While not a pollutant of concern with respect to Lake Clarity and this current Lake Tahoe TMDL, elevated bacteria levels in nearshore locations and associated potential human health hazards can also be expected as a result of sewage releases.

The ACOE (2003b) estimated sewage leakage contributes on the order of 0.4 percent of N and 1 percent of P of the total annual loads to Lake Tahoe. However, the migration of nutrients originated by sewage are dissolved nutrient species, and a comparison of the 1.75 MT of N and 0.47 MT of P to the dissolved N and P budgets to the Lake yields annual contributions on the order of 0.8 percent DN and 10 percent of DP. In addition, the ACOE (2003b) presented a number of limitations associated with its annual nutrient exfiltration estimates of 1.75MT of N and 0.47 MT of P:

- The 15.4 million gallon per year estimate was based on a 1983 Kennedy/Jenks Engineers field test study (20 years prior), and no additional field data on 2002 system conditions were collected by the ACOE (2003b) because of budget limitations.
- Field tests to quantify potential leakage are conducted by increasing hydrostatic pressure and filling an isolated portion of pipe with water and measuring pressure loss per unit time. These tests will identify discrete locations of exfiltration risk, and only a small subset of the Basin-wide sewage system was tested. The ACOE (2003b) placed little confidence in the accuracy of the correction and extrapolation factors used in their estimates.
- The ACOE (2003b) recommended a substantial testing program be conducted to improve the existing assessment of Basin-wide sewage system conditions.

The ACOE (2003b) also addressed the potential anthropogenic nutrient contribution of decommissioned septic systems to Tahoe Basin groundwater. Little definitive evidence exists documenting the potential contribution of legacy septic system leakage to the overall nutrient budgets.

PCOs for Groundwater

As outlined above, the primary sources of DN and DP to the groundwater system, leading to possible eventual delivery to the Lake, are urban infiltration and sanitary sewer exfiltration. The USGCG presents the PCOs recommended to reduce the annual DN and DP loading to Lake Tahoe from groundwater.

Urban Upland PCOs

The structure of the Watershed Model does not include a groundwater reservoir with associated flux estimates to Lake Tahoe. Rather, the Watershed Model routes infiltrated waters to short-term and long-term subsurface storage and flow-based integration with calibration of baseflows relative to Lake Tahoe Interagency Monitoring Program (LTIMP) stream data. The quality of the infiltrated urban storm water entering the groundwater system is directly linked to the surface water PCO recommendations made in Section 3.1. Therefore, the UGSCG conducted an integrated evaluation of how surface water PCO recommendations might influence groundwater quality, because existing and future practices include an increase in the implementation HSC and SWT that will ultimately increase the volume of urban storm water infiltration.

SWT-1B (Tables 3-6 and 3-7) includes the augmentation of detention basins to include adsorptive media at the soil/water interface. SWT-1B is intended to enhance the DP removal capability of the detention basin during infiltration of urban storm water. Preliminary research suggests that placement of iron hydroxides, aluminum hydroxides or other selective media at local points of urban infiltration is a feasible PCO for selective removal of pollutants of concern, particularly DP (Bachand and Heyvaert 2005). Pilot studies are being conducted in the field by CALTRANS on the efficacy of pollutant removal by activated alumina adsorptive media in infiltration basins treating runoff from impervious surfaces up to 3,500 m^2 in size (Dipen Patel, CALTRANS personal communication, 2007). The UGSCG has included the potential additional DP load reductions as a result of SWT-1B implementation, as discussed in the discussion regarding Quantification of Performance Estimates.

Sewage System Maintenance

The primary sources of concern with respect to human waste are sewage exfiltration and, to a lesser extent, decommissioned septic systems as noted by ACOE (2003b). The UGSCG has considered a multitude of possible PCOs to reduce the risk of human waste on groundwater quality with respect to DN and DP. The most feasible and likely cost-effective PCO options identified by the UGSCG include the following:

- Increased pollutant source control of active sewage lines reducing the loading of both DN and DP
- Focused DP *in situ* treatment of hot spots in spatial locations where DP concentrations are elevated.

Table 3-9 presents PSC-4, the PCO developed by the UGSCG for pollutant source control of groundwater loading associated with exfiltration. PSC-4 includes two levels of expected performance (indicated by Tier 1 and Tier 2; for detail, See Section 2.3). The estimated confidence the UGSCG has in determining achievable EMC values for each PSC-4 are provided in Table 3-9. (Confidence scale: 1=low confidence, 5=high confidence)

Table 3-9. PSC-4 for groundwater

PCO	Example BMPs	Applicable urban upland land uses	Confidence
PSC-4	a. Each of the eight sewage municipalities will implement the top	Not land-use specific	2

Tier 1	five priority action plans as identified by the ACOE (2003b). Maintenance efforts of all municipalities will be consistent with best existing practices conducted in the Basin		
PSC-4 Tier 2	b. Each municipality will be implement complete potential action plans as identified by ACOE (2003b). All sewage lines will be lined or double-wall protected within 10 years. Testing and maintenance will be above typical California sewage standards.		2

The ACOE (2003b) provides a recent and comprehensive evaluation that prioritizes specific facilities, sewage lines and other locations of greatest risk of sewage leakage/overflow within each of the eight sewage districts in Lake Tahoe. The ACOE (2003b) also provides specific actions and recommendations to reduce existing risk with associated cost estimates. The priorities and recommendations of the ACOE (2003b) are the primary resource for local managers to mitigate the potential long-term N and P loading from active sewage management.

PSC-4 for Tier 1 assumes that each of the eight sewage municipalities will implement the top five priority action plans as identified by the ACOE (2003b). Maintenance efforts of all municipalities will be consistent with existing practices currently conducted in the Basin. The ACOE (2003b) estimates the implementation costs of priority actions to be $30 million Basin-wide. Additional resources would be necessary to increase maintenance activities in some districts.

PSC-4 for Tier 2 assumes that each municipality will implement the complete potential action plans as outlined and prioritized by the ACOE (2003b). All sewage lines will be lined or double-wall protected by 2020. Sewage line integrity testing and maintenance will exceed typical California sewage practices in an effort to minimize anthropogenic contributions from active sewage routing. The ACOE (2003b) estimates the implementation costs of priority actions to be $90 million Basin-wide. Significant additional resources would be necessary to increase sewage maintenance, rehabilitation, and replacement activities in some districts.

In Situ Groundwater Treatment

The UGSCG also considered opportunities for advanced groundwater treatment of nutrient plumes. The approach to advanced treatment of dissolved nutrients in groundwater is considered to be similar to groundwater remediation of leaking underground storage tank releases. The geochemical differences between DN and DP in the subsurface make the concurrent treatment of both pollutants to achieve target effluent concentrations in Lake Tahoe groundwater complex and expensive. With respect to advanced groundwater treatment opportunities, the UGSCG recommends that the most cost-effective approach is to target DP for two reasons. First, P is the current limiting nutrient to the Lake, and geochemical differences between DN and DP make one treatment approach not suitable to retain/remove both pollutants simultaneously. Second, DP concentrations can be significantly reduced through relatively cost-effective, passive-filtration processes.

The most feasible approaches to DP remediation in groundwater are extracting/treating and *in situ* methods. Extracting/treating consists of pumping contaminated groundwater from the subsurface, treating the groundwater above ground, and reinjecting it into the subsurface. A more cost-effective and lower-maintenance opportunity considered by the UGSCG is passive *in situ* groundwater treatment by the physical placement of a reactive-barrier, filtration wall downgradient of an identified nutrient plume, as recommended by the ACOE (2003a).

Reactive barriers consist of trenching perpendicular to the groundwater flow path and packing the trench with a reactive media that has a high affinity for DP adsorption, such as activated alumina, diatomaceous earth, or iron hydroxides. The construction of such a barrier around the entire Lake perimeter is not physically or financially feasible. The UGSCG estimates treatment of 2.5 percent of the Lake Tahoe shoreline (2.85 km) using these reactive barriers as a first-order approximation. Locations of treatment would be selected where groundwater monitoring has identified DP concentrations in groundwater exceed 0.2 mg/L (i.e., maximum DP shallow monitoring well observation reported by ACOE (2003a)). Placement would be limited to areas where the shallow confining layers are more than 50 ft below the ground surface. Existing research and available literature suggests the placement of vertical reactive filtration barriers can result in achievable DP groundwater concentrations on the order of 0.03 mg/L (Dipen Patel personal communication), which is consistent with the ACOE (2003a) estimate of ambient Lake Tahoe groundwater DP concentrations of 0.034 mg/L. The sustained effectiveness of the *in situ* reactive barrier treatment is a function of the initial DP concentrations, because of the finite number of P adsorptions sites, and lifespans are limited by gradual material degradation. Reactive barriers might have some treatment capability for nitrate, but little information is available on filtration treatment of nitrate to achieve effluent concentrations near Lake Tahoe ambient conditions of 0.2 mg/L.

The main limitation with evaluating potential load reductions through *in situ* treatment is the dispersed spatial extent of potential loading of nutrients into groundwater. *In situ* reactive barrier placement and performance will be considered only under Tier 2, coupled with a strategic groundwater monitoring program to identify areas of elevated groundwater DP concentrations downgradient of suspected sewage leaks or high-density, decommissioned septic systems.

Quantification of Performance Estimates

Urban Upland PCOs

The UGSCG devised a simple mass balance evaluation, termed the *Urban Infiltration Box Model* (Figure 3-3), to estimate relative impacts on groundwater loading under different urban upland Treatment Tiers. The PCOs evaluated for the Urban Infiltration Box Model are the urban upland PCOs developed and presented in Section 3.1. All the urban upland PCOs developed by the UGSCG contain components that will influence dissolved groundwater nutrient loads in urban areas (Figure 3-3).

- PSCs will reduce nutrient EMCs of infiltrated volumes on pervious surfaces.
- HSC and SWT will increase the infiltrated volumes.
- SWT at Tier 2 includes an additional pretreatment of infiltrated water.

The U.S. Environmental Protection Agency's (EPA's) Storm Water Management Model (SWMM; Huber 1998) was used to track volumes for both surface runoff and infiltrated water using a continuous hydrology simulation. SWMM allowed the UGSCG to quantify the infiltrated volumes and track associated EMCs for urbanized areas for existing conditions, Tier 1, and Tier 2.

Both Tier 1 and Tier 2, developed for urban upland surface water load reductions, include increases in annual urban storm water infiltration. The Urban Infiltration Box Model provides an evaluation of the relative DN and DP annual loading to groundwater as a result of these recommended practices. Using SWMM output, the Urban Infiltration Box Model was developed to estimate the relative change in the DN and DP annual loads introduced to the groundwater reservoir as a result of urban upland PCO implementation (Section 3.1).

The UGSCG used the ACOE (2003a) groundwater data to inform and evaluate the infiltration results from SWMM existing conditions simulations. The process of relating SWMM outputs with ACOE (2003a) groundwater conditions is summarized in the bullets below. The interested reader is directed to Appendix UGSCG-B for a more detailed discussion of the approach.

- Nominal, 100-acre catchments representing each Setting (Section 4) were created. Average land use distributions, impervious area distributions and slopes were calculated for each Setting.
- A continuous hydrology simulation in SWMM was used to generate annual infiltration volumes
- SWMM output was extrapolated to represent the regional scale as reported by the ACOE (2003a) and compared to volume flux and water quality conditions in each region as reported by the ACOE (2003a). The comparisons reasonably agreed (See Appendix UGSCG-B).
- Lake Tahoe observations suggest storm water routed to infiltration typically has higher DN and DP concentrations than groundwater concentrations in close proximity. Using estimated infiltrated EMCs and anthropogenic groundwater EMCs from the ACOE, the UGSCG estimated a 76 percent removal of DP and a 0 percent removal of DN from infiltrated volumes in the unsaturated zone (unsaturated zone scaling factor). The estimated 76 percent DP removal from soil water interactions was found to be in agreement with the 85 percent removal of DP found in experiments in Ontario, Canada in similar soils and climate (Robertson et al. 1998; Robertson and Harman 1998, 1996, Robertson et al. 1991). Both the regional variability of DN groundwater concentrations and the relatively more complex geochemical cycling of DN in the subsurface make a simple scaling factor for DN unrealistic and outside of the Phase Two Lake Tahoe TMDL scope.
- Once a comparison of SWMM output to the ACOE data was completed, the SWMM output was used to evaluate the cumulative impacts of surface water PCOs on infiltration volumes and nutrient loads for Tier 1 and Tier 2. This simplified evaluation is referred to as the Urban Infiltration Box Model.

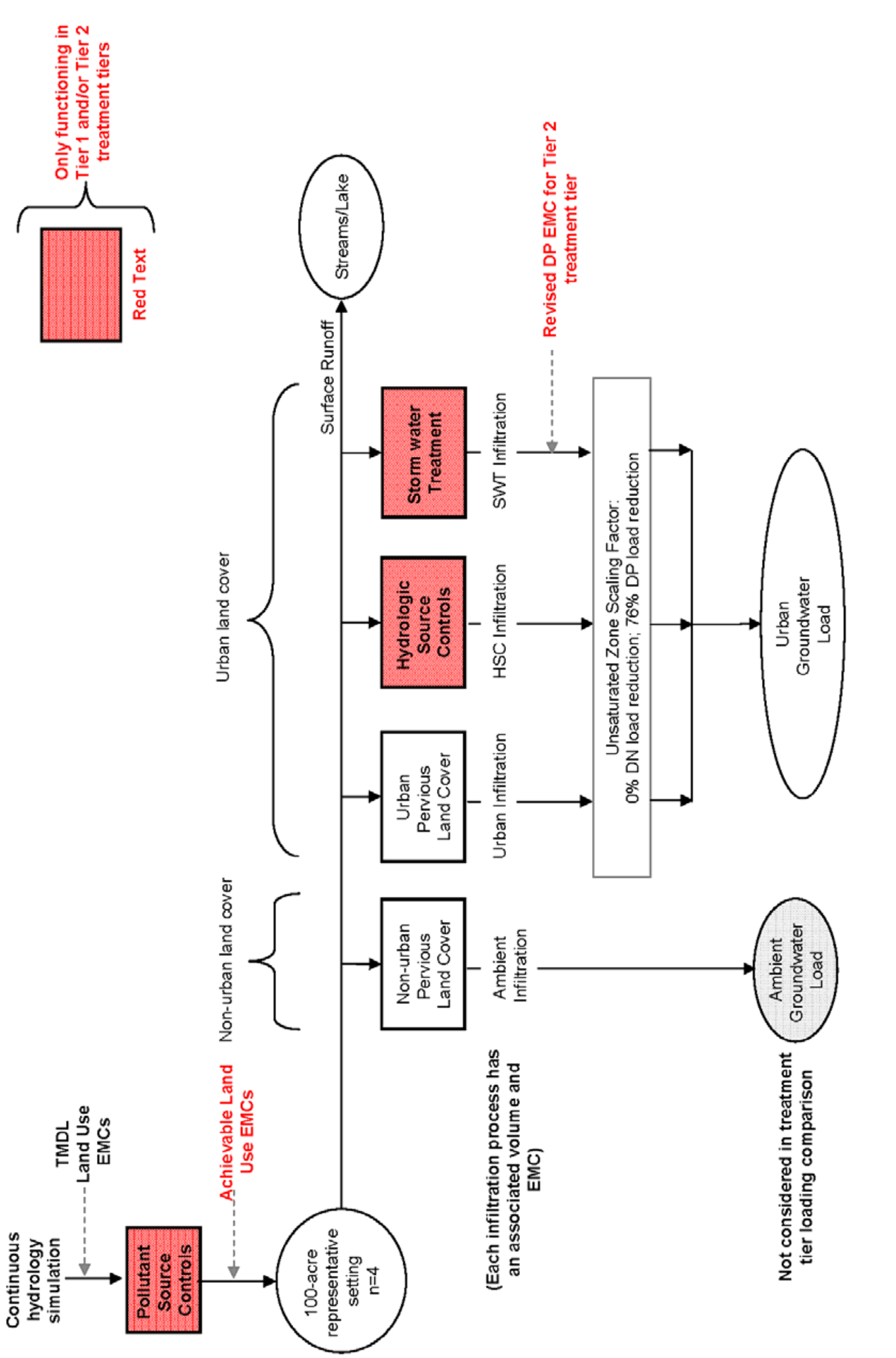

Figure 3-3. Urban infiltration box model used to evaluate the impact of urban PCOs on groundwater.

Figure 3-3 conceptually illustrates the pollutant generation in surface water and infiltration volume estimates employed by the Urban Infiltration Box Model. The surface water PCOs include PSC, HSC, and SWT load-reduction elements (Figure 3-1). PSCs are assumed to reduce the nutrients and particles available for transport within urban storm water. These reductions are accounted for as reductions in the land use EMC for each pollutant as a result of PSC implementation (Tables 3-2 and 3-3).

Infiltration on urban land cover is divided into 3 primary routes (Figure 3-3):

- Catchment Infiltration—dispersed infiltration on pervious surfaces within urban areas
- HSC Infiltration—localized infiltration via HSC
- SWT Infiltration—localized infiltration via SWT

Water that falls directly on pervious surfaces in urban areas (catchment infiltration) is infiltrated with the associated pollutant EMC as designated by the Treatment Tier. HSCs are a flow-based PCOs that are designed to infiltrate urban storm water, thereby reducing flow volumes delivered downstream. HSCs are assumed to provide negligible water quality improvements to infiltrated waters. SWTs provide both water quality improvement to storm water runoff as well as infiltrated runoff.

Tier 2 includes the placement of adsorptive media at the soil/water interface of detention basins (SWT-1B). Therefore, under Tier 2, DP infiltrated EMCs were set to 0.03 mg/L if water was infiltrated via SWT-1B. The unsaturated zone scaling factor for DP remained.

Urban infiltration volumes via pervious surfaces (per area of each Setting and Basin-wide) remain constant between Treatment Tiers because there is no appreciable change in the pervious coverage distribution under Tier 1 and Tier 2 (Table 3.10). HSC and SWT infiltration is not modeled in existing conditions but do vary across Settings within each Treatment Tiers. The volume of localized infiltration for each Setting is dictated by physical constraints on the Setting (i.e., slope, space available for HSC and SWT). The quality of water infiltrated and the estimated Setting and Basin-wide DN and DP loads per Treatment Tier and Setting are also presented in Table 3.10.

Table 3-10. Urban Infiltration Box Model output

	Infiltration Voumes, EMCs and Loads Per Acre of Setting											
Tier	Setting	Urban Infiltrated Volume (acre*ft/yr)	HSC Infiltrated Volume (acre*ft/yr)	SWT Infiltrated Volume (acre*ft/yr)	DN EMC (mg/L)	DP EMC (mg/L)	HSC DN Load (lbs/yr)	SWT DN Load (lbs/yr)	HSC DP Load (lbs/yr)	SWT DP Load* (lbs/yr)	Total DN Load (lbs/yr)	Total DP Load (lbs/yr)
Existing Conditions	CS	2.0	0	0	0.31	0.13	--	--	--	--	1.69	0.17
	DS	2.1	0	0	0.30	0.12	--	--	--	--	1.73	0.17
	CM	1.9	0	0	0.27	0.12	--	--	--	--	1.39	0.15
	DM	2.1	0	0	0.27	0.11	--	--	--	--	1.52	0.15
Existing Conditions	Basin-wide **	50235	0	0	0.29	0.12	--	--	--	--	39137	3952
Tier 1	CS	2.0	0.07	0.00	0.30	0.11	0.014	0.000	0.005	0.000	1.70	0.15
	DS	2.1	0.10	0.00	0.29	0.11	0.019	0.000	0.007	0.000	1.75	0.16
	CM	1.9	0.11	0.06	0.27	0.11	0.020	0.011	0.008	0.004	1.52	0.15
	DM	2.1	0.19	0.02	0.26	0.10	0.033	0.004	0.013	0.001	1.61	0.15
Tier 1	Basin-wide **	50235	2832	660	0.28	0.11	508	116	197	47	40836	3785
Tier 2	CS	2.0	0.14	0.01	0.28	0.10	0.026	0.001	0.01	0.000	1.64	0.14
	DS	2.1	0.20	0.00	0.27	0.09	0.035	0.001	0.01	0.000	1.70	0.14
	CM	1.9	0.23	0.16	0.26	0.09	0.039	0.026	0.01	0.003	1.61	0.13
	DM	2.1	0.33	0.09	0.24	0.08	0.051	0.015	0.02	0.002	1.63	0.13
Tier 2	Basin-wide **	50235	5469	1870	0.26	0.09	927	312	317	37	41130	3325

The main findings from the results of the Urban Infiltration Box Model, as shown in Table 3-10 include the following:

- Urban upland PCOs are estimated to infiltrate more than 3,500 ac-ft/yr more urban storm water under Tier 1 conditions, and over 7,250 ac-ft/yr more under Tier 2 than existing conditions, equating to an increase of 7 percent and 15 percent.
- Under Tier 1, the combined application of urban upland storm water PCOs are estimated to result in a 1 percent increase (+ 0.09 MT/yr) of DN and a 9 percent decrease in (– 0.16 MT/yr) of DP introduced to the groundwater reservoir via urban infiltration.
- Under Tier 2, the combined application of urban upland storm water PCOs are estimated to result in an 11 percent decrease (– 2.01 MT/yr) of DN and a 48 percent decrease in (– 0.87 MT/yr) of DP introduced to the groundwater reservoir via urban infiltration.
- An analysis was conducted by the UGSCG to evaluate the role PSCs play in the Tier 1 and Tier 2 load reduction estimates presented in Table 3-10. In other words, if the quality of urban storm water is not improved to the levels anticipated, what relative changes in groundwater DN and DP loads can we expect?
    - The increased infiltration of urban storm water without the simultaneous reductions in land use EMC values is estimated to increase DN loading to groundwater by 1.25 MT/yr (7 percent) under Tier 1and 2.5 MT/yr (14 percent) under Tier 2. Similarly, DP loading to groundwater could increase by as much as 0.13 MT/yr (7 percent) under Tier 1 and 0.22 MT/yr (12 percent) under Tier 2.
    - The results of this analysis suggests that if source control and urban water quality improvements are not conducted in concert with increased urban storm water infiltrations, both the Tier 1 and Tier 2 Treatment Tiers might result in increased groundwater DN and DP concentrations and loads in urban areas.

Sewage System Maintenance

On the basis of an evaluation of current practices and the opportunities and constraints for pollutant load reductions through PCOs targeting sewage exfiltration, the UGSCG estimated the following load reductions:

- Tier 1: 25 percent reduction in volume of sewage exfiltration and a corresponding 25 percent reduction in DN and DP contributions from this source based on professional judgment
- Tier 2: 50 percent reduction in volume of sewage exfiltration and a corresponding 50 percent reduction in DN and DP contributions from this source, based on professional judgment
- The UGSCG estimated the potential load reductions of the existing DN and DP contributions from sewage exfiltration conservatively for the following reasons:
    - On the basis of the ACOE's (2003b) reservations concerning the accuracy of the existing annual sewage exfiltration rate of 15.4 million gallons, the USGCG assumes the actual annual exfiltration rate could be greater.
    - The existing Lake Tahoe sewage system is nearly 40 years old with a 50-yr life expectancy. It is reasonable to assume that exfiltration and the associated DN and DP loading from sewage has been increasing, and it will continue to increase if adequate maintenance and upgrades are not implemented.
    - It is reasonable to assume that some exfiltration and line failure will occur even in the most advanced systems (ACOE 2003b) thus a 100 percent reduction in sewage loading is not anticipated as feasible.
- To remain consistent with the Lake Tahoe TMDL pollutants of concern, the ACOE (2003b) TN and TP sewage exfiltration estimates were scaled by 71 percent [2] to estimate existing conditions DN and DP loads, 1.2 MT/yr and 0.34 MT/yr, respectively. Existing conditions DN and DP loads

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[2] The 71 percent ratio is based on ACOE (2003a) total to dissolved nutrient speciation observations in Lake Tahoe groundwater.

were subsequently reduced by 25 percent and 50 percent to represent Tier 1 and Tier 2. Under Tier 1, sewage loading of nutrients is expected to be reduced by 0.3 MT/yr of DN and 0.03 MT/yr of DP. If Tier 2 is implemented, general estimates suggest a 0.6 MT/yr reduction in DN and a 0.06 MT/yr reduction in DP.

In Situ Groundwater Treatment

Estimates are made of the potential pollutant load reduction benefit of implementing *in situ* treatment of localized groundwater DP *hot spots* using reactive barriers. The UGSCG used the following data and assumptions according to the ACOE (2003a) groundwater study and professional judgment:

- The maximum shallow well DP concentration reported by the ACOE (2003a) in the Tahoe Basin was 0.2 mg/L (ACOE 2003a). The UGSCG made a general assumption 2.5 percent of the shallow groundwater at the Lake interface is at, or above, this concentration. Given existing information, *in situ* treatment action levels are considered by the UGSCG as 0.2 mg/L.
- The groundwater load associated with 2.5 percent of the total groundwater discharge to the Lake (1.6×10^6 m^3/yr) and a DP concentration > 0.2 mg/L can be estimated to be 0.33 MT/yr.
- Groundwater concentrations downgradient of the *in situ* treatment are expected to be 0.03 mg/L, resulting in a 0.28 MT/yr reduction of DP.
- The pollutant load reductions described could be accomplished through targeted application of 2.85 linear km interface reactive barriers near the Lake shore (i.e., 2.5 percent of the Lake perimeter).

Confidence in Performance Estimates

Urban Upland PCOs

1. SWMM models a constant infiltration rate for HSC and SWT, which is an empirical function of soil type. In reality, soils reach saturation during large runoff events, or shallow groundwater tables rise to the same elevation as infiltration points. Both of these temporarily minimize water lost to the subsurface. Observations during wet season conditions within Lake Tahoe have documented minimal infiltration via certain HSC and SWT features, significantly reducing water quality treatment during the largest pollutant loading events of the year. Strategic hydrologic sizing and morphology of HSC and SWT can greatly increase the seasonal stability of infiltration of a PCO for urban storm water (2NDNATURE 2006b).

2. The volume and loading estimates presented in Table 3-10 provide relative estimates to improve understanding regarding the potential implications of increasing the infiltration of urban storm water. The absolute EMC values presented in Table 3-10 represent the quality of water that would reach groundwater, following surface water PCOs and natural soil retention processes. The UGSCG did not conduct groundwater modeling to account for dilution or other geochemical processes beyond DP soil adsorption that would further influence Lake Tahoe groundwater conditions.

3. Dry wells are a common storm water infiltration structure installed to address localized ponding issues in urban areas with poor drainage. Dry wells are typically vertical holes filled with gravel. In some instances, urban storm water introduced to dry well can be routed directly into the shallow groundwater aquifer, minimizing the opportunity for soil/water interactions and subsequent DP adsorption. The Urban Infiltration Box Model did not include a characterization of dry wells functioning in this manner. Future modeling of the fate and transport of storm water infiltration can better constrain the hydrogeologic function of the variety of HSCs.

4. The UGSCG is confident that the nutrient mass reductions, as estimated by the Urban Infiltration Box Model, are comparable to overall groundwater dissolved nutrient fluxes to the Lake as estimated by the ACOE (2003a). Thus, the predicted annual load reductions in DN and DP in the groundwater flux to Lake as presented in Table 3-10 are reasonable as preliminary estimates. To better constrain the expected changes in groundwater loading of dissolved nutrients to the Lake as a result of PCO implementation, a more representative groundwater fate and transport modeling effort should be needed to include mixing, dilution, spatial heterogeneity of the Basin, and dominant geochemical processes that influence nutrients in the subsurface.

Sewage System Maintenance

The following limitations associated with the quantification of both existing sewage exfiltration rates and expected load reductions from sewage maintenance PCOs are provided:

1. Estimates of sewage exfiltration and associated nutrient loading to groundwater in the Tahoe Basin are poorly constrained. Actual dissolved nutrient loading to groundwater from sewage exfiltration from this source could be higher than the estimates used.

2. The vast majority of the sewage systems in the Tahoe Basin are nearing the end of predicted lifespan, and the risk of major leaks or overflows is increasing. Annual nutrient loads to groundwater from sewage exfiltration could be expected to increase within the next decade under current conditions.

3. Most sewage lines are in close proximity to the Lake, and high-nutrient plumes from sewage leaks would not have to travel far before crossing the Lake interface.

4. In addition to high nutrient concentrations, sewage leaks can introduce other potentially harmful pollutants, such as bacteria, to the nearshore Lake environment, posing both ecological and human health risks.

5. While the existing quantification of the actual annual DN and DP load contribution from sewage exfiltration are not well constrained, the decision to prioritize continued sewage maintenance and gradual system upgrades should be considered a priority to meet long-term load reduction goals.

In situ Groundwater Treatment

In situ groundwater treatment using reactive barriers is presented as a PCO to achieve DN and DP load reductions to Lake Tahoe via groundwater. The USGSG has high confidence that effluent concentrations of groundwater downgradient of a reactive barrier would result in consistent DP levels < 0.03 mg/L. Because of the limited amount of information regarding the spatial distribution and characterization of locations of elevated DP concentrations as a result of point source leaks, the quantification of the existing load reductions presented by the UGSCG are based on a number of assumptions. The load-reduction estimates could be greatly improved with additional strategic groundwater monitoring information in locations where sewage leaks have been identified.

Summary and Results

The relevant pollutants of concern via groundwater loading to Lake Tahoe (as evaluated by the Lake Tahoe TMDL) are DN and DP, the biologically available forms of N and P. The Basin-wide pollutant loading budget (Lahontan and NDEP 2007) estimates groundwater loading to Lake Tahoe contributes 35.7 MT of DN/yr or 17 percent of the total annual DN budget. Groundwater loading contributes an estimated 4.9 MT of DP/yr, or 36 percent of the total annual DP budget (Table 3-11).

Table 3-11 presents the DN and DP load-reduction summary of the three primary anthropogenic groundwater nutrient sources or treatment opportunities that were evaluated by the UGSCG: urban upland PCOs, sewage system maintenance, and *in situ* treatment. The mass and relative contribution of groundwater to the total DN and DP loads to Lake Tahoe annually are provided for reference (Phase One Lake Tahoe TMDL Report 2007).

Table 3-11. Estimates of groundwater loading relative to baseline conditions

2007 Nutrient budget	DN (MT/yr)	DP (MT/yr)
Groundwater contribution	35.7	4.9
% of total annual load to Lake Tahoe	17%	36%
Treatment Tier	**DN load reduction (MT/yr)**	**DP load reduction (MT/yr)**
Urban Upland Storm Water PCOs		
Tier 1	(0.1)	0.2
Tier 2	2	0.87
Sewage System Maintenance		
Tier 1	0.3	0.03
Tier 2	0.6	0.06
In-situ Groundwater Treatment		
Tier 2	not evaluated	0.28

Text in parenthesis indicates an estimated increase in annual load

The load reductions are estimates of the annual mass of DN and DP expected for groundwater loading. The UGSCG did not conduct any evaluations to quantify the fate and transport of nutrients once they reach the existing groundwater reservoir; thus, the assumption is made that the load reductions from these primary sources to groundwater would equate to annual load reductions in the overall groundwater loading to Lake Tahoe. The results of the UGSCG groundwater evaluation yield the following findings and recommendations:

1. On the basis of existing information, the greatest load-reduction opportunities for groundwater loading to Lake Tahoe are achieved by implementing urban upland storm water PCOs as outlined in Section 3.1. While HSC and SWT practices would result in an increase in urban storm water infiltration, effective PSC implementation is expected to improve the quality of storm water infiltrated to the shallow groundwater reservoir. The implementation of urban upland PCOs under Tier 1 and Tier 2 provides a twofold benefit for DP load reduction (i.e., load reductions are predicted in both storm water runoff as well as annual groundwater contributions to Lake Tahoe).

2. The load-reduction estimates for sewage maintenance PCOs appear relatively low in Table 3-11. On the basis of the ACOE (2003b) evaluations, sewage exfiltration can be a significant localized contribution of dissolved nutrients to Lake Tahoe. However, efforts to accurately quantify the system-wide contribution of the sewage system are difficult without substantially more information. Sewage waste does contain a significantly greater mass of DN and DP per unit volume than any other nutrient source to Lake Tahoe. The potential risk that a poorly maintained sewage system would contribute elevated loads of dissolved nutrients to localized, shallow groundwater warrants maintenance of the existing sewage system as a long-term priority.

3. Quantification of *in-situ* treatment of groundwater suggests that annual DP load reductions can be achieved using reactive-filtration barriers near the Lake shore. However, this PCO has a higher cost and limited effectiveness relative to other PCOs analyzed for groundwater load reductions.

4. The relatively high hydraulic conductivity within Lake Tahoe (i.e., Basin-wide mean hydraulic conductivity = 23 ft/day (ACOE 2003a)) suggests that improvements in the quality of infiltrated waters would result in a relatively quick response of the groundwater quality and reductions in the groundwater N and P annual loading rates to the Lake. In other words, if sources of nutrients to groundwater are reduced, the groundwater quality is anticipated to improve within a matter of years, although spatial heterogeneity within the Lake Tahoe Basin does exist.

3.4. Settings

Settings are used in this report to define the application of PCOs in Treatment Tiers. The purpose of this section is to define urban upland Settings. Section 5 describes the formulation of Treatment Tiers. The detailed approach and methods used to assign urban upland Settings to subwatersheds in the Watershed Model are provided in Appendix UGSCG-C. This section

- Identifies key physiographic characteristics used to define urban upland Settings
- Presents the classification of urban upland Settings
- Evaluates for each Setting the typical opportunities and constraints for PCO application

Summary of Approach

For the purposes of this UGSCG analysis, a classification of subwatersheds in the Watershed Model is needed to define potential PCO implementation. This classification is accomplished by defining Settings on the basis of key physiographic characteristics of a subwatershed that directly influence the planning, design, and construction of urban storm water quality improvement projects in the Basin. Numerous characteristics (and permutations or combinations of these) could be applied to define urban upland Settings in the Lake Tahoe Basin. Many different characteristics were considered for use in Setting classification (soils, slopes, impervious area, land use, and such). However, many of these characteristics are captured directly in Watershed Model computations of loads. The UGSCG approach therefore focused on a few key physiographic characteristics that relate to PCO selection and implementation rather than runoff characteristics. This approach allows PCO implementation to be conceptually represented by subwatershed in the Watershed Model and facilitates load computations in the model at the Tahoe Basin-wide scale that represent PCO implementation in the Treatment Tiers. Variations in loads by subwatershed based on soils, land use, and land use characteristics are computed directly in the Watershed Model.

After consideration of an extensive list of potential characteristics, selected key physiographic characteristics for definition of urban upland Settings are

1. Impervious area configuration
2. Average slope of urban upland area

In a simple way, this approach intends to consider both the spatial application of PCOs needed for pollutant load reductions and the feasibility of implementing different types of PCOs given typical opportunities and constraints for storm water quality project implementation in the Tahoe Basin.

Additional watershed characteristics (e.g., soils, land-use types, meteorology, depth to groundwater, upland forest drainage) are recognized as influencing the selection, application, and sizing of PCOs at the project scale. The approach for developing Treatment Tiers captures, to the extent practical, the effects of these variables on performance of PCOs rather than using them to define Settings (See Section 3.5).

Pollutant load reductions will not be constant for each Setting but will vary according to these secondary characteristics. As discussed above, part of this variability is computed directly in the Watershed Model, which already incorporates subwatershed characteristics such as land-use types, meteorology, and erosion potential.

Threshold for Urban Upland Setting

The UGSCG set a minimum threshold of impervious area for Lake Tahoe TMDL subwatersheds to be treated as urban upland Settings. Many of the subwatersheds in the Watershed Model have little or no urban development, and PCOs defined here are thus not applicable to these subwatersheds. The impervious area threshold reduces the number of subwatersheds assessed by the UGSCG while capturing the majority of *urban* area in the analysis. From review of Lake Tahoe TMDL subwatershed GIS layer and the impervious area GIS layer (Minor and Cablk 2004), it appears that a reasonable threshold for classifying a subwatershed as an urban upland Setting is 1 percent impervious area. Figure 3-4 illustrates the results using the 1 percent impervious area threshold assumption. The Lake Tahoe TMDL subwatershed delineation contains 184 subwatersheds. The 1 percent impervious area threshold yields 70 subwatersheds for assessment by the UGSCG. In aggregate, they represent roughly 96 percent of the total impervious area in the Basin. Figure 3-5 displays the specific subwatersheds analyzed as urban upland.

The urban upland Setting classifications developed by the UGSCG in this section are generalized descriptions of key physiographic characteristics of a subwatershed, used as a tool in the determination of the spatial application of PCOs, and the feasibility of implementing different types of PCOs on urban upland land uses. The classification of a subwatershed as an urban upland Setting means that urban upland PCOs are applied to urban upland land uses within the subwatershed. However, other PCOs (especially those for forested uplands) could also be applied to undeveloped land uses in the same subwatershed. To avoid duplication in Watershed Model computations, urban upland PCOs are considered applicable to particular developed land uses, and forest upland PCOs are considered applicable to other undeveloped land uses. Table A-1 in Appendix UGSCG-A lists the land uses assigned to either urban upland or forest upland.

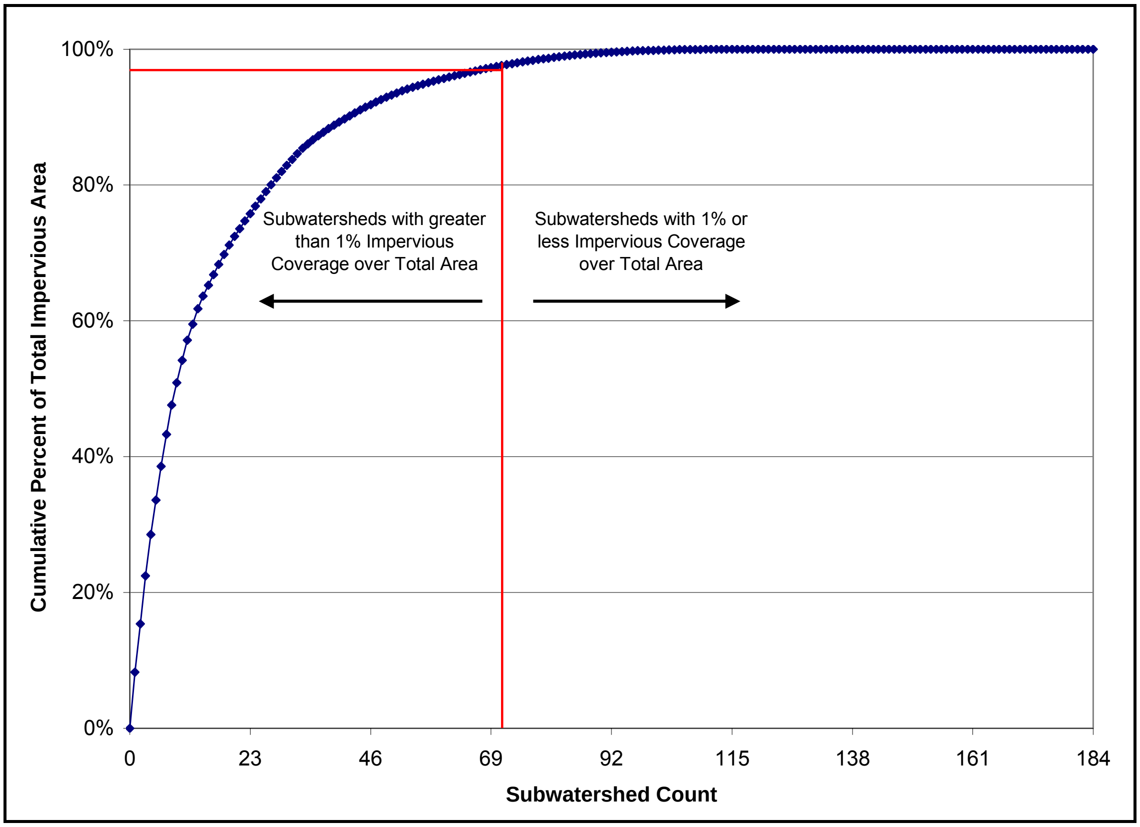


Figure 3-4. One percent impervious area threshold assumption.

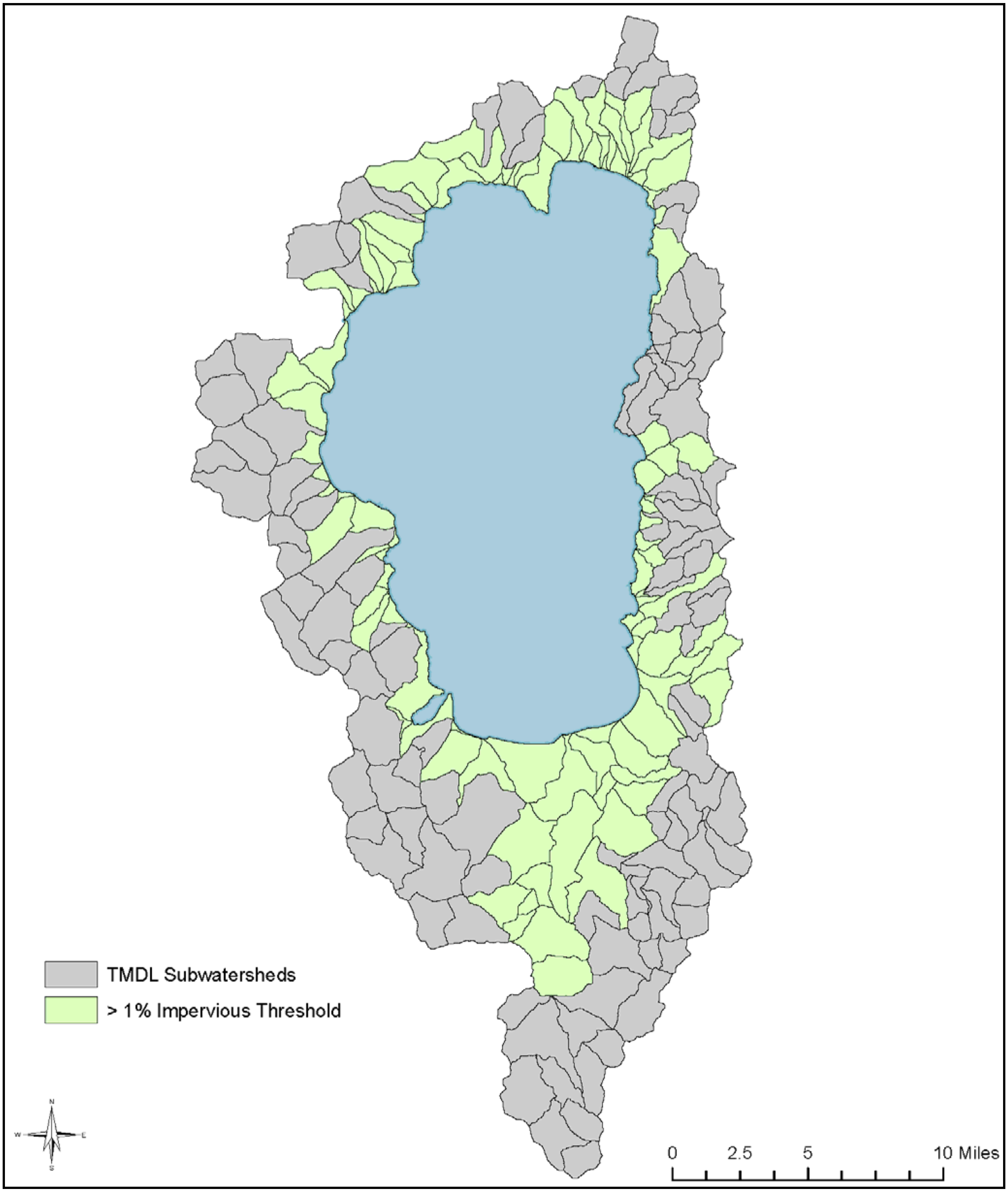


Figure 3-5. Subwatersheds meeting urban upland threshold.

Impervious Area Configuration

The configuration of impervious area is a key physiographic characteristic that discriminates the relative influence impervious area has on the planning, design, and construction of urban storm water quality improvement projects in the Basin. As the concentration of urban development increases, the opportunities for implementation of many types of storm water management improvements will decrease. To represent this characteristic, two categories of impervious area configuration were defined for urban upland Settings as either (1) dispersed, or (2) concentrated. For a description of the quantitative process used to determine breakpoints for classification of dispersed and concentrated impervious area by subwatershed, See Appendix UGSCG-C.

- **Dispersed:** Impervious area is situated throughout a Setting with significant area available for construction of storm water management improvements. The available area is either commingled within the extents of the existing impervious area, downstream of the impervious area, or a combination of both.
- **Concentrated:** Impervious area is situated in a relatively dense configuration within the Setting. Minimal pervious area is available for storm water management improvements both within the extent of the existing impervious area and downstream of the impervious area.

Average Slope of Urban Area

Average slope in a urban area was selected as a key physiographic characteristic because (1) slopes in a project area strongly influence the application and sizing of PCOs for storm water management, and (2) average slopes with the urban area of a subwatershed can be readily calculated in a GIS using layers developed for the Lake Tahoe TMDL with a Digital Elevation Model (DEM) of the Tahoe Basin. Two categories of average slopes define an urban upland Setting, as either (1) moderate, or (2) steep.

- **Moderate Slope:** Average slope within the urban area of a subwatershed that is less than 10 percent.
- **Steep Slope:** Average slope within the urban area of a subwatershed that is greater than 10 percent.

The 10 percent slope criterion was selected as the quantitative breakpoint between moderate and steep slopes using best professional judgment. In general, storm water projects in the Tahoe Basin tend to implement more intensive spatial applications of PCOs on slopes of roughly 10 percent or greater. Additionally, more armored PCO application is typical on slopes of roughly 10 percent or greater. This criterion recognizes that the determination of average slope in the urban area at a subwatershed scale is a broad approximation of actual storm water management project PCO implementation.

Assigned Urban Upland Settings

On the basis of the designation of impervious area configuration and average urban slope, urban uplands Settings were assigned to each subwatershed meeting the threshold criteria. Table 3-12 tabulates the number of subwatersheds assigned to one of the four urban upland Settings. With inclusion of the ungrouped intervening zones (See Appendix USGSG-C), there are a total of 107 subwatersheds defined as an urban upland Setting. Figure 3-6 illustrates the results of the Setting assessment for urban uplands and spatial classification of subwatersheds into urban upland Settings.

Table 3-12. Tabulation of urban upland Settings for urban subwatersheds

Count	Setting identification	Key physiographic characteristics: Impervious area	Key physiographic characteristics: Slope
21	Concentrated-steep	Concentrated	Steep
22	Concentrated-moderate	Concentrated	Moderate
45	Dispersed-steep	Dispersed	Steep
19	Dispersed-moderate	Dispersed	Moderate

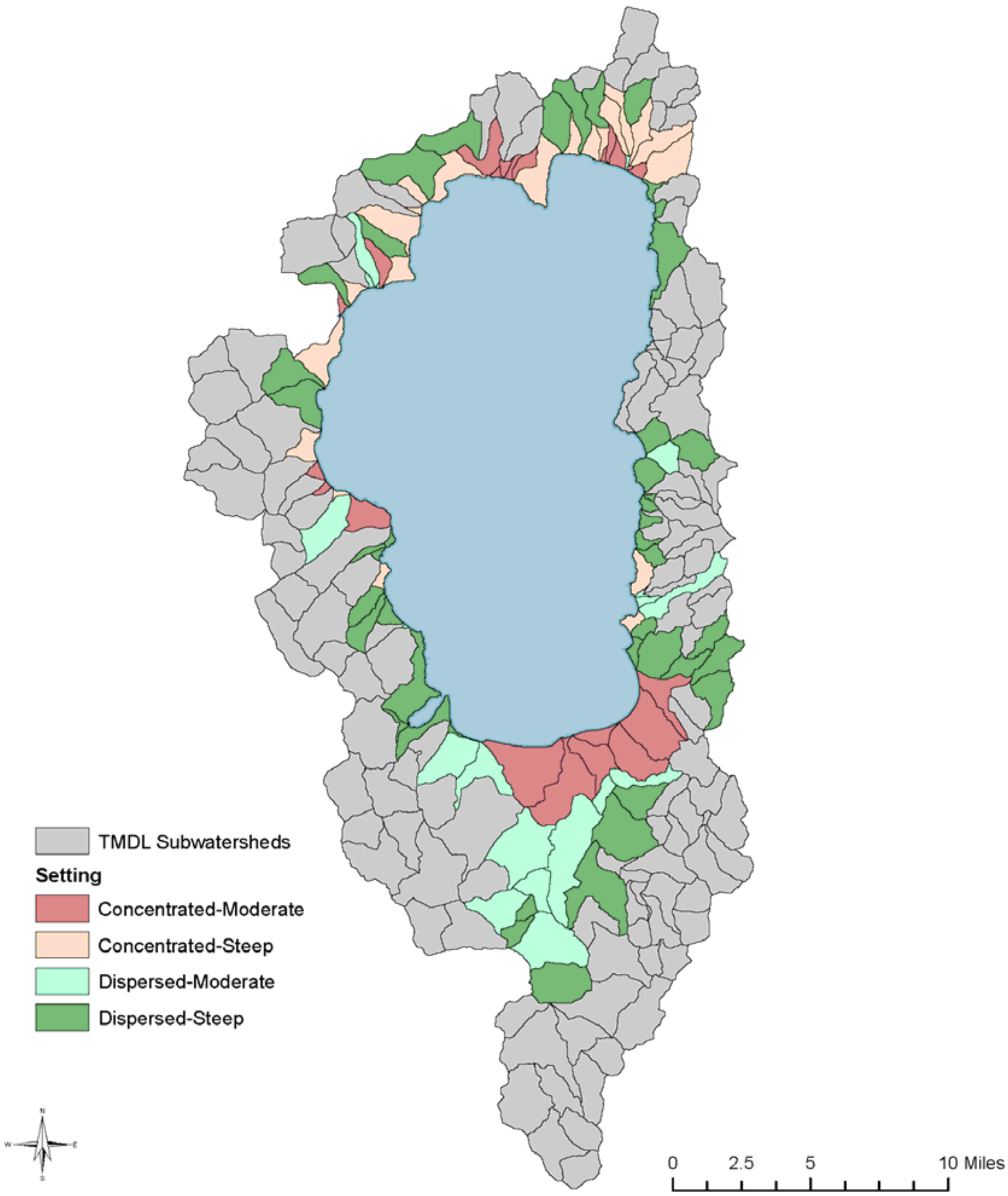


Figure 3-6. Urban upland Setting classification.

Opportunities and Constraints for PCO Application

This section summarizes how key characteristics within each Setting influence the selection and spatial application of PCOs under typical practice for each major element (i.e., PSC, HSC, and SWT). The information developed is used in Section 5 to guide the definitions of Treatment Tiers for each Setting and the rationale for selection of specific PCOs within each Treatment Tier, which in turn influence the estimation of costs in Section 6.

General Considerations for All Settings

The development of Settings within the urban upland analyses differentiates subwatersheds according to key physiographic characteristics that most directly influence the selection and application of PCOs. However, certain commonalties across all Settings were realized during Setting development. The influences of key commonalties on the UGSCG analysis are described below, as well as the approach for addressing each issue.

- **Private property BMPs implementation is uniform:** The distribution of completed private property BMP retrofits is independent of Setting definitions. Therefore, a uniform distribution of roughly 10 percent completed private property BMPs (residential and commercial) is used across Settings to estimate costs for Treatment Tiers. This assumption is included in Section 3.6, Cost Estimates.
- **Drainage through urban uplands:** Because Settings are based on subwatersheds, drainage through urban uplands from forested uplands occurs frequently. Commingled forest upland and urban upland runoff is assumed separated during urban upland PCO applications through conveyance improvements. In existing Tahoe Basin practice, this type of conveyance improvement is relatively common for storm water management. Therefore, SWTs in urban upland are assumed to operate only on urban upland runoff. This assumption is accounted for in Section 6.3, Cost Estimates.
- **Vegetated land uses are intermingled with urban land uses:** Urban uplands within the Lake Tahoe TMDL are actually quite rural by most standards, particularly for Settings with dispersed impervious area. Consequently, a high fraction of the urban upland area is occupied by vegetated land-use designations associated with forest upland. Load reductions on vegetated land uses in urban uplands, other than vegetated turf, are assumed to be achieved through application of PCOs from forested uplands. Section 3.6 describes how overlap with forest upland is avoided using the urban upland Input Tables.
- **Pollutant loading from sources independent of urban land uses:** Some specific pollutant sources in urban uplands (e.g., gullies) are not attributable to a specific land-use category or land-use condition. Pollutant loads associated with these specific sources might be quite large if associated with significant problems. Because the Watershed Model represents only land-use-based sources of pollutants, it is not feasible for the UGSCG to explicitly inform the Watershed Model regarding the application of PCOs or the associated pollutant load reductions. Instead, the UGSCG assumes that PCOs are applied to these specific sources in every Treatment Tier and are implicitly reflected in revised EMCs for land uses.

Specific Considerations by Setting

This section describes opportunities and constraints for PCO application specific to each Setting in the following order: (1) concentrated-steep; (2) concentrated-moderate; (3) dispersed-steep; and (4) dispersed-moderate.

The assumptions for each Setting are based on how the key physiographic characteristics (impervious area configuration and slope) impact the selection and spatial application of PCOs while considering typical limitations in available resources and land. Assumptions developed for each Setting are necessarily general and reflect the broad spatial scale of assessment performed by the UGSCG. An assessment conducted at the project implementation scale would certainly lead to more refined, and potentially different, opportunities and constraints.

Concentrated-Steep Setting

The concentrated-steep Setting is the most constrained of all Settings for PCO application given the concentrated impervious area and steep slopes. The urban uplands within this Setting are dominated by single-family and multifamily land uses. CICU land uses are minimal relative to the concentrated-moderate Setting because of the steeper slopes.

PSC

- Erosion potential is typically high given the impervious area and steep slopes.
- PSCs for road shoulder stabilization typically require more engineered and armored approaches such as curb and gutter or asphaltic concrete (AC) berms/swales.
- Conveyance improvements typically involve rock-lined channels and storm drain.
- Road sand application on secondary roads is highest in this Setting because of the combination of steep slopes and the frequency of use on these roads relative to dispersed Settings.

HSC

- HSCs that decrease runoff volumes through flow spreading or removal of impervious cover are difficult to implement.
- HSCs that require relatively flat terrain for storage and infiltration are less feasible.
- Minor volume reductions in runoff are accomplished by implementing pervious components in the drainage system (e.g., open-bottom sediment traps).

SWT

- SWTs with large footprints are not feasible without private property acquisition.
- The feasibility of certain volume-based PCOs is limited (e.g., most locations, even if publicly available, are not feasible for detention basins).
- Infiltration rates and PCO selection are not limited by high groundwater.
- Subsurface vaults or propriety flow separation devices are most commonly applied.

Typical Spatial Scale of PCO Application in Current Practice

- PSCs for road shoulder stabilization and conveyance stabilization are implemented at the highest rate compared to other Settings given the lack of opportunities for HSC and SWT.
- HSC implementation is minimal and is the least frequently applied in this Setting.
- SWTs capture minimal runoff volumes at outfalls of localized drainages.

General Considerations

- Publicly available land is minimal and acquisition of undeveloped private parcels situated at key drainage locations is unlikely.
- Average costs for private PCOs on a unit area basis are the highest of any Setting.

Concentrated-Moderate Setting

The concentrated-moderate Setting is highly constrained for PCO application given the concentrated impervious area and lack of publicly available land. The moderate slopes provide some increased opportunities for PCO applications relative to the concentrated-steep Setting. The urban uplands within this Setting are dominated by CICU land uses, which occupy a much greater percentage of the urban area relative to other Settings. Vegetated turf land uses are present in their most significant fraction within this Setting and relative to other Settings.

PSC

- Erosion potential is typically moderate because of the mild slopes. However, the land-use characteristics and concentrated impervious area typically influence road shoulder stabilization toward more armored techniques similar to the concentrated-steep Setting.
- PSCs for road shoulder stabilization trend toward more armored techniques such as curb and gutter or AC berms/swales because of space constraints and the frequency of use on roads relative to dispersed Settings.
- Conveyance improvements typically implement storm drains.

HSC

- HSCs that decrease runoff volumes through flow spreading or removal of impervious cover are limited because of land availability and resource constraints.

SWT

- SWTs with large footprints are infeasible without acquisition of developed properties. Space constraints and high acquisition costs typically result in smaller SWTs that might not capture substantial runoff volumes.
- Relatively shallow groundwater might limit localized infiltration rates and PCO selection.

Typical Spatial Scale of PCO Application

- PSCs for road shoulder stabilization are implemented at a high rate (but less than the concentrated-steep Setting) given the land uses present and the high concentration of impervious area.
- HSC implementation is minimal because of dense, impervious cover.
- Detention-based SWT is feasible depending on land availability. However, capture of a significant runoff volume is limited.

General Considerations

- Publicly available land is minimal and acquisition of undeveloped private parcels situated at key drainage locations is unlikely.
- Average costs for private PCO implementation on CICU land uses are high because of high-density impervious area associated with this land use.

Dispersed-Steep Setting

The dispersed-steep Setting includes increased opportunities for PCO application relative to the concentrated impervious area Settings. However, steep slopes within this Setting limit certain opportunities. The urban uplands within this Setting are dominated by single-family land uses intermingled with vegetated land uses. CICU land uses are very minor.

PSC

- Erosion potential is typically high because of the steep slopes.
- PSCs for road shoulder stabilization typically require more engineered and armored approaches such as curb and gutter or AC berms/swales.
- Conveyance improvements typically involve rock-lined channels and storm drain.

HSC

- Land availability presents opportunities to decrease runoff volumes through flow spreading or disconnection of impervious area. However, steep slopes limit the practical application of HSCs to stabilized locations with small tributary areas.

SWT

- Opportunities exist within the urban development and sometimes downstream of the urban development for storm water treatment.
- Infiltration rates and PCO selection are not limited by high groundwater. However, steep slopes limit broad application of certain SWTs (e.g., detention basins).

Typical Spatial Scale of PCO Application

- PSCs for road shoulder stabilization are implemented to a moderate degree. Typically, road shoulders parallel to the slope receive stabilization while road shoulders perpendicular to the slope are perceived to have less erosion potential and are not prioritized for stabilization because of limited resources.
- HSC implementation is an opportunity because of dispersed impervious cover but is limited because of steep slopes.
- Application of SWT is opportunity driven. Capture of the 20-year, 1-hour runoff volume is usually feasible for select areas of interest.

General Considerations

- Publicly available land is an opportunity dispersed throughout the Setting. Acquisition of undeveloped private parcels is typically not necessary.
- Average costs for private PCO implementation are high because of steep slopes.

Dispersed-Moderate Setting

The dispersed-moderate Setting is the least constrained of all Settings for PCO application. The urban uplands within this Setting are dominated by single-family land uses intermingled with a high amount of vegetated land uses. CICU land uses are present in higher proportion relative to the dispersed-steep Setting.

PSC

- Erosion potential is typically moderate throughout the Setting.

- Pervious stabilization of road shoulder and conveyances are typically preferred and feasible in this Setting (e.g., swales).

HSC

- Significant opportunities are present to decrease runoff volumes through flow spreading or disconnection of impervious area. In many cases, the current configuration of impervious area is disconnected and functions to disperse runoff.

SWT

- Opportunities exist within the urban development and sometimes downstream of urban development for storm water treatment and storage.
- Relatively shallow groundwater might limit localized infiltration rates and PCO selection.

Typical Spatial Scale of PCO Application

- PSCs for road shoulder stabilization are implemented at a modest rate compared to other Settings given the moderate slopes and opportunities for HSC and SWT.
- HSC implementation is a significant opportunity.
- Detention-based SWT is common and will typically capture the 20-year, 1-hour runoff volume for areas of interest.

General Considerations

- Publicly available land is an opportunity dispersed throughout the Setting. Acquisition of private parcels is typically not necessary.
- While this Setting is typically not next to the Lake, it is common that the urban area is adjacent to a stream or receiving water.
- Average costs for private PCO implementation are the least of any Setting.

3.5. Treatment Tiers

Treatment Tiers represent groups of PCOs that apply to a particular urban upland Setting and combine PCOs associated with each of the three major load reduction elements (i.e., PSC, HSC, and SWT). PCOs within a Treatment Tier were selected on the basis of feasibility in the Setting, estimated need for pollutant control, and probable cost-effectiveness in terms of load reduction. For each urban upland Setting, the UGSCG developed a generalized description of three scenarios: the existing condition, and two Treatment Tiers designed to (1) characterize the current BMP implementation practices, and (2) characterize a maximum level of BMP implementation.

Pollutant loading associated with the existing conditions is provided from the Watershed Model output from Phase One of the Lake Tahoe TMDL. The UGSCG assessed the existing conditions of each Setting and noted the key physiographic characteristics influencing pollutant loading, including the typical constraints and typical opportunities for storm water quality improvement. The description of the existing conditions in a Setting guided the selection of PCOs applied within a Treatment Tier. The existing conditions run of the Watershed Model is based on land use EMCs and calibration adjustments to LTIMP stream data loads. The estimation of loads for Treatment Tiers described below is based on the concept of predicting achievable loads for particular Settings and land uses with the application of PCOs (e.g., achievable effluent concentrations).

Each urban upland Setting includes two standard Treatment Tiers: Tier 1 and Tier 2. The two Treatment Tiers were selected to represent current practice in the Lake Tahoe Basin and an elevated standard of performance. The Treatment Tiers were selected to facilitate an assessment of pollutant load reductions that could be achieved from continued implementation using existing practice and from implementation of more advanced or intensive practices. Generalized descriptions for both Treatment Tiers are provided below.

- **Tier 1:** The existing practice load reduction associated with existing technology for PCO application. The spatial extent of PCO application within a Setting considers typical practice, opportunities, and site constraints. Tier 1 assumes that sufficient funding is available to address the most significant pollutant sources from public lands. Tier 1 includes assumptions regarding the use of public land and some limited acquisitions of private property for construction of water quality facilities that are consistent with current practice. Tier 1 assumes that PCOs continuously function as designed through routine maintenance and operations. Tier assumes a 50 percent implementation level for private-property BMPs required by current code.
- **Tier 2:** The maximum analyzed load reduction associated with advanced technology assuming no pumping or export of flows from the catchment. The spatial scale of PCO application exceeds existing practice to address all pollutant sources from public lands, including a more explicit focus on nutrients and fine sediment particles than Tier 1. Advanced technology PCOs include pretreatment of storm water before filtration, absorption, or infiltration for dissolved nutrients. The limitations associated with current funding, land acquisition, and other constraints are reduced compared to Tier 1. More aggressive land acquisition is assumed relative to Tier 1, and typical institutional constraints associated with maintenance and operations are assumed to be resolved by new funding mechanisms. Tier 2 assumes that PCOs continually function as designed, and at a higher level than Tier 1, through aggressive maintenance and operations. Tier 2 assumes 100 percent implementation of private BMPs required by current code.

Concentrated-Steep Setting

The concentrated-steep Setting is the most constrained for siting PCOs. The selection of PCOs within Tier 1 is driven more by constraints relative to opportunities as explained in the characterization of Settings in Section 3-4. Table 3-13 provides a summary of the PCOs selected for application in Tier 1 and Tier 2, the spatial scale of application for each PCO, and a brief rationale for selection.

To determine the spatial scale of PCO application for Tier 1, construction documents for recently completed storm water quality improvement projects were reviewed for the specific Setting. The difference between the selection of PCOs within Tier 1 and Tier 2 for this Setting is driven by an increase in opportunities for acquisition of land and a larger spatial application of PCOs.

Table 3-13. Concentrated-steep Treatment Tiers

PCO	Description of PCO function	Spatial scale of application Tier 1	Spatial scale of application Tier 2	Rationale for spatial scale of PCO application and key assumptions Tier 1	Rationale for spatial scale of PCO application and key assumptions Tier 2
PSC-1A	Road drainage system stabilization; distributed collection of pollutants; Road abrasives application reductions, maintenance and operations	70%	n/a	Primary opportunity for load reductions in Tier 1 for this Setting	Not applied
PSC-1B	PSC1A plus increased maintenance and operations; Use of alternative deicers; Use of advanced road abrasive collection technology	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-2A	Public fertilizer turf strategies focusing on education and advice on development of Fertilizer Management Plans	100%	n/a	Standard assumption for Tier 1	Not applied
PSC-2B	Advanced public turf management strategies, including limits on fertilizer application, ban on sales of P fertilizer and nonnative plants, incentives for compliance	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-3A	Private BMP implementation to reduce application and mobilization of pollutants	50%	n/a	Standard assumption for Tier 1	Not applied
PSC-3B	PSC3A plus additional education initiatives, management strategies and incentives for compliance; Ban on sales of P fertilizer and nonnative plants	n/a	100%	Not applied	Standard assumption for Tier 2
HSC-2	Decrease runoff reaching outlet in steep sloped catchments	5%	10%	Minimal volume reductions achieved; dispersal of runoff highly unlikely	Tier 1 plus some impervious surface removal
HSC-3	Private BMP implementation to detain and infiltrate runoff	50%	100%	Standard assumption for Tier 1	Standard assumption for Tier 2
SWT-2A	Mechanical separation	25%	n/a	Space constraints limit runoff capture	Not applied
SWT-2B	Mechanical separation with media filtration	n/a	100%	Not applied	Land acquisitions or extensive subsurface construction in right-of-way

Concentrated-Moderate Setting

The concentrated-moderate Setting is less constrained for siting PCOs relative to the concentrated-steep Setting because of milder slopes. However, the relatively dense impervious area limits the sizing and selections of certain PCOs. The selection of PCOs within Tier 1 is driven more by land availability constraints relative to opportunities as explained in the characterization of Settings in Section 3-4. Table 3-14 provides a summary of the PCOs selected for application in Tier 1 and Tier 2, the spatial scale of application for each PCO, and a brief rationale for selection.

Table 3-14. Concentrated-moderate Treatment Tiers

PCO	Description of PCO function	Spatial scale of application		Rationale for spatial scale of PCO application and key assumptions	
		Tier 1	Tier 2	Tier 1	Tier 2
PSC-1A	Road drainage system stabilization; distributed collection of pollutants; Road abrasives application reductions, maintenance and operations	60%	n/a	Slopes are mild, but high impervious density typically warrants stabilized road shoulders to collect pollutants	Not applied
PSC-1B	PSC1A plus increased maintenance and operations; Use of alternative deicers; Use of advanced road abrasive collection technology	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-2A	Public fertilizer turf strategies focusing on education and advice on development of Fertilizer Management Plans	100%	n/a	Standard assumption for Tier 1	Not applied
PSC-2B	Advanced public turf management strategies, including limits on fertilizer application, ban on sales of P fertilizer and nonnative plants, incentives for compliance	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-3A	Private BMP implementation to reduce application and mobilization of pollutants	50%	n/a	Standard assumption for Tier 1	Not applied
PSC-3B	PSC3A plus additional education initiatives, management strategies and incentives for compliance; Ban on sales of P fertilizer and nonnative plants	n/a	100%	Not applied	Standard assumption for Tier 2
HSC-1	Decrease runoff reaching outlet in moderately sloped catchments	10%	20%	Minimal spreading of flows based on land availability	Tier 1 plus impervious surface removal and pervious pavement
HSC-3	Private BMP implementation to detain and infiltrate runoff	50%	100%	Standard assumption for Tier 1	Standard assumption for Tier 2
SWT-1A	Surface detention and sedimentation	50%	n/a	Existing opportunities for storage are maximized	Not applied
SWT-1B	Surface detention and sedimentation with biological/chemical treatment processes	n/a	100%	Not applied	Land acquisitions increase opportunities for storage

Dispersed-Steep Setting

The dispersed-steep Setting is less constrained for siting PCOs relative to the concentrated-moderate and concentrated-steep Settings. However, the relatively steep slopes within this Setting limit the feasible application of some PCOs and reduce overall performance because of less capture of runoff. The selection of PCOs within Tier 1 does have significant opportunities as explained in the characterization of Settings in Section 3-4. Table 3-15 provides a summary of the PCOs selected for application in Tier 1 and Tier 2, the spatial scale of application for each PCO, and a brief rationale for selection.

Table 3-15. Dispersed-steep Treatment Tiers

PCO	Description of PCO function	Spatial scale of application		Rationale for spatial scale of PCO application and key assumptions	
		Tier 1	Tier 2	Tier 1	Tier 2
PSC-1A	Road drainage system stabilization; distributed collection of pollutants; Road abrasives application reductions, maintenance and operations	50%	n/a	Road shoulders parallel to slope stabilized; road shoulders perpendicular to slope not stabilized	Not applied
PSC-1B	PSC1A plus increased maintenance and operations; Use of alternative deicers; Use of advanced road abrasive collection technology	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-2A	Public fertilizer turf strategies focusing on education and advice on development of Fertilizer Management Plans	100%	n/a	Standard assumption for Tier 1	Not applied
PSC-2B	Advanced public turf management strategies, including limits on fertilizer application, ban on sales of P fertilizer and nonnative plants, incentives for compliance	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-3A	Private BMP implementation to reduce application and mobilization of pollutants	50%	n/a	Standard assumption for Tier 1	Not applied
PSC-3B	PSC3A plus additional education initiatives, management strategies and incentives for compliance; Ban on sales of P fertilizer and nonnative plants	n/a	100%	Not applied	Standard assumption for Tier 2
HSC-2	Decrease runoff reaching outlet in steep sloped catchments	15%	30%	Select opportunities to disperse runoff while considering physical constraints	Tier 1 plus additional drainage infrastructure to disconnect and disperse runoff
HSC-3	Private BMP implementation to detain and infiltrate runoff	50%	100%	Standard assumption for Tier 1	Standard assumption for Tier 2
SWT-2A	Mechanical separation	40%	n/a	Slopes limit opportunities for runoff capture	Not applied
SWT-2B	Mechanical separation with media filtration	n/a	100%	Not applied	Extensive subsurface construction for treatment

Dispersed-Moderate Setting

The dispersed-steep moderate Setting is the least constrained for siting PCOs. The selection of PCOs within Tier 1 has significant opportunities as explained in the characterization of Settings in Section 3-4. Table 3-16 provides a summary of the PCOs selected for application in Tier 1 and Tier 2, the spatial scale of application for each PCO, and a brief rationale for selection.

Table 3-16. Dispersed-moderate Treatment Tier

PCO	Description of PCO function	Spatial scale of application		Rationale for spatial scale of PCO application and key assumptions	
		Tier 1	Tier 2	Tier 2	Tier 2
PSC-1A	Road drainage system stabilization; distributed collection of pollutants; Road abrasives application reductions, maintenance and operations	40%	n/a	Least amount of road shoulders stabilized because of moderate erosion potential	Not applied
PSC-1B	PSC1A plus increased maintenance and operations; Use of alternative deicers; Use of advanced road abrasive collection technology	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-2A	Public fertilizer turf strategies focusing on education and advice on development of Fertilizer Management Plans	100%	n/a	Standard assumption for Tier 1	Not applied
PSC-2B	Advanced public turf management strategies, including limits on fertilizer application, ban on sales of P fertilizer and nonnative plants, incentives for compliance	n/a	100%	Not applied	Standard assumption for Tier 2
PSC-3A	Private BMP implementation to reduce application and mobilization of pollutants	50%	n/a	Standard assumption for Tier 1	Not applied
PSC-3B	PSC3A plus additional education initiatives, management strategies and incentives for compliance; Ban on sales of P fertilizer and nonnative plants	n/a	100%	Not applied	Standard assumption for Tier 2
HSC-1	Decrease runoff reaching outlet in moderately sloped catchments	30%	50%	Highest level of opportunities to disconnect and disperse runoff	Tier 1 plus additional drainage infrastructure to disconnect and disperse runoff
HSC-3	Private BMP implementation to detain and infiltrate runoff	50%	100%	Standard assumption for Tier 1	Standard assumption for Tier 2
SWT-1A	Surface detention and sedimentation	40%	n/a	Majority of runoff is typically perceived to not need treatment	Not applied
SWT-1B	Surface detention and sedimentation with biological/chemical treatment processes	n/a	100%	Not applied	Additional drainage infrastructure to route to treatment opportunities

Storm Water Collection, Pumping, and Treatment

Besides the two standard Treatment Tiers (i.e., Tier 1 and Tier), a specialized Treatment Tier was developed to collect and pump storm water from localized drainages to a regional facility suitable for advanced storm water treatment using mechanical processes similar to those applied for potable water supplies. For the purposes of this section, this special Treatment Tier analyzed by the UGSCG is referred to as the P&T Tier.

Figure 3-7 displays a conceptual approach for application of the P&T Tier. Storm water runoff from a drainage catchment(s) is collected and routed to localized storage locations. Each localized storage location has some capacity for detention of storm water runoff and is connected to a pump station. The localized pump stations convey runoff to a centralized storage facility and force main, which conveys runoff to a regional storage facility. The regional storage facility supplies the treatment system. After routing through the treatment system, runoff is conveyed via a closed storm drain system to the Lake, or an alterative outfall.

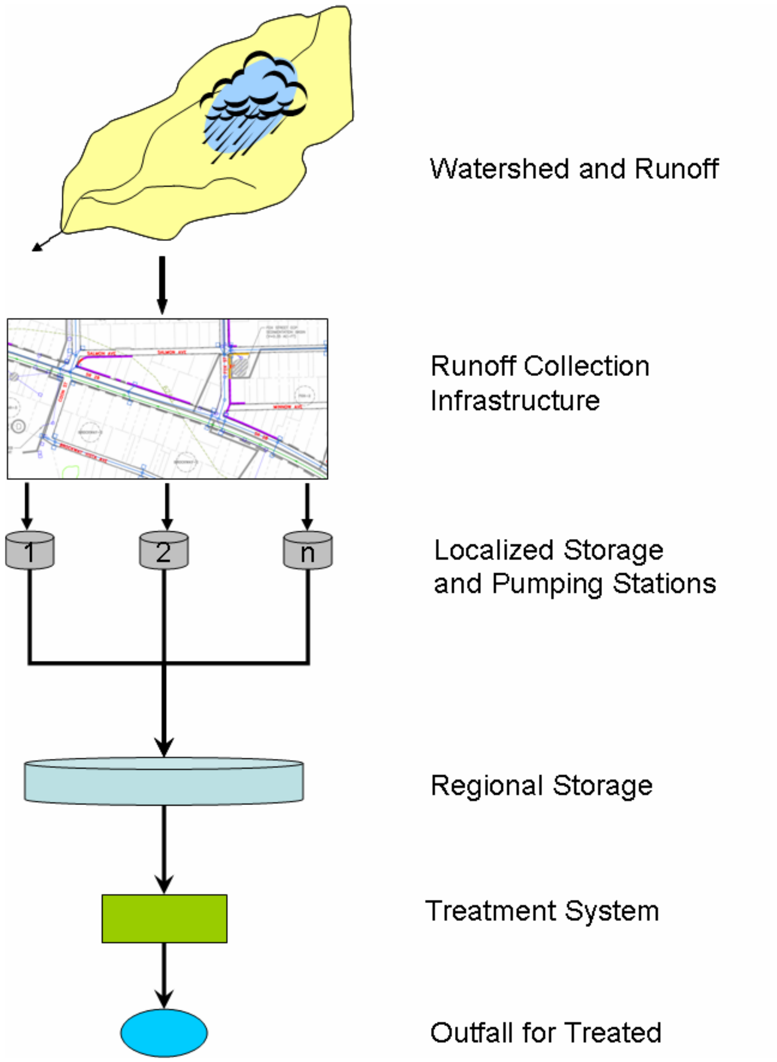


Figure 3-7. Conceptual approach for the P&T Tier.

Assumptions and Approach

This section describes the overall approach and the major assumptions made by the UGSCG. To evaluate the performance of the conceptual approach described, the UGSCG has constrained the analysis to one scenario by making numerous assumptions for each component shown in Figure 3-7. Note that the analysis performed by the UGSCG is only the first step in determining the feasibility of the overall concept for application within the Tahoe Basin. The work performed by the UGSCG was conducted with limited resources and makes very broad assumptions. A more thorough assessment of alternatives, optimization, and implementation considerations is recommended to determine the ultimate feasibility of the P&T Tier.

The specific assumptions used to develop the P&T Tier are explained and categorized below according to the major components shown in Figure 3-7.

Watershed and Storm Water Runoff

- The approach evaluates an upper threshold of potential load reductions achieved through the P&T approach. All runoff from a drainage catchment is assumed to be directed to localized collection points and load reductions are achieved through SWT at the treatment facility. Therefore, PCO implementation for both PSCs and HSCs are limited to infrastructure necessary to convey and collect runoff at localized detention points. Private-property BMP implementation is not assumed, and runoff from private property is routed to the localized collection points. This assumption was made to assess the maximum load reduction achievable from the treatment facility.
- A single regional treatment facility is applied to multiple adjacent urban subwatersheds designated as either concentrated-steep or concentrated-moderate. The overall concept of P&T is assumed to increase in feasibility through economies of scale associated with treating a relatively large area of contiguous, more densely developed land. Therefore, the P&T Tier is not applicable to all urban uplands in the Tahoe Basin but is applicable to particular regions in with the highest urban densities. The approximate regions proposed for a single P&T system are shown in Figure 3-8. The approach for simulation of this assumption in the Watershed Model Basin-scale extrapolation is discussed in Section 3-6.
- To estimate facility sizing, an average drainage catchment of 40 acres was assumed for each localized storage and pumping location. This drainage catchment size was assumed considering that many urban drainages with the regions designated in Figure 3-8 are in intervening zones, and have relatively small catchment areas draining to Lake Tahoe.

Collection System

- Infrastructure improvements associated with runoff collection and conveyance are assumed to separate urban runoff from forest runoff and direct only urban runoff to localized storage locations. This assumption is accounted for in cost estimates.
- Infrastructure improvements for the collection system are at the spatial scale of application assumed for Tier 1 in a concentrated-moderate Setting.
- The collection system draining to localized storage does not involve pumping.

Localized Storage and Pumping

- The majority of collection points for localized storage and pumping are located in highly developed areas. The availability of storage is a significant limitation. A nominal 5,000 cubic feet (cf) of storage is assumed for each 40-acre drainage catchment. This storage is achieved through either land acquisitions or by constructing large subsurface vaults. This assumption is reflected in cost estimates.
- Localize storage provides some capacity to improve capture for variable flows and settle coarse sediment to improve pump operations.
- The localized storage and pumping assumptions control the volume of runoff captured and routed to regional storage. All runoff routed to regional storage is assumed treated to the achievable effluent concentrations of the treatment facility (See the *Estimated Performance* subsection below). The input assumptions for simulation in the Watershed Model are discussed in Section 3-6.

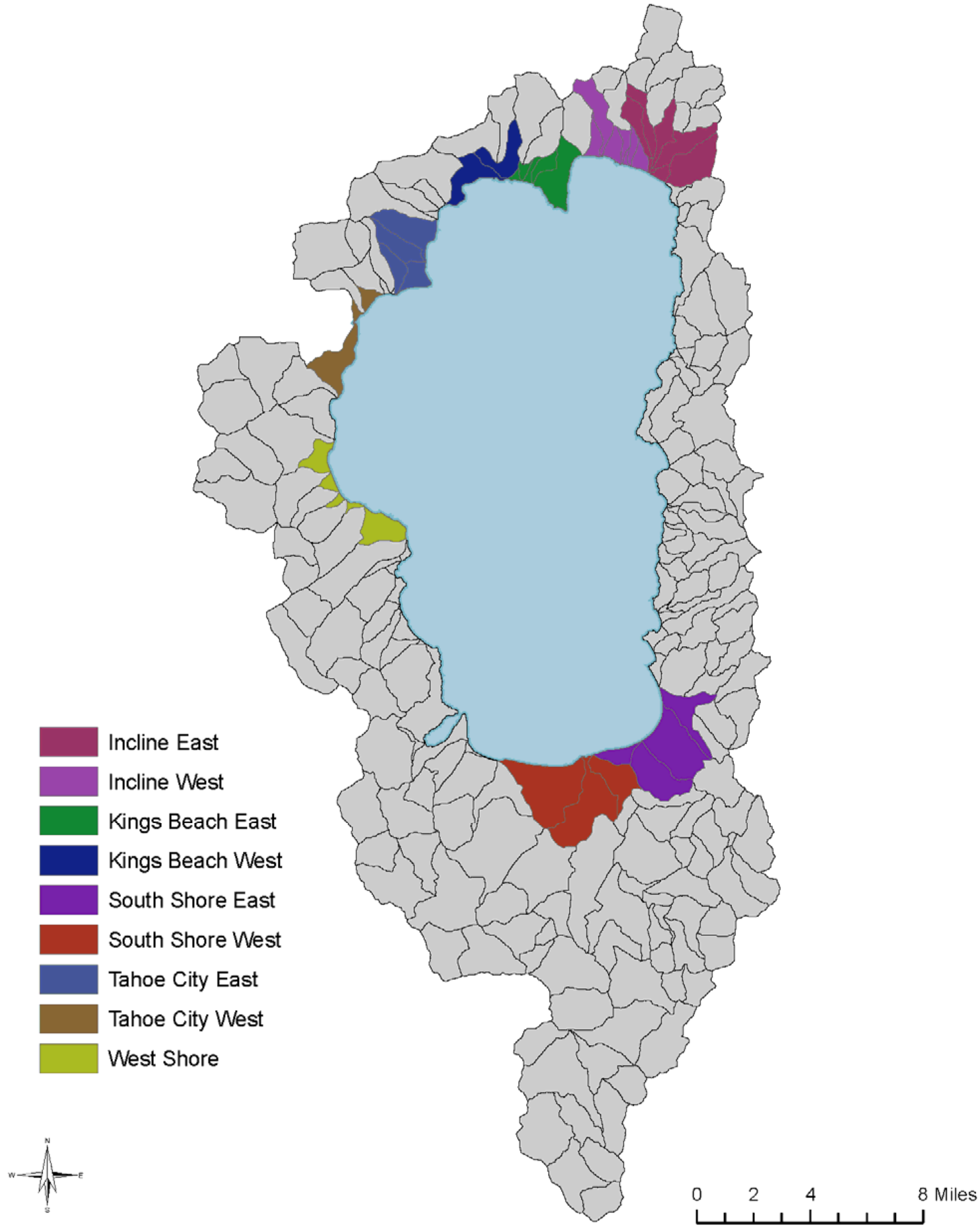


Figure 3-8. P&T regions.

Regional Storage

- The most efficient performance for the treatment facility is assumed to occur if the system receives regulated low flows and is operated frequently. To accomplish these criteria, regional storage is assumed to have substantial capacity, which is reflected in the cost estimates. This assumption allows the treatment system to operate at more uniform design flow rates while not impeding the quantity of runoff captured at localized storage and pumping locations.
- Regional storage is outside, but directly adjacent to the urban subwatersheds within a mile of urban development. Acquisition of undeveloped land is assumed.

Treatment System—Targeted Pollutants

Pollutants of concern for Lake clarity are species of N, P, and fine sediment. The treatment system was selected to target particulate species of N, P, and fine sediment. The removal of DN in the treatment system would require separate processes, and it would be difficult to achieve significantly lowered concentrations. Additionally, the pollutant budget described in Phase One of the Lake Tahoe TMDL highlights that the majority of N input to the Lake is from atmospheric deposition. Therefore, the UGSCG assumes that targeting DN in the treatment system is not economically feasible and the effluent concentration for DN is assumed to equal influent concentration. DP is assumed to be reduced in the treatment system to a relatively modest level by virtue of adsorption to soil particles removed in the process. Research evaluating the removal of DP in storm water is ongoing in the Tahoe Basin.

Treatment System—Selected System and Estimated Performance

Advanced treatment processes, commonly employed for potable water treatment, can remove particulates and turbidity from natural waters to near or below the detection limit for standard analysis methods. Advanced treatment processes include the following:

- Media filtration
- Coagulation and sedimentation
- Membrane filtration

Of these advanced treatment processes, membrane filtration is considered the most applicable process for storm water in Lake Tahoe Basin because the effluent quality would be consistent and predictable; the labor requirements are lower than coagulation and sedimentation systems; and variable and intermittent flows would not significantly affect performance of the system.

There are four general categories of membrane filtration systems that correspond to the range of particle sizes targeted for removal based on the pore size of the membrane. These categories include (1) microfiltration, (2) ultrafiltration, (3) nanofiltration, and (4) reverse osmosis, with reverse osmosis providing the highest level of treatment. As the pore size of the membrane decreases, the amount of pressure required to operate the system increases, as does the quantity of water rejected during backflush and the capital and operations costs.

Microfiltration was selected from the processes listed above for the UGSCG analysis on because of the relative benefits of lower operation costs and anticipated effluent qualities with relatively low concentration of particulates. Microfiltration surface water treatment systems have been demonstrated to reduce TSS concentrations in treated effluent to levels between non-detect and 5 mg/L for influent concentrations between 5 mg/L and 500 mg/L (data received from the Santa Monica Urban Runoff Recycling Facility [SMURRF]). The anticipated quality of runoff in the regional storage would fall within this influent range and a similar effluent quality appears feasible through microfiltration treatment of storm water in the Tahoe Basin.

Microfiltration Process Description

Microfiltration is a process whereby a stream of liquid carrying suspended solid particles is passed through a membrane having pores of a size that will allow the liquid and dissolved materials (permeate) to pass through and retain the solid particles (retentate). Crossflow microfiltration, as illustrated in Figure 3-9, simply passes solids carrying liquid along a tubular shaped membrane. This is done under relatively low pressure with the aid of a pump. The differential pressure across the membrane (trans-membrane pressure) is enough to cause water to permeate the membrane tube and be collected as clean filtrate while the solid particles are swept along and eventually out of the tube. A crossflow microfiltration system contains an array of multiple membrane tubes and ancillary systems for prescreening, backflushing, and pressure regulation.

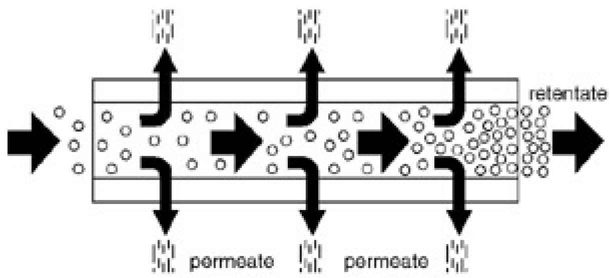


Figure 3-9. Crossflow microfiltration membrane tube diagram.

Figure 3-10 is an example of a 24-tube package, microfiltration water treatment plant. Feed water enters the unit after passing through a strainer. Once the membrane cell fills with raw water, the filtrate pump draws water through the membranes. A variable speed drive controls the speed of the filtrate pump and regulates filtrate flow as resistance to flow changes. The system shown uses submerged membrane modules. Filtrate is collected at the top of the modules. Low-pressure air for scouring during backwash is injected at the bottom of the modules. A backwash step (15- to 60-minute intervals) helps to minimize membrane fouling. The backwash process uses a low-pressure air scour (or liquid backwash) that reverses filtration removing accumulated particles from the surface of the membrane fibers. To address fouling layers that cannot be removed by backwashing alone, the standard design includes the ability to perform chemical maintenance washes and clean-in-place cycles. A horizontal removal system is simple enough that a single operator can remove a rack and access individual modules for repair or replacement. Between 2 percent and 5 percent of the total flow through the system is wasted during backflushing. For this assessment, this *reject water* is assumed to be routed back to the regional storage facility. However, the reject water could be disposed of to a sanitary system and pumped out of the Basin, concentrated and filtered, or temporarily impounded then treated by another method.

A 48-tube, 0.5–million-gallon-per-day (mgd) package microfiltration system was used for evaluating the economics and feasibility of microfiltration for storm water treatment in the Basin. A package system was chosen because it has known performance specifications, capital cost estimates, and O&M cost estimates. The facility shown in Figure 3-10 would fit inside a building with a footprint of roughly 20 feet by 30 feet.

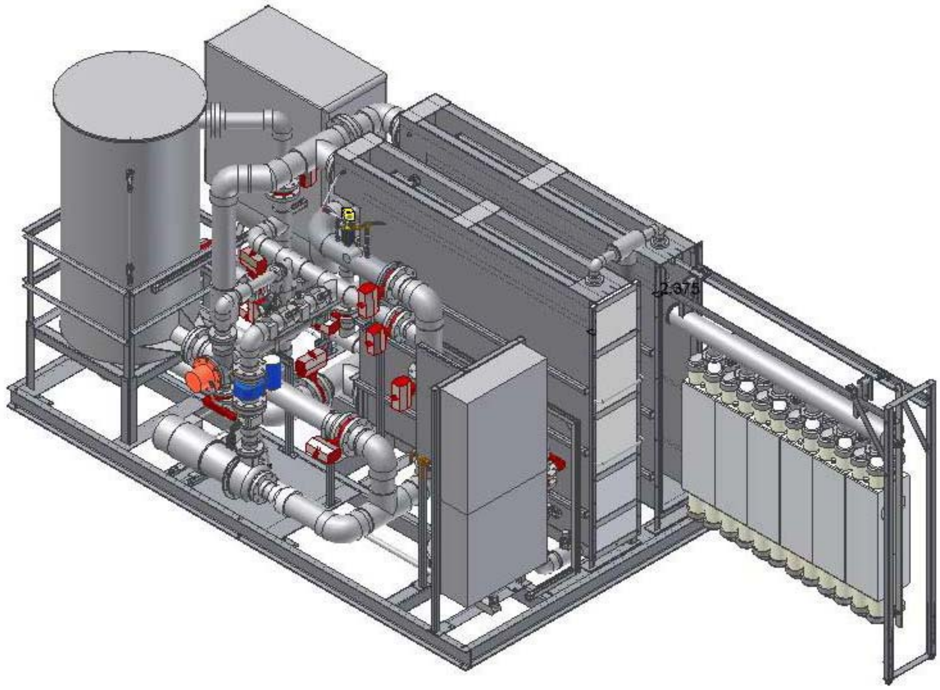


Figure 3-10. Example microfiltration-packaged water treatment facility (Memcor®).

Estimated Performance

As shown in Figure 3-11, the estimated performance of the microfiltration facility for reducing TSS concentrations is significant. Estimated concentrations of TSS from the facility would likely range between non-detect levels and 5 mg/L (based on personal communication with SMURRF and median value for TSS for the SMURRF facility reported in Bay and Brown 2005). Additional pollutants of concern associated with particulates (i.e., TN and TP) would also have substantially better quality in effluent concentrations. Table 3-17 lists effluent concentrations for all pollutants of concern for simulation in the Watershed Model. Achievable effluent concentrations for particulates are based on limited SMURRF data. Achievable effluent concentrations for DP are assumed to be reduced in the treatment system by virtue of adsorption to soil particles removed in the process. Specific data on DP removal at the concentrations of interest was not located. Performance of the system for DP was assumed to be slightly better than the achievable effluent quality of SWT-1B.

Figure 3-11. Estimated TSS performance for microfiltration

Table 3-17. Estimated treated effluent quality for microfiltration

Outlet	TN	DN	TP	DP	TSS	TSS < 63 µm
Treated	0.23	Influent	0.034	0.012	5	5

Confidence in Performance Estimates

The confidence associated with estimating the performance for the P&T Tier has a variable level of uncertainty because of the coarse scale of analysis performed by the UGSCG. The performance of the proposed treatment facility for TSS and particulate removal appears promising, because estimates are based on the real-world application—albeit for treatment of dry-weather flows and not storm water runoff. Additional work is necessary to further assess the achievable effluent quality for particulates, because effluent quality would be dependant on operations (e.g., blending with pretreated water) and influent characteristics (e.g., particle size distribution). For more information about the SMURRF, see http://santa-monica.org/epd/residents/Urban_Runoff/pdf/UR_SMURRF_Info_Sheets.pdf.

Note that example applications of treatment systems in other regions do no attempt to achieve the reductions in P and N concentrations desired in the Basin. Therefore, confidence in achievable effluent concentrations for dissolved nutrients is low because real-world examples do not have applicable data.

The largest uncertainty occurs for estimating the performance of runoff capture at localized collection points with subsequent routing to the treatment system. The modeling tools and resources available to estimate hydraulic performance of the system was limited. Actual performance and the hydraulic design would be quite complicated. The estimated quantity of runoff captured, as modeled in the Watershed Model should be viewed with considerable uncertainty. Additional studies will be necessary to improve confidence in results from this initial effort.

3.6. Analysis Methodology

Treatment Tiers provide the conceptual basis for estimating overall pollutant load reductions and costs. The analysis methodology translates the combination of PCOs that define a Treatment Tier to an Input Table for the Watershed Model. These Input Tables are the set of inputs to the Watershed Model for computation of pollutant load reductions by Setting. The product provided by the analysis methodology is the set of Input Tables with supporting assumptions and rationale. The UGSCG was not tasked with quantifying the Basin-wide pollutant load reductions for the urban upland source category for inclusion in the Lake Tahoe TMDL. Instead, the UGSCG was tasked with developing Input Tables for each Setting, and each Treatment Tier, in appropriate formats for input in the Watershed Model. Subsequent simulations in the Watershed Model use the input developed in this report to estimate pollutant load reductions for urban upland sources.

The Input Tables define the routing of runoff from specific urban upland land uses through PCOs. For PCOs associated with each major load-reduction element (i.e., PSC, HSC, and SWT), performance characteristics are specified by the Input Table that can be used in Watershed Model simulations. In each Input Table, the performance of PSCs for improving the quality of runoff is defined in terms of reduced EMCs by land use. After taking into account PSCs, the performance of HSCs for runoff reduction is specified using storage and infiltration parameters on a unit impervious area basis. The total volume of runoff captured by HSCs in a particular Treatment Tier and Setting will vary by subwatershed in the Watershed Model, but performance in terms of total runoff volume (% capture, or capture ratio) should be relatively uniform. After routing through HSCs, runoff is routed to SWT. SWT performance is defined by achievable effluent concentrations for the portion of the runoff treated. Bypassed flows for SWT are assumed to discharge to surface waters at influent concentrations. SWT inputs in the Input Table include storage and infiltration parameters that affect capture ratio, which are similar to the parameters defined for HSCs.

The UGSCG for the analysis methodology distributes urban upland land uses into one of four land-use groups to develop and simplify estimates of input for the Watershed Model. A land-use group is a collection of similar urban upland land uses that are routed to a specific PCO(s) as defined in the Treatment Tier for a particular Setting. As shown below in Table 3-18, the four land-use groups are defined by the UGSCG corresponding to (1) private impervious, (2) private pervious, (3) public impervious, and (4) public pervious. Only the nine land uses designated as urban upland are included in a land-use group (Table 3-18). Using this approach, the urban upland Input Tables avoid overlapping performance estimates with forest upland PCOs because urban upland PCOs never operate on pollutant sources from forest upland land uses.

Table 3-18. Applicable land uses by area

Land use groups			
Private impervious	**Private pervious**	**Public impervious**	**Public pervious**
CICU-Impervious	CICU-Pervious	Roads_Primary	Veg_Turf
Residential_MFI	Residential_MFP	Roads_Secondary	
Residential_SFI	Residential_SFP		

Land uses are distributed into each land use group on the basis of the following two objectives:

1. To provide input for the Watershed Model with a structure that is readily transferable and useable. To this end, pervious and impervious land uses are used as a key discriminator to define land-use groups. This is consistent with the Watershed Model representation of runoff processes, and allows for separate tracking and simulation in the Watershed Model. Note that land-use groups are not necessarily physically contiguous areas but are areas with similar characteristics that will have similar PCOs applied and be treated in the same way in the model.

2. To distinguish between private and public property for all cases in which PCOs are applied. This provides separate accounting and tracking of PCOs applied on private and public property for summaries of pollutant loading. Note that as a simplification, certain land uses were designated as public or private but could actually be a mixture of the two (i.e., CICU and vegetated turf). In such cases, each land use was placed in the dominant land-use group. For example, CICU is predominantly composed of private land uses in the Tahoe Basin.

The overall analysis methodology used to populate an Input Table is shown in the routing schematic for a Tier 2 concentrated-steep Setting (Figure 3-12). The methodology shown in Figure 3-12 illustrates the routing of runoff from each land use group through each major load-reduction element (i.e., PSC, HSC, and SWT). The Tier 2 routing is presented first because it is less complicated than Tier 1 routing because Tier 2 assumes the spatial scale of PCO application is 100 percent in each Setting.

The routing schematic shown in Figure 3-12 is repeated for each Setting for Tier 2 (Appendix UGSCG-D). For brevity, a single example is presented in the main report. The *callouts* shown on the schematic are provided to help the reader interpret the routing schematic.

- **Callout 1:** Each of the four land-use groups (Table 3-18) are routed to the major load-reduction elements. Routing to a PSC will change the characteristic land-use EMCs dependent on the Treatment Tier and PCO applied. Routing to a HSC will decrease runoff volumes. Routing to a SWT could decrease runoff volumes and would reduce pollutant loading through changes to effluent concentrations for treated runoff.

- **Callout 2:** The percentages highlighted in red represents the assumptions developed for each Setting and Treatment Tier (Section 5) regarding the spatial scale of PCO application to the specific land-use group.
- **Callout 3:** The labels within each major load-reduction element specify the specific PCO applied and are based on the Treatment Tier employed.
- **Callout 4:** The Setting-based decision note is provided to route a percentage of runoff from public, impervious surfaces to HSC to simulate the disconnection of impervious surfaces in the drainage system.
- **Callout 5:** The blue text represents routing of runoff calculated in the Watershed Model using input provided by the UGSCG.

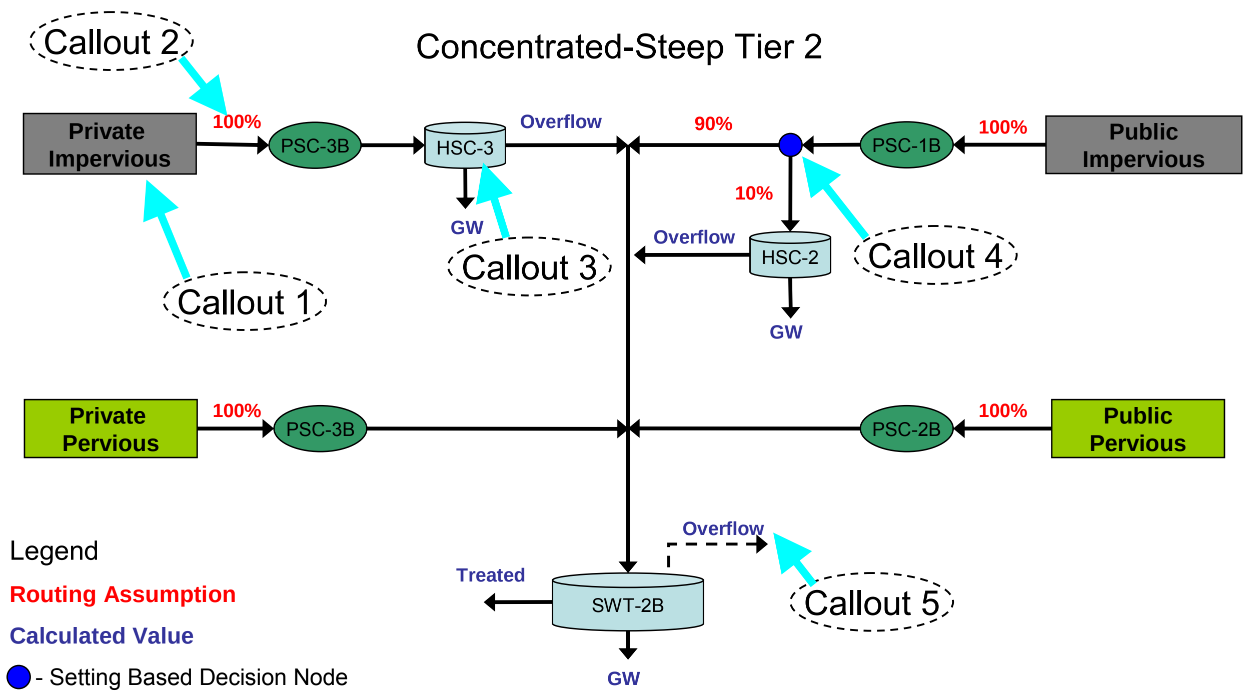


Figure 3-12. Analysis methodology to inform Input Tables for Tier 2.

The analysis methodology for a concentrated-steep Setting Tier 1 is shown in Figure 3-13. The Tier 1 routing is more complicated than the Tier 2 routing because the spatial scale of PCO implementation varies within a Setting. This assumption was necessary because it represents existing practice.

The routing schematic shown in Figure 3-13 is repeated for each Setting for Tier 1 (Appendix UGSCG-D). For brevity, a single example is presented here. Similar to Figure 3-12, callouts are provided to help the reader interpret the routing schematic. Callouts for Tier 1 focus on the routing differences relative to Tier 2.

- **Callout 1:** Because not all runoff is routed through PCOs in existing practice, the Tier 1 routing represents this scenario. The percentage of a land-use group routed directly to the outlet is the spatial area of the land-use group with no load reduction in Tier 1 based on the assumptions of the specific Treatment Tier.
- **Callout 2:** After routing through PSCs, runoff could be routed to the outlet for public areas. This assumption is included because in existing practice it is common for some areas to receive PSC,

but runoff from areas where PSCs are applied might not be routed to a HSC or SWT. Note that all private area routing to a PSC is assumed routed to SWT because private areas typically cannot direct or alter runoff pathways at the drainage catchment scale.

- **Callout 3:** Public pervious is assumed to receive 100 percent PCO application in Tier 1 before routing to the outlet. However, PSC-2A is a less-intensive PCO relative to PSC-2B and therefore results in less load reduction.

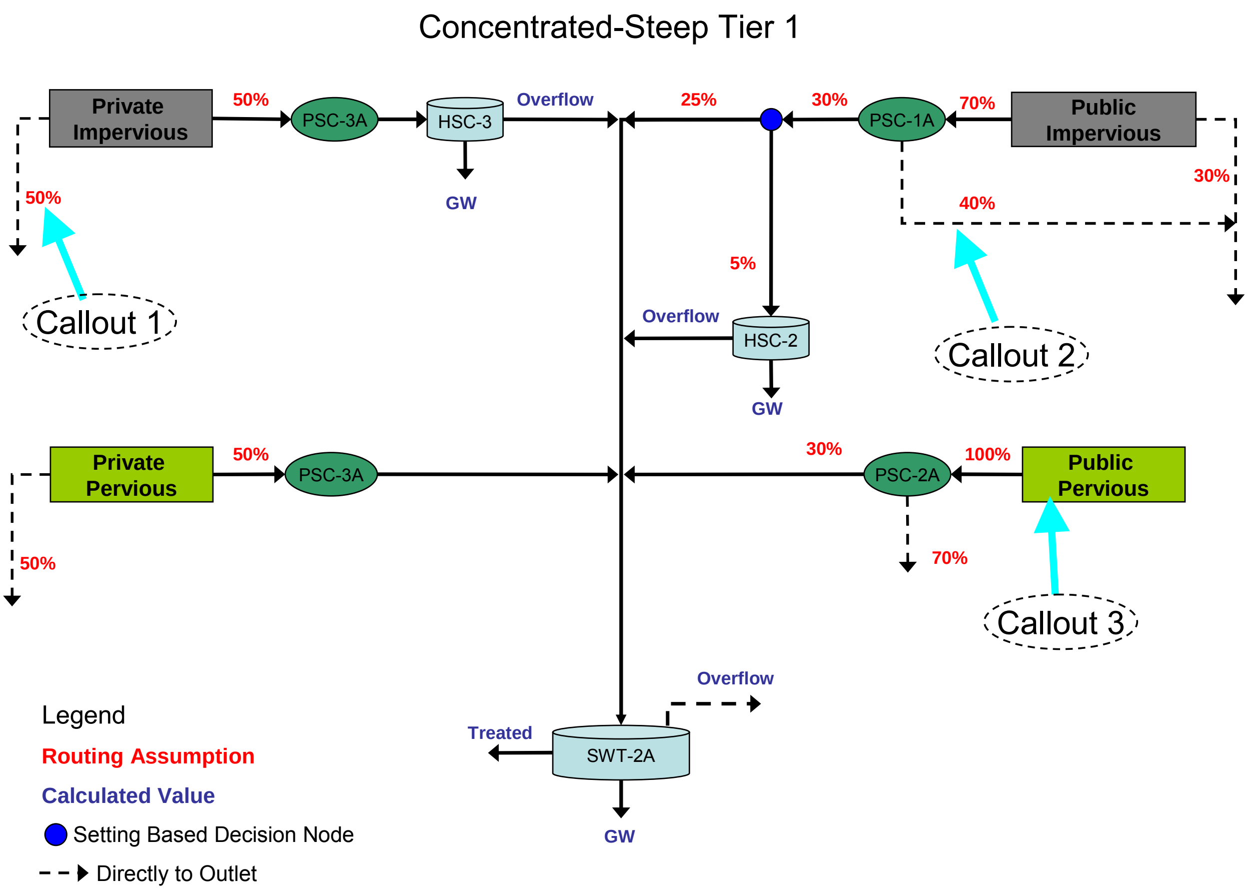


Figure 3-13. Analysis methodology to inform Input Tables for Tier 1.

A complete set of the routing diagrams for each Setting is provided in Appendix UGSCG-D. The process shown in Figure 3-12 and 3-13 is repeated for each Setting and results in a relatively simple way to complete Input Tables. The following section describes the Input Tables for the Watershed Model (Input Table), which is a tabular summary of the routing schematics.

Load Reductions

The Input Table developed by the UGSCG is shown in Table 6-2 for the concentrated-steep Setting. The Input Table identifies the routing of land use groups to the major load reduction elements for each Treatment Tier. This approach was necessary to organize all information analyzed by the UGSCG in understandable formats useable by the Watershed Model. For brevity, a single example Input Table and a single example of each specific Reference Table are described and displayed in the main text. Reference Tables are used within each Input Table to inform the Watershed Model by pointing to achievable effluent quality tables and volume-discharge relationship tables. The complete set of Input Tables and Reference Tables is provided in Appendix UGSCG-D.

Example Input Table

An example Input Table is provided in Table 3-19. Brief descriptions of the components of Table 3-19 are provided below for each column. As described above, the Input Table is illustrated using the routing schematics in Figures 3-12 and 3-13.

Table 3-19. Input Table example for concentrated-steep Setting

Treatment Tier	Land use group	Routing	% Spatial application	Reference table(s)		
				PSC	HSC	SWT
Tier 1	Private Impervious	Directly to outlet	50%			
		PSC to HSC to SWT	50%	Tier 1 EMC	HSC-3	SWT-2A
	Private Pervious	Directly to outlet	50%			
		PSC to SWT	50%	Tier 1 EMC		SWT-2A
	Public Impervious	Directly to outlet	30%			
		PSC only	40%	Tier 1 EMC		SWT-2A
		PSC to SWT	25%	Tier 1 EMC		SWT-2A
		PSC to HSC to SWT	5%	Tier 1 EMC	HSC-2	SWT-2A
	Public Pervious	PSC	70%			
		PSC to SWT	30%	Tier 1 EMC		SWT-2B
Tier 2	Private Impervious	PSC to HSC to SWT	100%	Tier 2 EMC	HSC-3	SWT-2B
	Private Pervious	PSC to SWT	100%	Tier 2 EMC		SWT-2B
	Public Impervious	PSC to SWT	90%	Tier 2 EMC		SWT-2B
		PSC to HSC to SWT	10%	Tier 2 EMC	HSC-2	SWT-2B
	Public Pervious	PSC to SWT	100%	Tier 2 EMC		SWT-2B

- **Treatment Tier:** The Treatment Tiers, either Tier 1 or Tier 2, for a particular Setting.
- **Land Use Group:** A collection of similar urban upland land uses that are routed to a specific PCO(s) within the major load reduction elements (i.e., PSC, HSC, and SWT).
- **Routing:** The pathway runoff is assumed to travel for each land use group and specific Treatment Tier. The percentage of a land use group routed *directly to outlet* receives no load reductions in Tier 1.
- **% Spatial Application:** The percentage routed through the specified path of major load reduction elements. This percentage of spatial application was developed by UGSCG in Section 3.5 – Treatment Tiers.
- **Pollutant Source Controls (PSC):** The Reference Table for assigning EMCs to land uses on the basis of load reduction achieved from PCO application.
- **Hydrologic Source Controls (HSC):** The Reference Table for routing runoff to a specific HSC.
- **Storm Water Treatment (SWT):** The Reference Tables for routing runoff to a specific SWT.

Components of Reference Tables

Examples of Reference Tables are separated in this section by major load reduction element. The Reference Tables are formatted to inform the Watershed Model using volume-discharge relationships (F-tables in LSPC terminology) or achievable effluent quality tables. The complete set of Reference Tables are provided in Appendix UGSCG-D.

PSC Reference Table

The process for developing characteristic EMCs based on estimated PSC performance and the associated data sources are described in Section 3.3. Table 3-20 is the summary EMC table developed in previous sections of this report for the Tier 1 and Tier 2 Treatment Tiers.

Table 3-20. Characteristic EMCs after PSC by Treatment Tier

Treatment Tier	Land use	PCOs (Achievable EMC)					
		TN	DN	TP	DP	TSS	< 63 µm
Tier 1	Roads_Primary	2.39	0.72	1.21	0.10	582	85%
	Roads_Secondary	2.32	0.42	0.41	0.12	100	85%
	CICU_Impervious	2.47	0.29	0.37	0.08	112	85%
	Veg_Turf	4.39	0.44	1.35	0.26	12	63%
	Residential_SFP	1.58	0.13	0.42	0.13	38	76%
	Residential_MFP	2.56	0.42	0.53	0.14	56	88%
	CICU_Pervious	2.23	0.26	0.63	0.07	150	85%
	Residential_SFI	1.58	0.13	0.42	0.13	38	76%
	Residential_MFI	2.56	0.42	0.53	0.14	56	88%
Tier 2	Roads_Primary	2.00	0.72	0.37	0.10	124	85%
	Roads_Secondary	1.80	0.42	0.23	0.10	50	85%
	CICU_Impervious	2.47	0.29	0.37	0.08	112	85%
	Veg_Turf	2.38	0.35	0.36	0.26	12	63%
	Residential_SFP	1.10	0.10	0.30	0.10	38	76%
	Residential_MFP	1.75	0.42	0.47	0.14	56	88%
	CICU_Pervious	1.75	0.14	0.47	0.04	150	85%
	Residential_SFI	1.10	0.10	0.30	0.10	38	76%
	Residential_MFI	1.75	0.42	0.47	0.14	56	88%

HSC Reference Table

As previously discussed in Section 3.3, HSCs reduce the total storm water runoff volume through increased infiltration. The representation of a HSC using F-tables (stage-discharge relationships in the Watershed Model) is relatively simple compared to representation of SWT. Runoff routed to an HSC might either infiltrate, evapotranspirate, or continue as surface runoff when the capacity of the HSC has been exceeded. Table 3-21 displays an example of a unit area F-Table for an HSC-3 (private property) with a constant infiltration rate based on saturated hydraulic conductivity of 0.3 inch/hour. This approach is more conservative than infiltration rates currently used to guide private property BMPs (See http://www.tahoebmp.org/documents.aspx).

All parameters in Table 3-21 are based on storage and infiltration of 1 acre of impervious area runoff. This unit area assumption provides a convenient means of scaling implementation of HSCs in the Watershed Model. The combination of a specified infiltration rate and the percentage of impervious area routed to the HSC (specified in the Input Table) allows for subwatershed-specific simulations of HSCs using Table 3-21. Values for overflow in Table 3-21, shown in the column titled *Overflow*, represent an upper-bookend to bound the algorithm. The actual rates of overflow are calculated by the Watershed Model.

Table 3-21. Unit-Area F-Table for HSC-3

Stage (ft)	Surface area (acres)	Volume (acre-ft)	Outlet 1	Outlet 2
			Infiltration (cfs)	Overflow (cfs)[1]
0	0	0	0	0
0.01	0.203	0.0007	0.136	0
0.1	0.203	0.0081	0.136	0
0.2	0.203	0.0162	0.136	0
0.3	0.203	0.0244	0.136	0
0.4	0.203	0.0325	0.136	0
0.5	0.203	0.0406	0.136	0
0.6	0.203	0.0487	0.136	0
0.7	0.203	0.0568	0.136	0
0.8	0.203	0.0650	0.136	0
0.9	0.203	0.0731	0.136	0
1	0.203	0.0812	0.027	0
1.01	0.203	0.0812	0.027	10

SWT Reference Table

As mentioned in Section 3-3, four different PCOs representing SWT were devised—two surface-storage, volume-based PCOs (SWT-1A and SWT-1B) and two flow-based PCOs (SWT-2A and SWT-2B). SWTs have multiple components depending on the PCO specified, which can include surface water load reductions due to both infiltrative volume loss or concentration reductions. Additionally, SWT could reduce concentrations before infiltration (i.e., groundwater pretreatment).

Because SWT can affect both runoff volumes and quality, the Reference Tables for SWT include normalized design treatment capacities (F-Tables) and characteristic effluent concentrations (Effluent Tables) for each PCO. For flow-based PCOs, the treatment capacity is equal to the normalized water quality design flow rate (e.g., 0.1 inch/hour over an impervious acre) and bypass is assumed to occur when this flow rate is exceeded. For volume-based PCOs, the treatment capacity is equal to the normalized water quality design volume (e.g., 1-inch over an impervious acre) and bypass is assumed to occur when this storage volume is exceeded.

The general approach to developing the F-Tables for volume-based PCOs is to first identify the design volume and storage depth for a selected PCO/Treatment Tier and then design an outlet structure required to achieve the desired drain time. The result is a design stage-discharge relationship that is described in the F-Table. All volume-based PCOs are assumed to drain within a 48-hour drain time for the water quality design volume. A further assumption was made that the outlet structure is designed such that the top half of the Basin drains in approximately one-third of the drain time (16 hours) and the bottom half drains in approximately two-thirds of the drain time (32 hours). This approach, which uses a two-stage drain time increases the availability of the PCO for storage, and reduces the bypass or overflow volume that otherwise would undergo no or little treatment. The standard orifice equation was used to develop realistic stage-discharge relationships:

$$Q = C \times A\,(2gh)^{0.5}$$

Where,

- Q = flow rate (cfs)
- C = discharge coefficient (0.61 for sharp-edged orifice)
- A = cross-sectional area of the orifice (ft^2)
- g = gravitational constant (32.2 ft/s^2)
- h = head above the orifice invert elevation (ft).

Figure 3-14 illustrates the stage-discharge relationship with the two-stage drain time using the standard orifice equation above.

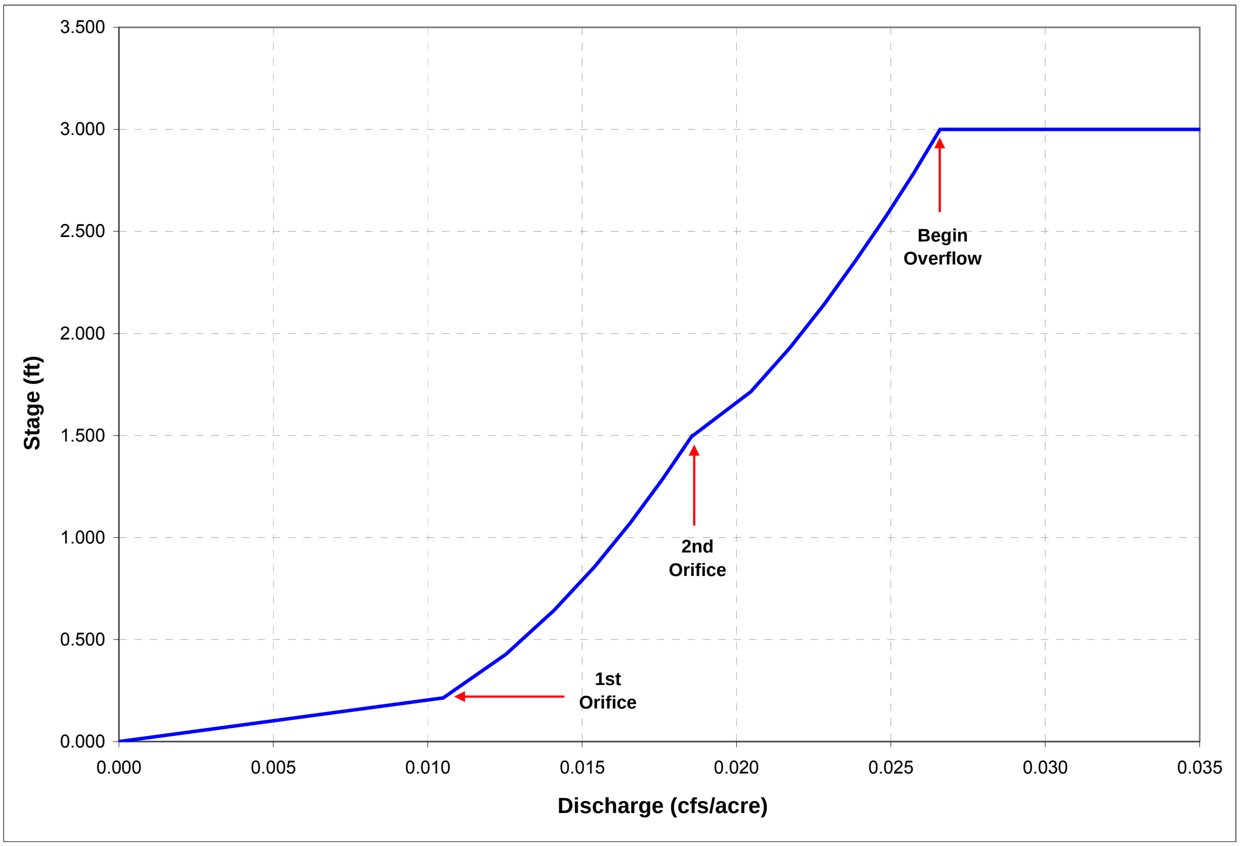


Figure 3-14. Stage-discharge relationship for two-stage drain time.

Infiltration rates were assumed for each PCO and Treatment Tier on the basis of assumed BMP characteristics and the range of urban area soil properties in the Tahoe Basin. Because SWT-1A and SWT-1B are surface detention-based systems, infiltration will likely be a larger component than for SWT-2A and SWT-2B. Also, because SWT-1B and SWT-2B are intended for Tier 2, it is assumed that these PCOs would be designed to infiltrate at a higher rate than for the existing practice PCOs.

Table 3-22 provides a summary of the assumed infiltration rates for each PCO. The infiltration rate assumptions in Table 6-5 are not directly associated with native soils. However, on the basis of the 1974 NRCS soil survey (USDA 1974), approximately 66 percent of the soils in the urban upland Settings are within hydrologic soil groups B and C, which have hydraulic conductivities ranging from 0.1 in/hr to 0.23 in/hr (James and James 2000). Therefore, the values listed in Table 3-22 are assumed reasonable and are maintained over time with the assumption of consistent maintenance. Note that the current version of the 2006 Tahoe Soil Survey does not include hydrologic properties for soil.

Table 3-22. Assumed infiltration rates for SWTs

PCO	Assumed infiltration rate (in/hr)
SWT-1A	0.2
SWT-1B	0.3
SWT-2A	0.05
SWT-2B	0.1

All F-Tables are normalized for one acre of impervious drainage area to facilitate scaling to the subwatershed scale in the Watershed Model. Table 3-23 is an example F-Table for a SWT-1A with a 48-hour drain time that is treating a 1-acre impervious area at an infiltration rate of 0.2 in/hr. The bypass rate in Table 3-23 represents an upper bookend for Watershed Model simulation to ensure untreated overflow occurs above the assumed water quality design depth of 3 feet. The actual rates of bypass are calculated by the Watershed Model.

Table 3-23. Example Unit Area F-Table for SWT-1A

Stage (ft)	Area (ac)	Volume (ac-ft)	Treated discharge (cfs)	Infiltration rate (cfs)	Bypass rate (cfs)
0.0000	0.0278	0.00E+00	0.00E+00	0.00E+00	0
0.4615	0.0278	1.28E-02	7.88E-03	1.93E-04	0
0.9231	0.0278	2.56E-02	1.58E-02	1.93E-04	0
1.3846	0.0278	3.85E-02	2.36E-02	1.93E-04	0
1.5100	0.0278	4.19E-02	2.86E-02	1.93E-04	0
2.0769	0.0278	5.77E-02	3.05E-02	1.93E-04	0
2.5385	0.0278	7.05E-02	3.25E-02	1.93E-04	0
3.0000	0.0278	8.33E-02	3.45E-02	1.93E-04	0
3.0001	0.0278	8.33E-02	0.00E+00	0.00E+00	10

Characteristic effluent concentrations are based on the BMP performance data sources described in Section 3.3 and summarized in Table 3-7. Table 3-24 is an example of an Effluent Table that identifies characteristic effluent EMCs for each outlet in the associated F-Table for SWT-1A.

Table 3-24. Example of achievable effluent quality table for SWT-1A

Outlet	TN	DN	TP	DP	TSS	TSS < 63 µm
Treated	0.9	0.09	0.17	0.05	66.0	66.0
Infiltration	0.9	0.09	0.17	0.05	66.0	66.0
Bypass	Influent	Influent	Influent	Influent	Influent	Influent

P&T Tier

P&T is a special Treatment Tier with a slightly different approach for model input relative Tier 1 and Tier 2. Unlike the standard Treatment Tiers, the P&T Tier cannot be simulated assuming partial implementation within the Watershed Model. Table 3-25 displays the subwatersheds in specific regions that could potentially be candidate areas for P&T. The subwatersheds in Table 3-25 are designated as either a concentrated-steep Setting or a concentrated-moderate Setting and are shown in Figure 3-6.

Table 3-25. Subwatersheds for the P&T Tier

Subwatersheds in each region								
Incline East	Incline West	Kings Beach East	Kings Beach West	South Shore East	South Shore West	Tahoe City East	Tahoe City West	West Shore
1010	1040	9010	9030	4010	5000	8010	8002	7001
1020	1050	9020	9004	4020	5010	8020	8003	7002
1021	1060	9007		4001	5050	8007	8004	7003
1023	1004	9006		4002		9001		7004
1030	1001	9005						7005
1031	1002							
1032	1003							
1005								

The Input Table for the P&T is provided in Table 3-26. The routing is relatively simple. Reference Tables for the F-Table and Effluent Quality Table are provided in Appendix UGSCG-D.

Table 3-26. P&T input table

Treatment Tier	Land use group	Routing	Percent spatial application	Reference table(s) PSC	Reference table(s) HSC	Reference table(s) SWT
P&T	Private Impervious	SWT	100%			P&T
	Private Pervious	SWT	100%			P&T
	Public Impervious	PSC to SWT	60%	Tier 1 EMC		P&T
		SWT	40%			P&T
	Public Pervious	PSC to SWT	100%			P&T

Cost Estimates

Cost estimates were developed for each Treatment Tier by Setting for both capital cost and O&M cost. Because storm water management improvements are typically constructed by catchment or project area, costs are desired that represent average costs per acre for each Treatment Tier. In addition, typical storm water quality improvement projects in the Tahoe Basin include many facilities and activities (piping, paving, utility relocation, and the like) that are not specific to PCOs for pollutant load reduction but are necessary infrastructure improvements for a comprehensive storm water system. As a basis for estimating costs of PCO application, a nominal project area of 80 acres was assumed within each Setting and a conceptual set of improvements defined to represent Treatment Tiers. Unit area costs were determined by dividing total system costs by the 80 acre project size. A project area of 80 acres was selected on the basis of GIS analysis of recently completed projects and review of the Water Quality Project Inventory: Lake Tahoe (NTCD 2005). While actual project area is highly variable, 80 acres was assumed as a reasonable bound for estimating costs.

Capital costs were estimated using a unit cost and quantity estimates for various facilities associated with a specific Treatment Tier and Setting. O&M costs were estimated using an assumed maintenance frequency for the relevant Treatment Tier and Setting. For the purpose of estimating total costs, project life expectancy was assumed to be 20 years, and O&M costs were summed over the 20-year period. Capital and O&M costs were summed for the 20-year period, and then divided by the 80-acre project area to estimate a unit cost in $/acre for each Treatment Tier in each Setting.

The following equation illustrates the overall approach.

$$UnitCost_{TreatmentTier}^{Setting} = \left(\frac{\sum Capital}{Area} \right) + \left(\frac{\sum_{0}^{20\,years} O\,\&\,M}{Area} \right) = \$_{TreatmentTier}^{Setting} \,/\, acre$$

Although more complex economic models might be used for financing purposes, the above equation provides a relatively simple basis for comparison. The methods used for costs are provided below in separate sections for capital and O&M. Specific capital cost estimates by Setting are provided in Appendix UGSCG-E. Additional tables providing more detail regarding the development of unit cost are also provided in Appendix UGSCG-E.

Basis for Estimates of Capital Cost

Estimated capital cost is the product of a unit cost and quantity of various facilities. Quantities were estimated using dimensions taken from the conceptual 80-acre area within a Setting. Unit costs were estimated at 2007 cost levels on the basis of recent engineer's estimates and bids from Tahoe Basin storm water quality improvement projects. The following steps were followed to estimate the capital cost for each Setting and Treatment Tier.

- **Step 1:** Construction items were aggregated into a single item, where feasible, to simplify estimates. For example, a *storm drain system* was developed, which incorporates storm drain, drop inlets, sediment traps, and manholes into a single item.
- **Step 2:** A unit cost was estimated using methods dependent on the construction item. The most recent cost data available was used from 2007 engineer's estimates and bid summaries for projects in the Basin. Certain unit costs were also adjusted by Setting depending on the opportunities and constraints discussed in Section 3.4. Table 3-27 displays the summary of unit cost estimates for each Setting.
- **Step 3:** The total quantities of facilities for the 80-acre project area were estimated for each construction item. This information was developed using GIS analysis of Settings and ratios by area to various estimates of quantities from engineer's estimates. Certain quantities were adjusted by Setting depending on opportunities and constraints discussed in Section 3.4. Table 3-28 displays the summary of total quantities by Setting.
- **Step 4:** The Setting-specific unit costs and total quantities were combined in a single table. The product of a unit cost and total quantity is the cost estimate for Tier 2. To develop an estimate for Tier 1, the spatial area of application developed in the Treatment Tier tables in Section 3.5 was applied to the quantities. Table 3-29 shows a cost estimate developed under these assumptions for the concentrated-steep Setting. The complete set of cost estimates is included in Appendix UGSCG-E.
- **Step 5:** To arrive at cost per unit area, the total cost within a Setting for a particular Treatment Tier was divided by the 80-acre project area. For example, the estimated cost per unit effort for a Tier 1 concentrated-steep Setting is $99,000/urban upland acre.

Table 3-27. Unit cost estimates based on Setting

No.	Item/description	Units	Setting based unit cost Concentrated -steep	Concentrated -moderate	Disperse-steep	Disperse-moderate
1	Mobilization	LS	$200,000	$200,000	$200,000	$200,000
2	Traffic Control and Construction Staking	LS	$200,000	$200,000	$100,000	$100,000
3	Temporary Erosion Control & SWPPP & NPDES Permit & Compliance	LS	$100,000	$100,000	$100,000	$100,000
4	Remove and Replace AC Driveways	SF	$10	$10	$10	$10
5	Adjust Utilities; Potholing	EA	$2,000	$2,000	$2,000	$2,000
6	Relocate or Abandon Utility	LF	$150	$150	$150	$150
7	Road Shoulder Stabilization	LF	$70	$70	$50	$40
8	Storm Drain System	LF	$210	$210	$210	$210
9	Separation of Forest Runoff from Urban Runoff	LF	$180	$180	$120	$100
10	Revegetation and Soil Restoration	SF	$2	$2	$2	$2
11	Tree Removal (Average 12"+)	EA	$600	$600	$600	$600
12	Detention Basin or functional equivalent (SWT-1A)	SF	n/a	$15	n/a	$15
13	Advanced Detention Basin or functional equivalent (SWT-1B)	SF	n/a	$66	n/a	$53
14	Mechanical Separation or functional equivalent (SWT-2A)	SF	$200	n/a	$200	n/a
15	Advanced Mechanical Separation or functional equivalent (SWT-2B)	SF	$438	n/a	$427	n/a
16	Pervious Conveyance Stabilization	LF	$120	$120	$120	$120
17	Miscellaneous Acquisitions	SF	$38	$41	$27	$28
18	Misc. Drainage Components	EA	$1,000	$1,000	$1,000	$1,000
19	Miscellaneous Activities not in Directly Included in Estimate	% of Subtotal	20%	20%	20%	20%
20	Planning, Design, and Oversight	% of Total	40%	40%	40%	40%
Private sector improvements						
21	Single-Family Private Property BMP Certified	Parcel	$4,700	$4,300	$4,300	$3,600
22	Multifamily Private Property BMP Certified	Parcel	$13,100	$11,500	$11,500	$10,000
23	CICU BMP Certified - Private	Parcel	$57,000	$51,300	$51,300	$45,000
24	CICU BMP Certified - Public	Parcel	$57,000	$51,300	$51,300	$45,000

Table 3-28. Estimated total quantity by Setting for 80-acre project area

			Setting based total quantity			
No.	**Description**	**Units**	**Concentrated -steep**	**Concentrated -moderate**	**Disperse-steep**	**Disperse-moderate**
1	Mobilization	LS	1	1	1	1
2	Traffic Control and Construction Staking	LS	1	1	1	1
3	Temporary Erosion Control & SWPPP & NPDES Permit & Compliance	LS	1	1	1	1
4	Remove and Replace AC Driveways	SF	8,300	6,850	7,900	6,700
5	Adjust Utilities; Potholing	EA	80	80	50	50
6	Relocate or Abandon Utility	LF	250	250	250	250
7	Road Shoulder Stabilization	LF	31,680	34,320	26,400	29,040
8	Storm Drain System	LF	7,920	8,580	5,280	5,808
9	Separation of Forest Runoff from Urban Runoff	LF	2,000	3,000	2,000	3,000
10	Revegetation and Soil Restoration	SF	75,000	75,000	100,000	100,000
11	Tree Removal (Average 12"+)	EA	40	40	80	80
13	Detention Basin or functional equivalent (SWT-1A)	SF	n/a	30,000	n/a	25,000
14	Advanced Detention Basin or functional equivalent (SWT-1B)	SF	n/a	30,000	n/a	25,000
15	Mechanical Separation or functional equivalent (SWT-2A)	SF	3,000	n/a	2,500	n/a
16	Advanced Mechanical Separation or functional equivalent (SWT-2B)	SF	3,000	n/a	2,500	n/a
17	Conveyance Stabilization	LF	2,000	1,000	2,000	1,000
18	Miscellaneous Acquisitions	SF	15,000	15,000	10,000	5,000
21	Transitional Elements	EA	40	40	30	30
Private sector improvements						
1	Single-Family Private Property BMP	Parcel	145	111	145	117
2	Multiamily Private Property BMP	Parcel	14	13	9	5
3	CICU BMP - Private	Parcel	5	10	3	9
4	CICU BMP - Public	Parcel	2	3	1	3

Table 3-29. Example cost estimate for concentrated-steep Setting

No.	Description	Units	Concentrated-steep	Total quantity	Tier 1 % of total	Tier 1 cost	Tier 2 % of total	Tier 2 cost
1	Mobilization	LS	$200,000	1	50%	$100,000	100%	$200,000
2	Traffic Control and Construction Staking	LS	$200,000	1	50%	$100,000	100%	$200,000
3	Temporary Erosion Control & SWPPP & NPDES Permit & Compliance	LS	$100,000	1	70%	$70,000	100%	$100,000
4	Remove and Replace AC Driveways	SF	$10	8,300	70%	$58,100	100%	$83,000
5	Adjust Utilities; Potholing	EA	$2,000	80	70%	$112,000	100%	$160,000
6	Relocate or Abandon Utility	LF	$150	250	70%	$26,250	100%	$37,500
7	Road Shoulder Stabilization	LF	$70	31,680	70%	$1,552,320	100%	$2,217,600
8	Storm Drain System	LF	$210	7,920	70%	$1,164,240	100%	$1,663,200
9	Separation of Forest Runoff from Urban Runoff	LF	$180	2,000	100%	$360,000	100%	$360,000
10	Revegetation and Soil Restoration	SF	$2	75,000	70%	$105,000	100%	$150,000
11	Tree Removal (Average 12"+)	EA	$600	40	70%	$16,800	100%	$24,000
12	Mechanical Separation or functional equivalent (SWT-2A)	SF	$200	3,000	30%	$180,000	0%	$0
13	Advanced Mechanical Separation or functional equivalent (SWT-2B)	SF	$438	3,000	0%	$0	100%	$1,314,000
14	Pervious Conveyance Stabilization	LF	$120	2,000	70%	$168,000	100%	$240,000
15	Miscellaneous Acquisitions	SF	$38	15,000	50%	$285,000	100%	$570,000
16	Misc. Drainage Components	EA	$1,000	40	70%	$28,000	100%	$40,000
17	Miscellaneous Activities not in Directly Included in Estimate	% of Subtotal	20%	1	100%	$865,142	100%	$1,471,860
18	Planning, Design, and Oversight	% of Total	40%	1	100%	$2,076,341	100%	$2,943,720
			Estimate of Cost for Public Project:			**$7,267,193**		**$11,774,880**
								Private sector improvements
1	Single-Family Private Property BMP Certified	Parcel	$4,700	145	50%	$340,750	100%	$681,500
2	Multifamily Private Property BMP Certified	Parcel	$13,100	14	50%	$91,700	100%	$183,400

No.	Description	Units	Concentrated-steep	Total quantity	Tier 1 % of total	Tier 1 cost	Tier 2 % of total	Tier 2 cost
3	CICU BMP Certified - Private	Parcel	$57,000	5	50%	$142,500	100%	$285,000
4	CICU BMP Certified - Public	Parcel	$57,000	2	50%	$57,000	100%	$114,000
					Estimate of cost for private sector:	**$631,950**		**$1,263,900**
					Estimate of total cost for 80-acre project area:	**$7,900,000**		**$13,040,000**
					Estimate of total cost in $/acre:	**$99,000**		**$163,000**

Basis for Estimates of O&M Costs

O&M costs are estimated for a 20-year period to account for routine and nonroutine maintenance to derive a long-term estimate of O&M cost. The definitions of routine and nonroutine maintenance are as follows:

- **Routine maintenance** includes activities such as visual inspection of storm water facilities, cleanout of collection facilities, and sweeping of impervious surfaces. The frequency of routine maintenance is dependent on the Treatment Tier. Tier 1 estimates maintenance frequency relative to levels comparable to existing practice. Tier 2 estimates a significantly higher maintenance frequency than Tier 1. An important assumption made by the UGSCG is that the runoff concentrations for both PSC and SWT are markedly improved relative to Tier 1 because of intensive maintenance and upkeep of facilities.
- **Nonroutine maintenance** includes infrequent activities required to renew capacity or repair the functional condition of storm water facilities (e.g., detention pond dredging, infiltration channel regeneration, storm water filter replacement). Nonroutine maintenance is performed on an as-needed basis from information gathered during routine maintenance inspections. The frequency for nonroutine maintenance varies depending on the storm water facility.

The following steps were followed to estimate the average annual O&M cost for each individual storm water facility on the basis of the 20-year period of analysis. The steps relate to the O&M estimation procedure displayed in Tables 3-30 and 3-31 for Tier 1 and Tier 2, respectively. Tables 3-30 and 3-31 are specific to the concentrated-steep Setting.

- **Step 1:** For each storm water facility that would typically require maintenance, an estimate of the frequency of each maintenance activity on a yearly basis was made. The frequency of maintenance varies by Treatment Tier.
- **Step 2:** For each maintenance activity the following estimates were made:
  - The total hours required to perform the maintenance
  - The number of maintenance personnel required to perform the maintenance
  - The equipment required to perform the maintenance
- **Step 3:** The number of similar storm water facilities within a Setting was tabulated to arrive at a quantity for O&M. This quantity varies by Treatment Tier. Additionally, the type of facility varies for SWT depending on the Treatment Tier.
- **Step 4:** The values estimated in Steps 1–3 above were multiplied together assuming a 20-year period of analysis to arrive at the total number of maintenance hours for personnel and equipment associated with each maintenance activity over the 20-year period.

- **Step 5:** The total number of hours for each maintenance activity was multiplied by an estimate of hourly costs for maintenance personnel and equipment to arrive at a total cost associated with each maintenance activity for the 20-year period assuming 2007 dollars. No escalation in maintenance personnel cost or equipment cost over time are assumed. This simple approach was taken to estimate annualized O&M costs related to a base year of implementation. Estimates of hourly cost were as follows:
    - Maintenance personnel = $45/hour
    - Vacuum assisted street sweeper = $110/hour
    - Vactor truck or functionally equivalent equipment = $150/hour
- **Step 6:** The total cost of labor and maintenance was divided by the assumed project size of 80 acres to arrive at a 20-year cost for maintenance and operations in dollars per acre.
- **Step 7:** The values derived per unit of effort for the concentrated-steep Setting were applied to the remaining Settings using the ratio of capital costs relative to the concentrated-steep Setting.

Table 3-30. Tier 1 estimate of O&M costs in concentrated-steep Setting

Storm water facility	Maint. category	Maintenance description	Freq. per year	Labor and equipment assumptions	Tier 1 quantity	Labor cost for 20-year period	Equipment cost for 20-year period	Total cost
Sediment Traps and Drop Inlets	Routine	Vactor collected sediment and debris	0.5	0.5 hour per location, 2 person crew, 1 vactor truck	14	$6,300	$10,500	$16,800
Roads	Routine	Vacuum assisted street sweeper	4	4 hour for project area, 1 person crew, 1 sweeper	1	$14,400	$36,000	$50,400
Storm Drain Pipes	Routine	Inspect	1	2 hours for 2,000 lf, 2 person crew	3	$10,800	$0	$10,800
Pervious Conveyances	Routine	Inspect	1	4 hours for site, 1 person crew	1	$3,600	$0	$3,600
Pervious Conveyances	Nonroutine	Sediment removal and repair	0.05	8 hours per 500 lf, 2 person crew, 1 vactor truck or functional equivalent	21	$30,240	$50,400	$80,640
SWT-1A	Routine	Vactor collected sediment and debris	2	4 hour per location, 2 person crew, 1 vactor truck	2	$28,800	$48,000	$76,800
Unplanned repair	Nonroutine	Miscellaneous replacement and repair	0.2	16 hours per repair, 2 person crew, 1 vactor truck or functional equivalent	1	$5,760	$9,600	$15,360
				Admin and oversight (assume 20%):				$51,000
				Total labor and equipment for 20-year period:		$94,100	$145,000	$305,000
						Estimate of O&M for 20-year period per acre:		$4,000

Table 3-31. Tier 2 estimate of O&M costs in concentrated-steep Setting

Storm water facility	Maint. Category	Maintenance description	Freq. per year	Labor and equipment assumptions	Tier 2 quantity	Labor cost for 20-year period	Equipment cost for 20-year period	Total cost
Sediment Traps and Drop Inlets	Routine	Vactor collected sediment and debris	3	0.5 hour per location, 2 person crew, 1 vactor truck	20	$54,000	$90,000	$144,000
Roads	Routine	Vacuum assisted street sweeper	24	4 hour for project area, 1 person crew, 1 sweeper	1	$86,400	$216,000	$302,400
Storm Drain Pipes	Routine	Inspect	1	2 hours for 2,000 lf, 2 person crew	4	$14,400	$0	$14,400
Pervious Conveyances	Routine	Inspect	1	4 hours for site, 1 person crew	1	$3,600	$0	$3,600
Pervious Conveyances	Nonroutine	Sediment removal and repair	0.2	8 hours per 500 lf, 2 person crew, 1 vactor truck or functional equivalent	30	$172,800	$288,000	$460,800
SWT-1B	Routine	Vactor collected sediment and debris	3	4 hour per location, 2 person crew, 1 vactor truck	5	$108,000	$180,000	$288,000
SWT-1B	Routine	Advanced Treatment Upkeep	1	8 hour per location, 2 person crew, 1 vactor truck or functional equivalent	5	$72,000	$120,000	$192,000
SWT-1B	Routine	Performance Monitoring and Inspection	12	2 hour per location, 1 person crew	5	$113,400	$0	$113,400
SWT-1B	Routine	Advanced Treatment Replacement and Disposal of Materials	0.2	Labor assumed in upkeep - materials charge shown only as equipment charge	5	$0	$150,000	$150,000
Unplanned repair	Nonroutine	Miscellaneous replacement and repair	0.4	16 hours per repair, 2 person crew, 1 vactor truck or functional equivalent	1	$11,520	$19,200	$30,720
		Admin and oversight (assume 20%):						$340,000
		Total labor and equipment for 20-year period:				$511,200	$894,000	$2,039,300
						Estimate of dollars per acre:		$25,000

Storm Water Collection, Pumping, and Treatment

The P&T Tier requires a slightly different approach for cost estimates than the standard Treatment Tiers. A constraint to P&T is that it cannot be simulated using an assumption of partial implementation within the Watershed Model. This constraint is applied because the cost estimates below assume regional implementation.

The capital cost estimate (Table 3-32) was made assuming that a minimum of 320 acres of urban upland is serviced by one treatment facility.

- **Step 1:** The nominal 80-acre catchment used in the standard Treatment Tiers was used to estimate costs for the collection system to route runoff to localized detention and pump stations. A Tier 1 level of infrastructure improvements for a concentrated-moderate Setting was assumed to collect and route runoff. Two pump stations were assumed per 80-acre catchment. Private property is assumed to drain to pump stations without implementation of BMPs.
- **Step 2:** The capital cost estimated from one 80-acre catchment was multiplied by 4 to arrive at a total cost for the collection system serving the treatment facility for the assumed 320 acres.
- **Step 3:** The treatment facility system costs were estimated separately. Only major costs items were considered (e.g., storm drain system, force main, treatment facility, land, regional storage).
- **Step 4:** The cost of the total collection system and the treatment facility system were summed then divided by 320 acres to arrive at a unit area cost for comparison to Tier 1 and Tier 2.

The O&M cost estimate (Table 3-33) was made assuming that a minimum of 320 acres of urban upland is serviced by one treatment facility. The process for estimating O&M cost was similar to that conducted in the steps outlined for Tier 1 and Tier 2.

Table 3-32. P&T Tier estimate of capital cost

No.	Description	Units	Unit cost	Max quantity	% of max	Cost
	Single catchment capital costs					
1	Mobilization	LS	$200,000	1	50%	$100,000
2	Traffic Control and Construction Staking	LS	$200,000	1	50%	$100,000
3	Temporary Erosion Control & SWPPP & NPDES Permit & Compliance	LS	$100,000	1	60%	$60,000
4	Remove and Replace AC Driveways	SF	$10	6,850	60%	$41,100
5	Adjust Utilities; Potholing	EA	$2,500	80	60%	$120,000
6	Relocate or Abandon Utility	LF	$150	250	60%	$22,500
7	Road Shoulder Stabilization	LF	$70	34,320	60%	$1,441,440
8	Storm Drain Collection System	LF	$210	8,580	60%	$1,081,080
9	Separation of Forest Runoff from Urban Runoff	LF	$180	3,000	100%	$540,000
11	Tree Removal (Average 12"+)	EA	$600	40	50%	$12,000
12	Slope Protection or Stabilization	SF	$20	8,000	50%	$80,000
13	Localized Detention for Pump Stations	SF	$66	10,000	100%	$660,000
14	Pump Station (10 HP)	EA	$150,000	2	100%	$300,000
15	Conveyance Stabilization	LF	$150	1,000	50%	$75,000
16	Miscellaneous Acquisitions	SF	$41	5,000	100%	$205,000
17	Transitional Elements	EA	$1,000	40	60%	$24,000
18	Miscellaneous Activities and Contingency	% of Subtotal	20%	1	100%	$972,424
19	Planning, Design, and Oversight	% of Total	0%	1	100%	$2,042,090
			Estimate of total for 80-acre drainage catchment:			$7,877,000
			Assuming 4 drainage catchments			4
			Total for 4 catchments averaging 80 acres each			$31,508,000
	P&T facility capital costs					
1	Storm Drain System to Treatment Facility	LF	$300	16,400	100%	$4,920,000
2	Force Main Station (100 HP)	EA	$300,000	1	100%	$300,000
3	Force Main Storage	LS	$750,000	1	100%	$750,000
4	Regional Storage Land	SF	$30	75,000	100%	$2,250,000
5	Regional Storage/Facility Construction	LS	$500,000	1	100%	$500,000
6	Treatment Facility (0.5 mgd)	EA	$750,000	1	100%	$750,000
7	Storm Drain to Outlet	LF	$150	3280	100%	$492,000
8	Miscellaneous Activities not Included in Estimate	% of Subtotal	20%	1	100%	$1,992,400
9	Planning, Design, and Oversight	% of Total	40%	1	100%	$4,782,000
	Estimate of cost for regional treatment facility and associated regional infrastructure:					$16,736,000
			Estimate of total cost for P&T serving 320 acres :			$48,244,000
			Estimate of cost per acre:			$151,000

Table 3-33. P&T estimate of O&M costs

Storm water facility	Maint. category	Maintenance description	Freq. per year	Labor and equipment assumptions	Quantity	Labor cost for 20-year period	Equipment cost for 20-year period	Total cost
Storm Drain Pipes	Routine	Inspect	1	2 hours for 2,000 lf, 2 person crew	20	$72,000	$0	$72,000
Localized Detention to Pump Stations	Routine	Vactor collected sediment and debris	8	6 hour per location, 2 person crew, 1 vactor truck	8	$691,200	$1,152,000	$1,843,200
Pump Station Maintenance	Routine	Repair and Maintain Pumps	2	8 hour per location, 1 person crew	8	$230,400	$384,000	$614,400
Entire System	Routine	Performance Monitoring and Inspection	12	6 hours per system check during events, 1 person crew	1	$64,800	$0	$64,800
Treatment System	Routine	General Maintenance	48	8 hours; 1 person; general maintenance and operations of facility	1	$345,600	$0	$345,600
Regional Storage	Routine	Collect and Dispose of Sediment and Debris	3	16 hours per cleaning; 2 person crew; 2 vactor trucks or functional equivalents	1	$86,400	$288,000	$374,400
Unplanned repair	Nonroutine	Miscellaneous replacement and repair	0.5	40 hours per repair, 2 person crew, 1 vactor truck or functional equivalent	1	$36,000	$60,000	$96,000
				Admin and oversight (assume 20%):				$682,000
				Total labor and equipment for 20-year period:		$1,058,400	$1,536,000	$4,092,000

Materials for 20-year period

Storm water facility	Maint. category	Maintenance description	Freq. per year	Materials assumptions	Unit cost	Units	Quantity	Total cost for 20-year period
Local Pump	Nonroutine	Replace Pump Stations	0.05	Cost equal to initial capital for pump	$20,000	EA	8	$160,000
Force Main	Nonroutine	Replace Force Main	0.05	Cost equal to initial capital for pump	$40,000	EA	1	$40,000
Treatment System Replacement	Nonroutine	Replace System	0.05	Cost equal to initial capital system	$375,000	EA	1	$375,000
Power	Routine	System Power	1	Pump Station, Force Main, and Facility	$0.15	KWh	50,000	$150,000

Materials for 20-year period								
Storm water facility	Maint. category	Maintenance description	Freq. per year	Materials assumptions	Unit cost	Units	Quantity	Total cost for 20-year period
Treatment System Materials and Energy	Routine	Operating Costs	1	Energy and Materials per 1000 gallons treated	$0.12	1000 gallons	70,000	$168,000
							Total materials for 20-year period:	$893,000
							Total labor, equipment, and materials for 20-year period:	$4,985,000
							Estimate of O&M per acre for 20 years:	$16,000

3.7. Results

Load-Reduction Estimates

The UGSCG was tasked with developing Input Tables for each Setting and each Treatment Tier in applicable formats for use in the Watershed Model to estimate pollutant load reductions. Preliminary results from the Watershed Model, using the input provided by the UGSCG, are provided in Table 3-34 and Table 3-35. Table 3-34 displays pollutant loads reductions relative to the baseline condition by Setting among the Treatment Tiers evaluated. Table 3-34 presents pollutant load reductions on a unit area basis (kg per acre) by Setting among the Treatment Tiers evaluated.

Treatment Tiers represent steps or levels in expected water quality performance within a Setting. Therefore, the estimated average annual load reductions shown in Tables 3-34 and 3-35 can not be added together across Treatment Tiers within a specific Setting. For example, the load reductions shown in Tier 2 of the concentrated-moderate Setting represent the maximum estimate of potential load reductions for each pollutant of concern in that Setting. However, because Settings represent separate geographic areas, estimated average annual load reductions may be added across Settings for different Treatment Tiers. For example, Tier 2 load reductions in the concentrated-moderate Setting could be added with Pump and Treat Tier load reductions in the concentrated-steep Setting to estimate a mixed Treatment Tier scenario.

Table 3-34. Estimate of average annual load reduction by Setting (metric tons)

Setting	Pollutant of concern	Tier 1	Tier 2	Pump & treat
Concentrated-moderate	Fines < 63 µm	484	794	812
	TN	5.2	12.6	6.9
	TP	1.3	2.2	2.0
Concentrated-steep	Fines < 63 µm	232	329	495
	TN	2.3	6.5	3.7
	TP	0.9	0.8	1.2
Dispersed-moderate	Fines < 63 µm	146	287	n/a
	TN	1.5	4.9	n/a
	TP	0.4	1.0	n/a
Dispersed-steep	Fines < 63 µm	131	226	n/a
	TN	1.2	5.0	n/a
	TP	0.5	1.2	n/a

Table 3-35. Estimate of average annual load reduction by Setting (kg per acre)

Setting	Pollutant of concern	Tier 1	Tier 2	Pump & treat
Concentrated-moderate	Fines < 63 µm	77	126	73
	TN	0.8	2.0	0.6
	TP	0.2	0.3	0.2
Concentrated-steep	Fines < 63 µm	46	65	45
	TN	0.4	1.3	0.3
	TP	0.2	0.2	0.1
Dispersed-moderate	Fines < 63 µm	50	98	n/a
	TN	0.5	1.7	n/a
	TP	0.1	0.3	n/a
Dispersed-steep	Fines < 63 µm	31	53	n/a
	TN	0.3	1.2	n/a
	TP	0.1	0.3	n/a

Cost Estimates

Estimates of costs were developed for both capital construction and O&M. Cost estimates are presented as dollars per urban upland acre. Total cost is taken as the sum of the construction cost and O&M costs over the entire 20-year period. A more thorough description of the methods for estimating costs is provided in Section 6.2. Specific capital cost estimate tables by Setting are provided in Appendix UGSCG-E.

Table 3-36 displays the estimate of capital cost and O&M activities over a 20-year period per urban upland acre. Capital and O&M costs are combined because the performance of a Treatment Tier is linked to the estimated load reduction achieved through O&M activities in the UGSCG analyses. This point is particularly relevant when relating costs and performance for Tier 2 to the P&T Tier, which both have significant O&M costs associated with estimated performance.

Table 3-36. Estimate of total cost assuming a 20-year maintenance interval

	Dollars per urban upland acre				
Treatment Tier	Concentrated-steep	Concentrated-moderate	Dispersed-steep	Dispersed-moderate	P&T Tier
Tier 1	$103,000	$99,900	$57,200	$40,600	$167,000
Tier 2	$188,000	$213,400	$131,500	$123,400	

For comparative purposes, Tables 3-37 and 3-38 are provided and illustrate the estimates of cost for capital and O&M, respectively.

Table 3-37. Estimate of capital cost to implement Treatment Tier

Treatment Tier	Dollars per urban upland acre				
	Concentrated-steep	Concentrated-moderate	Dispersed-steep	Dispersed-moderate	P&T Tier
Tier 1	$99,000	$96,000	$55,000	$39,000	$151,000
Tier 2	$163,000	$185,000	$114,000	$107,000	

Table 3-38. Estimate of O&M cost to implement Treatment Tier

Treatment Tier	Dollars per urban upland acre over 20-year period				
	Concentrated-steep	Concentrated-moderate	Dispersed-steep	Dispersed-moderate	P&T Tier
Tier 1	$4,000	$3,900	$2,200	$1,600	$16,000
Tier 2	$25,000	$28,400	$17,500	$16,400	

Confidence in Results

The UGSCG analyses developed input for the Watershed Model to estimate pollutant load reductions achievable in the urban upland/groundwater source category. The following discussion provides a qualitative review of relative confidence based on the UGSCG's work to date and a preliminary review of output from the Watershed Model. Table 3-39 displays the current confidence in results for each Treatment Tier and Setting assessed by the UGSCG. On the basis of direction provided by the SCIC, the UGSCG has used the following ranking system to estimate confidence by Treatment Tier:

Confidence is expressed as a value between 1 and 5, where lower numbers indicate less confidence. Ratings of 1 and 2 are considered too low to be suitable for management decisions, and future values are likely to change significantly. Ratings of 3, 4, and 5 are sufficiently high that management decisions are possible, and future values are not expected to change significantly. The rationale for the confidence rankings shown in Table 3-39 are discussed for each Treatment Tier.

Table 3-39. Assessment of confidence in results

Setting	Treatment Tier		
	Tier 1	Tier 2	P&T Tier
Concentrated-steep	3	4	2
Concentrated-moderate	3	4	2
Dispersed-steep	3	4	n/a
Dispersed-moderate	3	4	n/a

Tier 1

Tier 1 was assigned a confidence ranking of 3. This value was assigned because the process for developing the Treatment Tier in each Setting relied on an assessment, based on best professional judgment, of existing practice to determine the spatial scale of PCO application. The assumed spatial scale of application (See Section 5) strongly influences pollutant load reductions achieved, as well as overall costs. Additionally, Tier 1 relies more strongly on pollutant load reductions achieved through PSC relative to the other Treatment Tiers evaluated. Confidence in estimating the performance of PSC for reducing pollutant loading is low.

Tier 2

Tier 2 was assigned a confidence ranking of 4. This value was assigned because Tier 2 implements the maximum spatial scale of improvements and therefore requires fewer assumptions regarding PCO application across Settings. Additionally, Tier 2 applies a somewhat redundant approach for pollutant load reduction by assuming all storm water runoff is routed to SWTs, which are sized to capture a significant fraction of the runoff volume. Using this approach, the SWT performance is the controlling factor for achievable load reductions. The UGSCG has greater confidence in SWT performance relative to PSCs because SWT has a much larger body of monitoring data to support performance.

While the confidence ranking of Tier 2 is greater than Tier 1, there are still some significant assumptions associated with Tier 2 for consideration.

- The performance of Tier 2 assumes significant O&M activities. The level of effort and resources necessary to accomplish the activities for O&M in Tier 2 are at least an order of magnitude greater than existing practice, and the effects of this increase on water quality performance are difficult to assess because sufficient data is lacking.
- The confidence in capital cost estimates for Tier 2 is less relative to capital cost estimates Tier 1. This is because the assumption for a maximum spatial scale of implementation of each major load-reduction element (i.e., PSC, HSC, SWT) is likely too conservative and somewhat inefficient for actual project design.

P&T Tier

The P&T Tier was assigned a confidence ranking of 2. This value was assigned because the UGSCG analyses of this specialized Treatment Tier were limited and conducted at a very broad scale. The UGSCG made numerous assumptions using best professional judgment to develop this specialized Treatment Tier, and the representation in the Watershed Model is very simplistic relative to the hydrologic and hydraulic complexities of a real-world application. More detailed study is necessary to evaluate the ultimate feasibility and potential load reductions that could be achieved. The current confidence in the estimated performance of the P&T Tier is too low to be suitable for management decisions on the basis of the analyses completed to date.

Uncertainty

The following list identifies the primary factors reducing confidence in UGSCG estimates. Recommendations made in Section 3.7 address some of the issues below in the context of improving confidence in pollutant loading estimates.

- Minimal calibration data for intervening zones around the Basin exists to date, and a large portion of the urban uplands is situated in intervening zones. Consequently, pollutant loads estimated in the Watershed Model for the existing conditions assessment have minimal calibration data in intervening zones. The existing conditions assessment in the Watershed Model is the baseline for load-reduction estimates in urban uplands.
- Modeling assumptions include static concentrations for pollutants of concern with variable flow rates. Lack of sufficient understanding regarding the variability of pollutant loads with flow rates, seasons, and other factors could affect overall PCO performance on an annual average basis.
- Defining the effectiveness of PSC implementation is difficult and minimal supporting data exists, both in Tahoe and elsewhere, on a BMP or land-use basis.
- Results are sensitive to hydrologic computations that affect capture ratios of PCOs, where the capture ratio is sensitive to variability of physical parameters that affect runoff at smaller scales than simulated.

- The accessibility of data sets for Lake Tahoe treatment BMP (SWT) performance is limited and difficult to assess in a statistically robust manner.
- Defining the spatial extent of PCO application in Tier 1 is based on best professional judgment.
- Very limited data exists on the effects of maintenance on PCO performance.
- Efforts to date for estimating O&M costs do not include validation and comparison with existing storm water utilities.

Conclusions

Conclusions are provided for estimated performance based on results from the Watershed Model simulations and estimated cost-effectiveness among Treatment Tiers.

Estimated Performance and Cost Effectiveness

- Tier 2 provides the greatest load reduction at the basin-scale for all pollutants of concern. This result was expected because PCO application is greatest in Tier 2 across all Settings.
- The concentrated settings provide the greatest opportunity for pollutant load reductions because of the relative density of urban upland land uses relative to dispersed settings. However, PCO application is more costly in concentrated settings because more constraints are present.
- The Pump and Treat Tier provides a similar, or greater, load reduction relative to Tier 2 for fines (<63um) and total phosphorous in concentrated Settings. However, the results from the Pump and Treat Tier should be viewed with caution. As described in more detail in the section above, *Confidence in Results,* the current confidence in the estimated performance of the Pump and Treat Tier is too low to be suitable for management decisions.
- Load reductions for nitrogen are less in the Pump and Treat Tier relative to Tier 2 because the SWT process selected for the Pump and Treat Tier focused on the removal of fine sediment.
- On an average annual basis, the Basin-wide infiltrated DN loads from urban uplands to groundwater are estimated to remain relatively static under Tier 1 and decrease by 6 percent under Tier 2 relative to existing conditions. The Basin-wide infiltrated DP loads are estimated to decrease by 4 percent under Tier 1 and 18 percent under Tier 2 relative to existing conditions (Table 3-11). This finding is based on the assumption that urban storm water quality is improved in Tier 1 and Tier 2 as a result of urban upland PCO implementation for PSC and SWT (Section 3-1) prior to infiltration. The UGSCG believes if the Treatment Tiers are implemented in their entirety (i.e., greater infiltration of better quality storm water), these results of relative Basin-wide urban infiltration loading of DN and DP to groundwater could be reasonable estimates.

Estimated Cost-Effectiveness

- Tier 1 provides the smallest load reduction among the Treatment Tiers evaluated. However, Tier 1 provides the greatest load reduction relative to the resources expended. This finding is supported by the existing approach for storm water project implementation in the Tahoe Basin, where projects are designed to maximize existing opportunities while avoiding significant constraints. In Tier 2, the increase in pollutant load reductions corresponds to a non-linear increase in costs in order to resolve constraints associated with existing development (e.g., acquisition of land, O&M intensive advanced SWT, etc.).
- PCO application in concentrated Settings is significantly more costly to implement relative to dispersed Settings for both the Tier 1 and Tier 2 Treatment Tiers because more constraints are present in concentrated Settings.
- The resources needed for O&M of Tier 2 and Pump and Treat Tier would be significant—at least an order of magnitude greater than the current resources devoted to water quality O&M in the Tahoe Basin.

Recommendations

The following recommendations are provided on the basis of the UGSCG analysis.

- Many opportunities exist to improve the accuracy of the land-use EMC values for existing and anticipated future conditions by standardizing water quality data collection, prioritizing future water quality monitoring to constrain sites representing 100 percent land use coverage, and defining rigorous statistical methods to consistently reduce large data sets to identify representative land-use EMC values.
- Developing and maintaining a robust storm water quality database for the Tahoe Basin is needed for data integration and to analyze the extensive storm water quality monitoring data that has been collected in Lake Tahoe over the past few decades. The majority of land-use-based storm water quality data is readily available only from summary tables presented in individual evaluation reports, as well as mean, minimum, and maximum EMC values from specific monitoring sites. Future efforts to statistically integrate Tahoe-specific storm water monitoring data will improve the confidence in land use based achievable EMC values for each pollutant of concern.
- Assessment tools are needed that link water quality observations based on the subwatershed conditions, drainage characteristics, and the intensity of PCO implementation across similar land-use types to increase confidence in the existing conditions as well as predicted achievable EMC values.
- Because fine sediment has recently been considered the most critical pollutant of concern for Lake clarity, future focused investigations addressing the fine sediment generation and PSC impacts on fine sediment loading is advisable to improve load-reduction estimates. There is an extremely limited amount of accessible and applicable fine sediment distribution data from the Tahoe Basin and elsewhere.
- Additional performance monitoring and data are needed regarding the effectiveness of O&M activities for reducing pollutant loads.
- Additional studies will be necessary to improve confidence in the feasibility of the P&T Tier. Additional work is necessary to assess the achievable effluent quality for all pollutants of concern from a treatment facility and to assess performance of a collection system for runoff capture at localized collection points with subsequent routing to the treatment system.

3.8. References

2NDNATURE. 2006a. Lake Tahoe BMP Monitoring Evaluation Process, Synthesis of existing research. Prepared for U.S. Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, CA. <ftp://2ndnatureinc.com/2ndnature/Tahoe%20References/>. Accessed August 16, 2007.

2NDNATURE. 2006b. Detention Basin Treatment of Hydrocarbon Compounds in Urban Stormwater, South Lake Tahoe, California. Prepared for South Tahoe Public Utility District, Final Report March 2006. <ftp://2ndnatureinc.com/2ndnature/Tahoe%20References/> Accessed August 16, 2007.

2NDNATURE. 2007. Water quality evaluation of a fertilized turf surface in the Lake Tahoe Basin (2002-2006). Prepared for Nevada Tahoe Conservation District, Draft Final Report April 20, 2007. <ftp://2ndnatureinc.com/2ndnature/Tahoe%20References/>. Accessed August 16, 2007.

ACOE (U.S. Army Corps of Engineers). 2003a. Lake Tahoe Basin Framework Study Groundwater Evaluation. Prepared for Lake Tahoe Basin Framework Implementation Study. October 2003. <http://www.spk.usace.army.mil/projects/civil/tahoe/documents.html#groundwater>. Accessed August 16, 2007.

ACOE (U.S. Army Corps of Engineers). 2003b. Lake Tahoe Basin Framework Study; Wastewater collection systems overflow/release reduction evaluation. Lake Tahoe, California and Nevada. Final report April 2003. <http://www.spk.usace.army.mil/projects/civil/tahoe/documents.html#groundwater>. Accessed August 16, 2007.

Bachand, P., J. Trejo-Gaytan, J. Darby, and J. Reuter. 2006a. Small-Scale Studies on Low Intensity Chemical Dosing (LICD) for Treatment of Highway Runoff. P. Bachand and Associates, Davis, CA, and the University of California–Davis, Department of Civil & Environmental Engineering, Davis, CA.

Bachand, P., J. Reuter, A. Heyvaert, and R. Fujii. 2006b. Chemical Treatment Methods Pilot (CTMP) for Treatment of for Urban Runoff - Phase I. Feasibility and Design. Prepared for the City of South Lake Tahoe and the U.S. Forest Service, South Lake Tahoe, CA.

Bachand, P., and A. Heyvaert. 2005. Adsorptive Media Investigations and Testing for Improved Performance of Stormwater Treatment Systems in the Tahoe Basin. Prepared for Placer County Department of Public Works, Truckee, CA.

Bay, S., and J. Brown. 2005. Evaluation of Best Management Practice (BMP) Effectiveness. Southern California Coastal Water Research Project. Agreement No. 02-113-254-0. Prepared for State Water Resources Control Board, Los Angeles, CA.

Bergsohn, I. Hydrogeologist, South Tahoe Public Utility District, personal communication, July 2007.

Caltrans (California Department of Transportation). 2001. Final Report, Caltrans Tahoe Basin stormwater monitoring program, Monitoring Season 2000-2001. CTSW-RT—01-038. August 2001. <http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/index.htm#tahoe>. Accessed August 16, 2007.

Caltrans (California Department of Transportation). 2003a. Stormwater Monitoring and Data Management, 2002-2003 Annual Data Summary Report. CTSW-RT-03-069.51.42. 2003. <http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/index.htm#tahoe>. Accessed August 16, 2007.

Caltrans (California Department of Transportation). 2003b. Tahoe Highway Runoff Characterization and Sand Trap Effectiveness Studies, 2000-03 Monitoring Report. CTSW-RT-03-054.36.02. <http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/index.htm#tahoe>. Accessed August 16, 2007.

Caltrans (California Department of Transportation). 2004. BMP Retrofit Pilot Program Final Report. CTSW-RT-01-050. California Department of Transportation, Marysville, CA.

Caltrans (California Department of Transportation). 2005. Deicer Report for Fiscal Year 2004/2005. Prepared for Tahoe Regional Planning Agency, Stateline, NV, by California Department of Transportation, Marysville, CA.

Caltrans (California Department of Transportation). 2006a. Caltrans Lake Tahoe Storm Water Small-Scale Pilot Treatment Project - Phase IV Final Report. CTSW-RT-05-157-04-02. California Department of Transportation, Marysville, CA.

Caltrans (California Department of Transportation). 2006b. Stormwater Monitoring and Research Program, 2004-2005 Annual Data Summary Report. CTSW-RT-06-167.02.03. <http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/index.htm#tahoe>. Accessed August 16, 2007.

Caltrans (California Department of Transportation. 2007. Caltrans Media Filter Pilot Studies in the Tahoe Basin. LTIMP Presentation. California Department of Transportation, Sacramento, CA.

Desert Research Institute (DRI). 2004. Evaluation of Effectiveness of Three Types of Highway Alignment Best Management Practices for Sediment and Nutrient Control. Prepared for US Forest Service, South Lake Tahoe, CA, and Nevada Division of State Lands and Nevada Department of Transportation, Carson City, NV.

Desert Research Institute (DRI) & Tahoe Environmental Research Center (TERC). 2005. Efficiency Assessment of Stormwater Treatment Vaults in the Round Hill General Improvement District. Prepared for Nevada Tahoe Conservation District (NTCD), Stateline, NV, and Nevada Division of State Lands, Carson City, NV.

Entrix, Inc. 2005. Kings Beach Watershed Improvement Project. Administrative Draft Hydrologic Conditions Report. Prepared for Placer County, Truckee, CA.

Froelich, P. 1988. Kinetic Control of Dissolved Phosphate in Natural Rivers and Estuaries: A Primer on the Phosphate Buffer Mechanism. *Limnology and Oceanography* 33(4)2.

Geosyntec Consultants. 2005. Lake Tahoe Basin Stormwater BMP Evaluation and Feasibility Study. Prepared for the Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA, and the Tahoe Research Group, Tahoe City, CA.

Geosyntec Consultants and Wright Water Engineers 2006. Analysis of Treatment System Performance - International Stormwater Best Management Practices (BMP) Database [1999-2005]. <www.bmpdatabase.org>. Accessed April 16, 2007.

Grismer, M.E. and M.P. Hogan. 2005. Simulated Rainfall Evaluation of Revegetation/Mulch Erosion Control in the Lake Tahoe Basin: 2. Bare Soil Assessment. *Land Degradation and Development*. 16:397-404 (2005).

Gunter, M.K., and D. Thomas. 2005. Characterization of nutrient and suspended sediment concentrations in stormwater runoff in the Lake Tahoe Basin. Master Thesis. University of Reno, NV.

Heyvaert, A.C., Bachand, P., Thomas, J., and J. Reuter. 2006a. Phosphorus Sorption Characteristics of Soils from Selected Stormwater Infiltration Sites in the Lake Tahoe Basin. Tahoe Environmental Research Center, University of California–Davis, Davis, CA.

Heyvaert, A.C., Reuter, J. and C.R. Goldman. 2006b. Subalpine Storm Water Treatment with a Constructed Surface Flow Wetland. *Journal of the American Water Resources Association* 42 (1):45-54.

Heyvaert, A.C., J.E. Reuter, and E.W. Strecker. 2004. Evaluation of Selected Issues Relevant to the Design and Performance of Stormwater Treatment Basins at Lake Tahoe. Draft Report. Prepared for California Tahoe Conservancy, South Lake Tahoe, CA.

Huber, W.C., and R.E. Dickinson. 1998. Storm Water Management Model User's Manual, Version 4, EPA/600/3-88/001a (NTIS PB88-236641/AS), Environmental Protection Agency, Athens, GA, 595 pp.

James, W., and R.C. James. 2000. Hydrology: A Guide to the Rain, Temperature and Runoff Modules of the USEPA SWMM4. Computational Hydraulics International, Ontario, Canada.

Lahontan and NDEP 2007. Lake Tahoe TMDL Technical Report. Lahontan Regional Water Quality Control Board and Nevada Division of Environmental Protection. South Lake Tahoe, CA and Carson City, NV.

Loeb, S.L. 1986. Algal biofouling of oligotrophic Lake Tahoe: causal factors affecting production. Pp. 159-173. *In* L.V. Evans and K.D. Hoagland, eds., Algal Biofouling. Elsevier Science (Pub.) B.V. Amsterdam.

Minor, T., and M.E. Cablk. 2004. Estimation of Impervious Cover in the Lake Tahoe Basin Using Remote Sensing and Geographic Information Systems Data Integration. *Journal of Nevada Water Resources Association* 1(1):58–75.

Mitchell, C.R., and H.M. Reisenauer. 1972. Lake Tahoe Basin Fertilizer Use Study 1972. University of California–Davis, Davis, CA.

Murphy, D., and C.M. Knorr, eds. 2000. Lake Tahoe Watershed Assessment. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Nevada Tahoe Conservation District. 2005. Water Quality Project Inventory: Lake Tahoe. Nevada Tahoe Conservation District. Stateline, NV.

Northwest Hydraulic Consultants (nhc) and Geosyntec Consultants. 2006. Methodology to Estimate Pollutant Load Reductions. Prepared for Lahontan Regional Water Quality Control Board. South Lake Tahoe, CA.

Natural Resources Conservation Service (NRCS) - U.S. Department of Agriculture. 1974. Soil Survey of Tahoe Basin Area, CA and NV. U.S. Department of Agriculture, South Lake Tahoe, CA.

Natural Resources Conservation Service (NRCS) - U.S. Department of Agriculture. 2006. Soil Survey of Tahoe Basin Area, CA and NV. U.S. Department of Agriculture, South Lake Tahoe, CA.

Patel, D. California Department of Transportation, Office of Water Programs, personal communication, May 9, 2007.

Reuter, J.E., A.C. Heyvaert, M. Luck, S.H. Hackley, E.C. Dogrul, M.L. Kavvas, and H. Askoy. 2001. Investigations of Stormwater Monitoring, Modeling and BMP Effectiveness in the Lake Tahoe Basin. 205j grant technical report to the Tahoe Regional Planning Agency, Stateline, NV and to the California State Water Resources Control Board, Sacramento, CA

Robertson, W.D., Cherry, J.A., et al. 1991. Ground-Water Contamination from Two Small Septic Systems on Sand Aquifers. *Groundwater* 29(1).

Robertson, W.D., S.L. Schiff, and C.J. Ptacek. 1998. Review of phosphate mobility and persistence in 10 septic system plumes: *Groundwater* 36:1000–1010.

Robertson, W.D., and J. Harman. 1996. Phosphate plume persistence at two decommissioned septic system sites: *Ground Water*, 37: 228-236.

Robertson, W.D., and J. Harman. 1998. *Phosphate Plume Persistence at Two Decommissioned Septic System Sites.* Department of Earth Sciences, University of Waterloo, Ontario, Canada.

Robertson, W.D., D.W. Blowes, C.J. Ptacek, and J.A. Cherry. 2000. Long-Term Performance of In Situ Reactive Barriers for Nitrate Remediation. Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada. Journal: Ground Water Vol. 38, No. 5, Pgs. 689-695.

SH+G. 2003. Assessment of Seasonal Pollutant Loading and Removal Efficiency of Detention Basins. Prepared for Tahoe Regional Planning Agency, Stateline, NV, and the U.S. Environmental Protection Agency, Washington, DC.

Sharpley, A. 1995. RCA III, Fate and Transport of Nutrients: Phosphorus. Working Paper No. 8, U.S. Department of Agriculture, National Agricultural Water Quality Research Laboratory, Durant, OK. <http://www.nrcs.usda.gov/technical/land/pubs/wp08text.html>. Accessed August 16, 2007.

Strecker, E., W. Huber, J. Heaney, D. Bodine, J. Sansalone, M. Quigley, M. Leisenring, D. Pankani, and A. Thayumanavan. 2005. *Critical Assessment of Stormwater Treatment and Control Selection Issues*. WERF-02-SW-1. Prepared for the Water Environment Research Foundation, Alexandria, VA.

Strecker, E.W., M.M. Quigley, B.R. Urbonas, J.E. Jones, and J.K. Clary. 2001. Determining Urban Storm Water BMP Effectiveness. *Journal of Water Resources Planning and Management* 127(3)144–149.

Strecker, E. and J. Howell, 2003. Preliminary Water Quality Evaluation for Lake Tahoe TMDL. Draft Technical Report prepared by GeoSyntec Consultants for Lahontan Regional Water Quality Control Board. South Lake Tahoe, CA.

Strecker, E., J. Howell, A. Thayumanavan, and M. Leisenring. 2005. Lake Tahoe Basin Stormwater BMP Evaluation and Feasibility Study. Final report to the Lahontan Regional Water Quality Control Board and the Tahoe Research Group. South Lake Tahoe, CA.

SWQIC (Storm Water Quality Improvement Committee). 2004. Formulating and Evaluating Alternatives (FEA) for Water Quality Improvement Projects. Prepared for Storm Water Quality Improvement Committee, South Lake Tahoe, CA. by Northwest Hydraulic Consultants, West Sacramento, CA.

Tahoe Environmental Research Center (TERC). 2005. *Performance Assessment of the Coon Street Basin, Kings Beach, CA*. Prepared for Placer County Department of Public Works, Truckee, CA.

TRPA (Tahoe Region Planning Agency). 1988. Water Quality Management Plan for the Lake Tahoe Region – Volume II. Handbook of Best Management Practices. Tahoe Regional Planning Agency, Stateline, NV.

TRPA (Tahoe Region Planning Agency). 2004. TRPA Code of Ordinances. Updated December 2004. Tahoe Region Planning Agency, Stateline, NV.

USGS (U.S. Geological Survey). 2005. Changes in Ground-Water Flow and Chemistry after Completion of Cattlemans Detention Basin, South Lake Tahoe, California—November 2001 to November 2003. Prepared for El Dorado County, Tahoe Engineering Unit, South Lake Tahoe, CA.

4. Forested Uplands Sources

4.1. Introduction

Forested uplands represent roughly 80 percent of the land within the Lake Tahoe Basin. The term *forested upland* is used in the Tahoe Basin total maximum daily load (Lake Tahoe TMDL) to group a complex of landforms and ecological Settings that are beyond direct water influence (e.g., streams, wetlands, beaches) and outside urbanized uplands. As the forested uplands land area is the largest in the Basin, it is likely to exert an extremely large influence on Lake Tahoe water quality. Many of the fine sediment particles, known to contribute to Lake clarity loss, are derived from forest upland source areas in the watershed. This report describes and discusses methods and treatments that are expected to reduce sediment movement from those forest upland Settings and provide land managers with opportunities to help improve Lake clarity and overall watershed health. This information is intended to be used with other approaches such as urban treatment, stream (SEZ) treatment, approaches to improve air quality, and so on, to achieve an overall reduction in pollutant loading to Lake Tahoe, ultimately resulting in an overall improvement in water quality and Lake clarity.

Water quality in the Lake Tahoe Basin integrates an extremely broad set of environmental variables. Most of those variables, such as sediment and nutrient mobilization and transportation, exist and operate beyond immediate stream and watercourse channels. Those areas outside an SEZ are commonly referred to as uplands and constitute a complex variety of site types and conditions. Infiltration and its inverse, runoff, play a major causative role in the erosion cycle. Once runoff and associated erosion reaches a creek, stream, or other water course, it can be quantified. However, linking a specific source area to the sediment carried in that runoff is extremely problematic, at best. However, if one begins an assessment of water quality at the upland sediment source area it is possible to gain a useful understanding of water quality impacts from those areas.

This report discusses the potential load reductions that can be expected from various levels of treatment in forested uplands of the Tahoe Basin. Forested uplands consist of an extremely broad range of site types. Analysis of sediment reduction in forested uplands is extremely complex because of the nature of sites (e.g., varying soils and slopes), interactions between site types (e.g., roads, ski slopes, and forested areas within one defined area) and the dearth of quantified erosion process information associated with forested uplands. Nonetheless, the Forested Uplands Source Category Group (FUSCG) members—Mark Grismer, Michael Hogan, Kevin Drake, and others—have developed the most complete data set available that is based on actual field research and real-time measurements of erosion at a range of sites within the Tahoe Basin. That data provides a great deal of the basis of this report.

The FUSCG considered the sediment and nutrient loading from forested upland soils, ranging in functional condition from drastically disturbed (e.g., unpaved roads) to relatively undisturbed (or not recently disturbed, e.g., forests). These soils have the potential to be mobilized at the present time or could be mobilized in the future as part of forest management activities. A considerable body of knowledge has been developing in the past three decades related to Lake Tahoe Basin erosion. Descriptions of the erodibility, hydraulic conductivity, organic matter content (OM%) and other relevant soil parameters of interest here have been developed by the USDA-NRCS in Tahoe Basin soil surveys (1974, 2006). There is a considerable body of erosion and related water quality research that has been conducted in the Basin during the past three decades that has been valuable toward development of the modeling equations used here. Much of this research has been summarized in the Comprehensive Science Plan for the Lake Tahoe Basin (Tahoe Science Consortium 2007) as well as in some technical journal articles (e.g., Grismer and Hogan 2005b; Johnson et al. 2001, and Miller et al. 2006). From the hydrologic perspective of estimating runoff and erosion, rainfall simulation (RS) studies by Guerrant et al. (1991) and Naslas et al. (1994a, 1994b) provided some of the basis for the effects of forest soil type (volcanic or granitic) on runoff and erosion rates, as well as the later work by Grismer and Hogan. Effects of forest practices and conditions on runoff water quality (nutrient concentrations) have been evaluated in a number of studies by research groups associated with Dale Johnson and Wally Miller at the University of Nevada-Reno. The first comprehensive Basin-wide assessment of stream loadings was completed by Simon et al. (2004) of the U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS). This study, together with Lake Tahoe Interagency Monitoring Program (LTIMP) stream-monitoring data was incorporated into the first Basin-wide modeling effort (Tetra Tech 2005) that enabled determination of loading rates from 20 land-use categories. This model (Loading Simulation Program in C++ [LSPC]) and associated studies and calibration revealed that the majority of the sediment and nutrient loading outside urban land uses occurs from soils that have been affected by road development, recreation and past logging activities. Such soils have been degraded in part or whole through loss of structure, infiltration capacity, and aggregate stability (a measure of erodibility). Finer textured soils associated with those of volcanic (andesitic) origin are generally more readily degraded and eroded as compared to those of granitic or metamorphic geologic origin. Perhaps more importantly, the LSPC modeling revealed the need for quantitative information about sediment and nutrient loading rates as functions of land use (cover), slope, soils, and location within the Basin. For example, much of the earlier research on runoff water quality from plots or locations could not be used directly in the modeling effort because pertinent hydrologic parameters were not included in the study (e.g., runoff rates, areal extent). Similarly, while soil survey information about soil OM% should provide direct information complementary to that of erodibility, there is not yet quantitative information relating OM% to erodibility or sediment yield (SY) in the Basin. While limited data on sediment nutrient loading in runoff exists, the FUSCG has quantified sediment and fines loading from the different soil types through recent data collection and associated research.

Sediment Sources

Sediment sources from upland soils are dependent on three primary factors: (1) soil origin or parent material, (2) level of disturbance and associated soil physical condition, and (3) slope. Elevation in the subbasin is also a factor in that elevation and climate are associated with a particular location (e.g., higher elevations on the west shore have higher precipitation amounts, resulting in greater potential runoff). While there is a range of soil erodibility across the various soil types composing the Basin subwatersheds, RS studies of erosion rates combined with analyses of surface soil particle-size distributions have indicated that the various soil types can largely be classified in terms of erosion potential (EP) as either granitics or volcanics (Grismer and Hogan 2004). Metamorphic rock-based soils (a small fraction of the Basin) tend to behave hydrologically as granitics. Some *mixed* volcanic/granitic soils occur along the Lake's west shore where volcanically deposited soils overlay older granitics. Finer-grained volcanic soils are more readily mobilized by runoff events (rainfall or snowmelt), could, as a result of the finer grains, have greater potential aggregate strength as compared to the larger grained granitic soils that are more difficult to mobilize in most runoff events, and could lack structure. Steeper slopes result in greater runoff rates, hence mobilization power to transport sediments downslope. In contrast, improved soil tilth (the physical and biological functional condition of the soil) increases soil infiltration rates or capacity, thereby reducing runoff rates in nonsaturated soil conditions. In the analyses completed here, greater SYs are found from the volcanic soil dominated subwatersheds across the west and north shores of the Tahoe Basin as compared to the granitic soil dominated subwatersheds of the south and east shores.

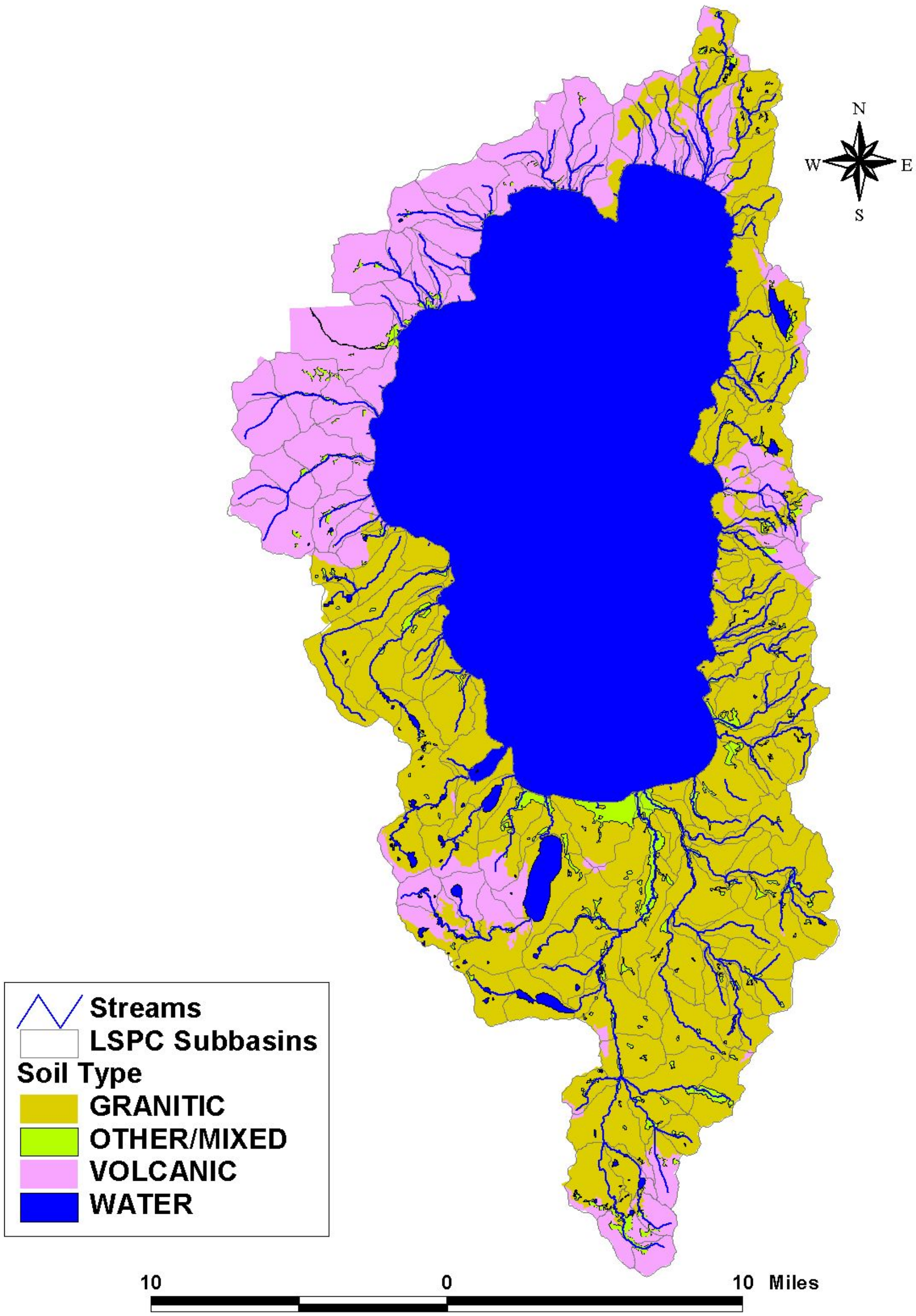


Figure 4-1. Soil parent material types in the Lake Tahoe Basin.

Fine Sediment Sources

Fine sediment movement results from soil aggregate breakdown associated with lack of soil cover and high levels of soil disturbance. Research in the Tahoe Basin has shown that the production of fine sediment (i.e., silts and clays) in runoff can be directly related to the overall erodibility of a soil in a subbasin. Thus, quantification of SY enables direct determination of the fractions of the total sediment load that are silt and clay-sized particles. Fine-sediment loadings are particularly associated with bare or nearly bare soils found in unpaved roads, some ski runs, and recreation areas in forested uplands.

Nutrient Sources

Nutrient loading in runoff is a function of several factors associated with relative functionality of the soil, the soil type, elevation, aspect, and, of course, type and intensity of disturbance. In general, Tahoe Basin soils have low levels of nutrients compared to many other watersheds, and those low nutrient levels have resulted in the original famed Lake clarity. However, studies by the Johnson and Miller research groups at the University of Nevada–Reno have highlighted the range of nutrient concentrations possible in runoff from forested areas before and after burns and underscored that burning results in a temporary (seasonal) sharp increase in total nitrogen (TN, or TKN) and phosphorus (TP) concentrations that return to pre-burn levels in the next growing season. Unfortunately, as with other soil nutrient concentration studies, the related hydrologic parameters, such as infiltration and runoff rates associated with the reported nutrient concentrations, are not available, limiting their utility in the watershed modeling process.

In undisturbed forest soils, most nutrients are bound in the soil particulate, organic and plant matter above and below the ground surface. Finer-textured soils are more readily able to adsorb or bind nutrients and make them available for plant use. Further, in forested Settings, high-carbon soil organic matter tends to result in a slow nutrient cycling (or turnover) rate. However, because the nutrients can be particulate bound, when the particulates are mobilized following disturbance, more nutrients are transported to streams. Fire-based disturbances *liberate* a fraction of the nutrients in organic and plant matter that are then readily mobilized during subsequent runoff events. As the soil *recovers* or *heals* by rebuilding long-chain organic carbon compounds, these nutrients are gradually readsorbed and bound in the soil organic matter and plant tissues. Generally, disturbances that result in loss of soil hydrologic function (i.e., infiltration capacity) also result in greater nutrient losses. Across the Basin, nutrient losses are expected to be greatest from the finer-textured volcanic soils and recently burned areas. Wildfire effects on forest soil erosion and nutrient runoff conditions were not evaluated as part of this analysis, because wildfires are considered *extreme events* over which we have limited control. This analysis is focused on evaluating existing (not theoretical) loading and load reduction opportunities.

LTIMP monitoring revealed a wide range in sediment and nutrient concentrations of tributary streams to Lake Tahoe that appear spatially dependent within the Basin. Calibration of the LSPC model to the LTIMP water quality data resulted in determination of long-term average annual runoff TKN and TP concentrations that vary by land-use category within each subwatershed as well as from subwatershed to subwatershed. These values capture the range of TN and TP concentrations reported in the studies conducted by Johnson and Miller's groups. In the FUSCG analysis, the LSPC-generated nutrient concentrations are adopted for each land-use category of each subwatershed. As a first approximation, reductions in nutrient loading in this analysis result only from decreased runoff associated with improved soil hydrologic conditions from restoration efforts. This assumption neglects the possibility of nutrient leaching through increased interflow that could result; however, no information to the contrary is available.

Overall Sediment and Nutrient Sources

When all other factors are held constant, the greatest sediment and nutrient loading in forested upland areas of the Tahoe Basin is expected from bare, disturbed volcanic soils followed by bare, disturbed mixed (metamorphic/granitic/volcanic), and then granitic soils. Larger particle sizes and very limited nutrient levels found in granitic soils reduce their relative overall contribution to stream and Lake sediment and nutrient loading with the exception of very disturbed granitic soil areas lacking cover and soil structure (aggregate stability).

4.2. SCG Analysis Overview

The FUSCG analyses used a combination of information types to derive loading reductions for forested upland Settings. For general disturbed areas such as ski runs, roads, and recreation sites, a large database of actual field-derived data from the Lake Tahoe region was employed for the analyses. For forest practices, because there is very little field-derived data available from the Lake Tahoe area, the FUSCG generally relied on information gathered from practitioners in the forestry field and, where there was disagreement in outcome or cost, used a reasonable average. The data was then grouped into the land-use categories used as input for the LSPC model. That model is being used to determine potential sediment and nutrient load reductions that might be expected from a range of treatments.

Because models generalize specific data, data was processed and regrouped into appropriate categories that were then used as inputs for the model. The SCG's assessment relied on two parallel tracks of information development (which are shown graphically in a flowchart in Figure 4-6). Track 1 (blue boxes in flowchart) focused on defining the framework for the analysis and included the following steps:

1. Acquiring land-use categories used in LSPC model.
2. Grouping of land-use categories into Settings on the basis of PCO application and existing soil functional condition (See Section 4.4).
3. Defining three groups of treatments (Treatment Tiers) for each Setting that represent range of effectiveness, cost, and effort (See Section 4.5).
4. Assigning each land use–Treatment Tier combination a functional condition class (A–F), which corresponds to a regression equation that predicts loading (runoff, sediment and nutrients) (See Section 4.6).

Track 2 (yellow boxes in flowchart) focused on the processing and analysis of field-measured data to be used in the LSPC model. Track 2 included the following steps:

1. Acquiring spatial data from LSPC model (land use, soil type, slope, surface flow, and so on)
2. Organizing field RS data from Tahoe region by LSPC model parameters.
3. Developing equations to predict loading for various levels of treatment and/or soil conditions (See Section 4.6). Equations were developed to predict the following parameters:
   - Infiltration rate = *f(soils, treatment)*
   - Runoff = *f(surface flow, infiltration rate)*
   - Sediment load = *f(soils, slope, runoff, area)*
   - Fines (silt) load = *f(sediment load)*
   - Nutrient load = *f(land-use, runoff, area)*
4. Stratifying loading equations into functional condition classes (See section 6).

The two tracks come together in the final analysis step (green box in flowchart), which is performing the loading calculations for all 184 subwatersheds in the Tahoe Basin. Flows and loads were first summed for each land-use category across subwatersheds, then for each Setting (group of land uses), and finally across the entire Basin to develop an overall table of estimated potential load reductions. (See Table 4-10).

4.3. Pollutant Control Options

Initially, the FUSCG developed a broad list of pollutant control options (PCOs) that could be applied to different land uses commonly found in the forested upland portion of the Lake Tahoe Basin such as roads, ski runs, and forested areas. Because unpaved roads are typically subject to ongoing disturbance by vehicle travel, most road PCOs (Setting A) are aimed at capturing runoff and conveying it away from watercourses or infiltrating runoff on-site. PCOs for ski runs and other disturbed soils (Setting B) range from surface treatments that can temporarily reduce SY to more intensive restoration treatments that aim to control sediment and runoff at the source by restoring key ecological functions (such as infiltration capacity). Developing and evaluating PCOs for forested areas (Setting C) was more difficult because there is very little measured data from the Tahoe region that could be used to assess the impacts of forest thinning and fuels management treatments. However, fuels-reduction treatments are planned for much of the forested portion of the Tahoe Basin in the near future. Fuels treatments range in intensity from hand crews, to prescribed fire, to mechanical harvesting systems; their potential impacts on runoff and erosion processes in the Tahoe Basin are poorly understood. PCOs for forested areas include many of the same treatments used on roads and ski slopes and are aimed at mitigating any impacts of forest management treatments and reducing loading from areas that have been disturbed by past logging activities (such as abandoned roads and trails).

The initial list of PCOs was refined on the basis of the FUSCG members' experience as well as input from key agency personnel, land managers, fire districts, ski area operation managers, and researchers. Some PCOs were grouped together on the basis of similar characteristics (application, cost, effectiveness). Other PCOs were excluded if they were no longer being used or deemed ineffective. No PCOs were excluded on the basis of cost or current regulatory constraints. Table 4-1 provides a list of the PCOs that were evaluated. Descriptions of each PCO can be found in Appendix FUSCG-A, Table A-1.

Table 4-1. PCOs evaluated for each Setting

Organic matter amendments	Traffic exclusion
Ripping-subsoiling	Pine needle filter berms
Tilling	Flow path check dams
Soil surface roughening	Hydroseeding
Seeding	Infiltration ditches
Mulching	Infiltration swales
Irrigation	Rock-lined ditches
Functional restoration	Settling ponds
Road obliteration	Waterbars/rolling dips

4.4. Pollutant Control Settings

Settings are the spatial building blocks for the Lake Tahoe TMDL load-reduction analysis process. The FUSCG defined Settings by grouping forested uplands land-use categories from the LSPC model into Settings on the basis of two criteria: (1) types of PCOs that could be applied to reduce loading, and (2) existing soil functional conditions (i.e., level of disturbance). Three FUSCG Settings have been defined, ranging from drastically disturbed soil conditions (e.g., unpaved roads) to relatively undisturbed soil conditions (e.g., forested areas).

PCO Settings and Spatial Resolution

Sediment and nutrient loading to streams in a subbasin are largely controlled by the spatial distribution of soils, slope, and elevations encountered in the particular subwatershed. Steeply sloping, high-elevation areas can have large sediment and nutrient losses that are captured in lower gradient areas downslope resulting in a smaller fraction of the upslope area materials being loaded to streams. This is a well-documented problem in erosion studies (See reviews by Merritt et al. 2003; Grismer in press 2007b). In contrast, such high-elevation, steep areas might intersect directly with stream zones resulting in direct loading of sediment and nutrients. Evaluating loading at the localized plot scale (1–10 m) might not capture this effect and would result in overestimation of stream loading. Similarly, modeling that does not include slope variations at the ~10 m scale might miss terrain features that limit or exacerbate stream loading. In the FUSCG loading analyses, Settings were composed of 1–5 land-use categories within each subwatershed, but modeling analyses were completed at the land-use category scale, ranging from less than one acre (e.g., unpaved roads) to hundreds of acres (e.g., EP3), depending on the category. Here, FUSCG modeling results were based on use of a *scaling factor*, or perhaps more appropriately referred to as a Soils-Geology Factor (SGF), which depended largely on soil type rather than subwatershed area. SGF was determined for each subwatershed through matching of the overall subwatershed sediment loading from the FUSCG land-use categories to that from LSPC, which was calibrated to the LTIMP data. That is, with few exceptions, SGF in the subwatershed analyses did not depend on the subwatershed area considered (ranging from one to several hundred acres), suggesting that once established, the modeling equations more or less quantitatively captured the runoff and erosion processes.

FUSCG Land-Use Settings

The LSPC land-use layers represented in the forested uplands portion of the Basin were organized into Settings on the basis of existing functional condition and PCO application and to some degree established the scale of analysis. Many land-management practices and related PCO applications occur at roughly the one-hectare scale (and sometimes smaller, e.g., unpaved roads). Similarly, much of the actual field measurements used to quantify erosion are conducted at or below this scale. On the other hand, the LSPC-derived, land-use scale varied from less than one hectare to hundreds of hectares depending on the size of the particular subwatershed considered. This, in turn, affected the *scale* of FUSCG Settings crafted from the LSPC land-use categories. Nonetheless, for the purposes of discussion here, the spatial scale of 1–10 hectares was assumed for these analyses. Table 4-2 summarizes the grouping of LSPC land-use layers into FUSCG Settings.

Table 4-2. LSPC land-use categories grouped into FUSCG Settings

Setting	LSPC Land-use category
A	Roads_Unpaved
B	Veg_unimpacted EP5
	Ski_Runs-Pervious
	Veg_Recreational
C	Veg_Burned
	Veg_Harvest
	Veg_unimpacted EP4
	Veg_unimpacted EP3
	Veg_unimpacted EP2
	Veg_unimpacted EP1

Below are definitions for the LSPC land-use layers listed in Table 4-2. These definitions were taken directly from the LSPC model report (Tetra Tech 2005).

- **Veg_Unimpacted:** Forested areas that have been minimally impacted in the recent past. This layer was further divided into five EP categories (EP1-EP5) by Simon et al. (2004). The five EP land uses are synthesized categories that include the effects of geology, soil type (erodibility), land use or cover, average land slope, and elevation (precipitation level). EP1 represents the lowest relative EP, while EP5 represents the highest relative EP.
- **Veg_Recreational:** Lands that are primarily vegetated and are characterized by relatively low-intensity uses and small amounts of impervious coverage. These include the unpaved portions of campgrounds, visitor centers, and day use areas.
- **Veg_Ski Runs-pervious:** Lands within otherwise vegetated areas for which some trees have been cleared to create a run.
- **Veg_Burned:** Areas that have been subject to controlled burns or wildfires in the recent past.
- **Veg_Harvested:** Lands that management agencies have thinned in the recent past for the purpose of forest health and defensible space (areas cleared to reduce the spread of wildfire).
- **Roads_Unpaved:** Unpaved U.S. Forest Service (USFS) and California and Nevada state park roads and recreational trails (trails buffered to 2-foot width, based on Basin-wide average trail width).

Coordination with Urban and Groundwater SCG on Setting Definition

The FUSCG worked closely with the Urban and Groundwater SCG (UGSCG) to resolve concerns about potential spatial overlap before conducting the analyses. The concerns stemmed from the spatial distribution of certain LSPC land use categories, some of which are in both *urban* and *forested* areas. The land-use categories in question were veg_recreational and CICU_pervious (Commercial/Institutional/Communications/Utilities). A simple geographic information system (GIS) analysis was conducted to examine the spatial arrangement of these land uses. Plan Area Map boundaries were used to delineate *urban* from *forested* for this analysis. The analysis showed that approximately 90 percent of the CICU_pervious land use is within *urban* areas (the remaining 10 percent in *forested* areas totaled approximately 250 acres). For the veg_recreational land use, approximately 70 percent is within forested areas and the remaining 30 percent in *urban* areas accounts for a total area of less than 100 acres. Given the spatial scale of this analysis, the potential areas of overlap were not considered to be significant. Because each SCG defined Settings on the basis of LSPC land-use categories, it was most efficient to assign each land use to one group at 100 percent treatment level rather than disaggregating land uses or adjusting treatment levels. On the basis of the findings of the GIS analysis and the types of treatments that would likely be associated with reducing loading from each land use, 100 percent of the CICU_pervious land use was included in the UGSCG analyses and 100 percent of the veg_recreational land use was included in the FUSCG analyses. For a table showing all LSPC land-use categories and to which SCG each was assigned, See Table 4-3 .

Table 4-3. LSPC land-use categories and SCG assignments

Land-use description	Subcategory name	SCG responsible
Water Body	Water_Body	n/a
Single Family Residential	Residential_SFP	UGSCG
	Residential_SFI	UGSCG
Multi Family Residential	Residential_MFP	UGSCG
	Residential_MFI	UGSCG
Commercial/Institutional/ Communications/Utilities	CICU-Pervious	UGSCG
	CICU-Impervious	UGSCG

Transportation	Roads_Primary	UGSCG
	Roads_Secondary	UGSCG
	Roads_Unpaved	FUSCG
Vegetated	Ski_Areas-Pervious	FUSCG
	Veg_Unimpacted EP1	FUSCG
	Veg_Unimpacted EP2	FUSCG
	Veg_Unimpacted EP3	FUSCG
	Veg_Unimpacted EP4	FUSCG
	Veg_Unimpacted EP5	FUSCG
	Veg_Recreational	FUSCG
	Veg_Burned	FUSCG
	Veg_Harvest	FUSCG
	Veg_Turf	UGSCG

General Description of Settings

FUSCG Settings are described below. For a map showing the spatial arrangement of the Settings within the Tahoe Basin, see Figure 4-2.

Setting A

This Setting includes only unpaved roads which, by land area, accounts for less than one percent (0.2 percent or 311 acres) of the forested uplands in the Basin. Much of this road network is gated forest roads owned and maintained by the USFS-Lake Tahoe Basin Management Unit (LTBMU). In general, unpaved roads in the Tahoe Basin are bare, extremely compacted, and associated with minimal infiltration and high runoff.[3] Most PCOs that are applicable to roads are not applicable to other Settings, because most road PCOs are designed to reduce sediment and nutrient loading while still accommodating vehicle traffic. Road PCOs also require frequent maintenance to maintain effectiveness. For these reasons, unpaved roads have been classified as a discrete Setting.

Setting B

Setting B includes areas such as ski runs, unpaved portions of campgrounds, and areas with extremely high EP, such as exposed bedrock and extremely steep, bare slopes (EP5), accounting for 1.1 percent (1,878 acres) of the forested uplands portion of the Tahoe Basin. With the probable exception of EP5, most of these areas have been subject to major anthropogenic soil disturbance (e.g., removal of topsoil and trees/vegetation, grading, compaction) and have received some form of surface treatment aimed at controlling erosion and reestablishing vegetation (such as hydroseeding, tackifier, straw mulch, erosion control fabric). In general, these areas are characterized by low to moderate vegetation cover, little or no functional mulch cover, and low soil infiltration capacity (high runoff).

Setting C

This Setting includes undeveloped forested upland areas—162,639 acres that account for the remaining 98.7 percent of forested uplands in the Basin and roughly 80 percent of the land use in the entire Basin. These areas are generally managed for forest and watershed health, wildlife, defensible space, and scenic values. Some of these areas have been subject to recent management activities such as thinning, fuels

[3] Note that the USFS-LTBMU has committed considerable resources to inventorying, improving and decommissioning unpaved roads in the last several years as part of their Access and Travel Management Plan.

reduction, controlled burns or wildfires (veg_burned and veg_harvested categories) in the recent past. As a result of long-term fire suppression in the Tahoe Basin, most of this Setting has severely overstocked fuels and various levels of fuels reduction treatments are planned throughout the Basin in the next ~20 years. In general, areas within this Setting are characterized by sustainable soil-plant communities, high levels of soil-hydrologic function, and thick mulch/duff layers.

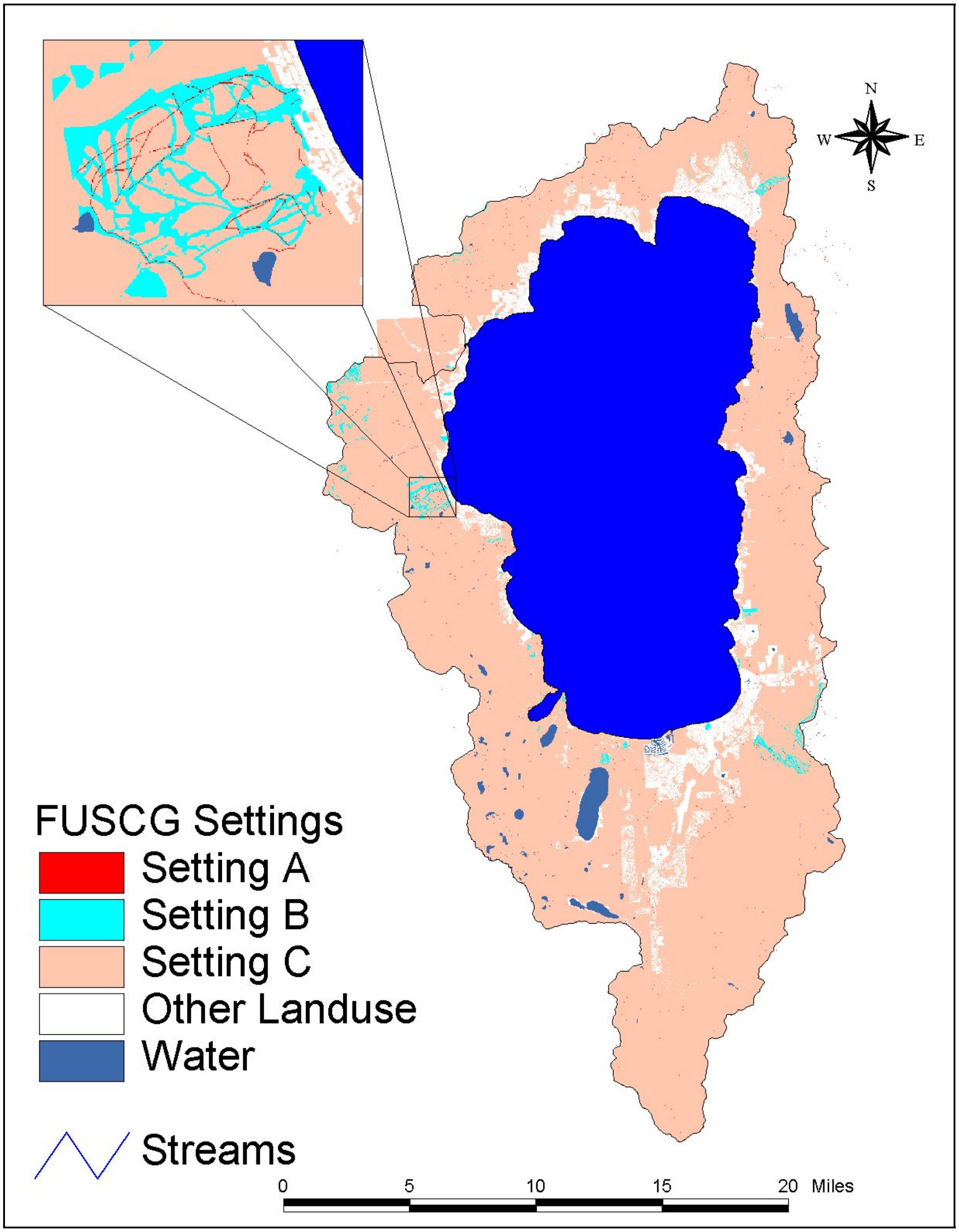


Figure 4-2. FUSCG Settings map.

4.5. Treatment Tiers

Three groups of treatments (T*reatment Tiers*) have been selected for evaluation across a range of Settings. The Treatment Tiers described below are incremental improvements in soil cover and tilth conditions and represent a wide range of effectiveness, effort, and cost. The Treatment Tiers and associated Settings are listed in Table 4-4.

General Description of Treatment Tiers

Baseline

- The *no action* alternative.
- Values will serve as a baseline for assessing the relative effectiveness or benefits of the three Treatment Tiers.
- Subwatershed sediment and nutrient loading at this level is equal to that generated by the calibrated LSPC model for the FUSCG land-use categories outlined above.

Treatment Tier 1

- Low treatment intensity.
- This Treatment Tier is intended to capture the most common or *standard* treatments currently being applied in different Settings.
- For drastically disturbed areas such as ski slopes, this includes primarily surface treatments such as hydroseeding. For forested areas, this includes *standard* forest management practices such as cut-to-length (CTL) thinning and required best management practices (BMPs), as defined by the USFS and other land management entities.

Treatment Tier 2

- Medium treatment intensity.
- This level of treatment is considered to be a more *functional* level of treatment, somewhere in between Tier 1 and Tier 3 in terms of effectiveness. In some cases, this treatment can be considered the *state-of-the-art.*

Treatment Tier 3

- Highest treatment intensity.
- Across all Settings, this Treatment Tier is designed to achieve the *Tier 3*.
- This Treatment Tier describes a level of treatment that includes all elements necessary (to the best of the group's understanding) to develop site conditions that will, in time, mimic and sustain native or *undisturbed* conditions.

Table 4-4. Definition of Treatment Tiers for each FUSCG Setting

Treatment Setting	Baseline functional condition	LSPC land-use category	Treatment Tier 1	Treatment Tier 2	Treatment Tier 3
A	Bare, highly compacted	Roads_Unpaved	Full BMP retrofit (waterbars, rolling dips, armored drainage ditches, stabilize ruts) + annual maintenance	Full BMP retrofit (waterbars, rolling dips, armored drainage ditches, stabilize ruts) + on-site sediment capture + annual maintenance	Full obliteration/ functional restoration (recontouring, soil restoration, seed, functional mulch cover, block vehicle access)
B	Disturbed; surface treatment; no functional mulch cover	Veg_unimpacted EP5	Surface treatment (hydroseeding + tackifier)	Surface treatment with functional mulch cover (pine needles, tub grindings)	n/a
		Ski_Runs-Pervious	Surface treatment (hydroseeding + tackifier)	Surface treatment with functional mulch cover (pine needles, tub grindings)	Full recontouring, functional restoration (tilling, organic amendments, organic fertilizer, seed, functional mulch cover), establishment of native hydrology and vegetation
		Veg_Recreational	Surface treatment (hydroseeding + tackifier)	Surface treatment + functional mulch cover (pine needles, tub grindings)	Full recontouring, functional restoration (tilling, organic amendments, organic fertilizer, seed, functional mulch cover), establishment of native hydrology and vegetation
C	Relatively undisturbed, managed forest	Veg_Burned	Ground-based equipment + req'd BMPs	Ground-based equipment + full BMPs	Ground-based equipment + full BMPs + restore legacy roads/trails
		Veg_Harvest	Ground-based equipment + req'd BMPs	Ground-based equipment + full BMPs	Ground-based equipment + full BMPs + restore legacy roads/trails
		Veg_unimpacted EP4	Ground-based equipment + req'd BMPs	Ground-based equipment + full BMPs	Ground-based equipment + full BMPs + restore legacy roads/trails
		Veg_unimpacted EP3	Ground-based equipment + req'd BMPs	Ground-based equipment + full BMPs	Ground-based equipment + full BMPs + restore legacy roads/trails

Treatment Setting	Baseline functional condition	LSPC land-use category	Treatment Tier 1	Treatment Tier 2	Treatment Tier 3
		Veg_unimpacted EP2	Ground-based equipment + req'd BMPs	Ground-based equipment + full BMPs	Ground-based equipment + full BMPs + restore legacy roads/trails
		Veg_unimpacted EP1	Ground-based equipment + req'd BMPs	Ground-based equipment + full BMPs	Ground-based equipment + full BMPs + restore legacy roads/trails

Description of Treatment Tiers by Setting

Treatment Tiers for Setting A

For unpaved roads, Tiers 1 and 2 describe two levels of BMP retrofits and maintenance while Tier 3 describes a full obliteration of the road. Tier 1 represents a fairly standard package of improvements aimed at capturing and conveying runoff from the road surface through waterbars and armored drainage ditches. Tier 2 includes the same package of road improvements but goes a step further to include infiltration swales (or other infiltration infrastructure) to increase on-site sediment capture. The types of PCOs associated with Treatment Tiers 1 and 2 require frequent maintenance (ideally annually) to maintain their desired functionality. The Tier 3 treatment for unpaved roads describes full removal, recontouring, and functional restoration of the road (a.k.a. obliteration). Because the Tier 3 treatment level is intended to represent very high load reductions, the FUSCG made the assumption that roads could be completely decommissioned and restored (as opposed to paved). In this case, full road obliteration and restoration of ecological functions is the most effective treatment approach to ensure long-term load reduction.

Treatment Tiers for Setting B

Setting B includes areas where significant soil disturbance has taken place (e.g., removal or burial of topsoil, removal of vegetation). Treatment Tiers associated with Setting B range from a typical surface-level *revegetation* treatment (minimal level of function) to full-functional restoration and recapitalization of the soil-plant ecosystem. Tier 1 and 2 treatments could lead to a short-term reduction in erosion but will not provide sustainable, long-term results because key ecosystem functions have not been adequately restored. Tier 3 includes the elements necessary (to the best of the group's understanding) to restore critical ecosystem functions that provide sustainable sediment source control. For the EP5 land-use category, no treatments were evaluated for Tier 3. This is because this land-use category is likely composed of areas where the substrate is too dense or the land is too steep to restore hydrologic function (such as exposed bedrock or extremely steep, bare slopes). The best possible treatments for reducing sediment and nutrient loading from these areas are the types of surface treatments described in Tiers 1 and 2.

Treatment Tiers for Setting C

Setting C includes relatively undisturbed forested upland areas with soils that are characterized by limited erodibility, high-infiltration rates, and sustainable soil nutrient conditions. Because of long-term fire suppression, most of the forested upland portion of the Lake Tahoe Basin has severely overstocked fuels (both standing and down) and high stand densities. Thinning and fuels reduction treatments are planned for forests throughout the Tahoe Basin over the next ~20 years, focused primarily within the wildland-urban interface during the next ~5 years. Thinning and fuels reduction treatments can range widely in cost, intensity, and potential impacts on soil erosion.

Forest management treatments typically have three distinct components: (1) a primary thinning/harvesting treatment (e.g., CTL harvesting, conventional harvesting or *skidding*, hand crews); (2) a secondary ground-fuels treatment (e.g., chipping, mastication, pile burning); and (3) mitigation treatments or BMPs (e.g., waterbars, mulching, ripping). From a sediment or nutrient-loading analysis standpoint, forest management is wrought with uncertainty. Depending on the specific treatments applied and local physiographic factors (soil type, slope angle, soil moisture/seasonality), ground-based mechanized thinning and fuels treatments have the potential to increase runoff and erosion, at least at the local scale. However, given the types of low-impact treatments being employed and planned in Tahoe Basin fuels management efforts (primarily hand treatment and CTLsystems) and regulatory limitations on mechanical treatment on steep slopes and SEZs, fuels treatments are unlikely to increase sediment and nutrient loading at the subwatershed scale (the scale of this analysis). Therefore, the main opportunities to reduce loading from forested areas are related to careful planning and implementation of BMPs/PCOs (e.g., obliteration of roads, landings and trails). For the FUSCG analyses, Treatment Tiers for Setting C were defined as follows:

- **Tier 1**. Ground-based equipment followed by *required* BMPs. This is considered the *standard* level of treatment. These activities are presumed to result in no functional change to the soil infiltration conditions when employed in small areas of the Tahoe Basin.
- **Tier 2**. Ground-based equipment followed by *full* BMPs. This is a medium level of treatment that includes BMP treatments aimed at increasing infiltration and reducing runoff in areas disturbed by thinning and fuels reduction treatments. This Treatment Tier results in an improvement in some of the forested areas that are more prone to erosion while resulting in little additional improvement in areas with existing low EP.
- **Tier 3**. Ground-based equipment followed by *full* BMPs and functional restoration of legacy roads and trails. This is considered the highest load reduction analyzed, because it includes full obliteration (functional restoration treatment) of legacy roads and trails within the project area. Legacy roads and trails are old, abandoned roads and trails—long-standing pollutant sources in upper watersheds throughout the Tahoe Basin that are disbursed and largely uninventoried. Rather than limiting the scope of load-reduction opportunities to simply mitigating potential new impacts of proposed forest management activities, this Treatment Tier addresses an important existing source of pollutant loading in forested upland areas.

Thinning and fuels reduction treatments associated with Setting C Treatment Tiers were defined very generally for two main reasons: (1) limited data to differentiate soil impacts of different ground-based treatments, and (2) inability to evaluate the locations and site-specific conditions spatial distribution of specific treatment types within a subwatershed because of the resolution of the LSPC model. *Ground-based equipment* includes common mechanical harvesting methods, mastication, chipping, and the like. These Treatment Tiers do not include hand crews, because the potential impacts of hand-thinning on loading are negligible, especially at the subwatershed-scale. These Treatment Tiers also do not include prescribed fire (broadcast or pile burning), as the impacts of fire on sediment and nutrient loading are very site-specific and extremely difficult to predict at the subwatershed-scale. While a great deal of fire-related research is in progress, the FUSCG decided to exclude prescribed fire from this *first cut* analysis on the basis of the resolution of the LSPC model and the lack of agreement in the existing body of water quality-related prescribed fire research. For a brief summary of existing research on the effects of prescribed fire on runoff, sediment, and nutrient yield, see the Literature Review (Appendix FUSCG-B).

The following forest management BMP definitions are being used in FUSCG analyses. These definitions were developed in close coordination with the USFS-LTBMU.

- **Required BMPs**. Waterbar/mulch skid trails, landings and temporary roads; close temporary roads.
- **Full BMPs**. Till, mulch and construct waterbars on all skid trails; obliterate/recontour (i.e., full functional restoration) all landings and temporary roads. This level of post-treatment BMPs is intended to restore hydrologic function in disturbed areas to levels that are equivalent or higher than undisturbed soil conditions.

4.6. Analysis Methodology

This section describes the data sources and analysis methods that were employed to estimate load reductions for forested uplands of the Tahoe Basin.

Data Sources

Sediment Yield and Infiltration/Runoff Data

The FUSCG load reduction analyses relied heavily on erosion data developed from RS studies by Grismer and others (Grismer and Hogan 2004, 2005a, 2005b; Grismer and Ellis 2006; Grismer et al. 2007 in-press a; Grismer et al. 2008 submitted b and Hatchett et al. 2006) as corroborated by similar RS studies by Miller and others (e.g., Guerrent et al. 1991) relating soil type and land treatments/conditions to SYs and particle-size distributions in runoff for the Tahoe Basin. Information from the most recent Tahoe Basin soil survey (USDA-NRCS 2006) is also included indirectly through definition of the vegetated land-use categories outlined above; that is, implicit to land-use categories EP1 to EP5 is the soil type, erodibility, cover, OM%, and depth provided by the soil survey.

The field data developed by Grismer and others was from extensive and ongoing field RS on an approximately one-square-meter scale. This scale of measurement is not expected to capture the hillslope length associated with the subwatershed analyses conducted here and, if applied directly, is generally considered to result in overestimation of runoff rates and sediment loads (Merritt 2003; Grismer 2007 in-press b). Modest *scale factors* (SGFs) were developed for each subwatershed and employed across all land-use categories (i.e., one SGF per subwatershed). SGFs were optimized such that the FUSCG baseline sediment loading for each subwatershed was identical to that from the LSPC model (Tetra Tech 2005). An in-depth analysis of SGF variability across the Basin is beyond the scope of this report and is provided elsewhere (Grismer 2008 submitted a). In brief, SGF was primarily a function of soil classification and was relatively constant between subwatersheds within the larger watersheds (e.g., Upper Truckee River watershed). Consistent with that expected, SGFs of roughly 0.10 were employed for most granitic-dominant subwatersheds, while values of 0.5–4 were employed for volcanic soil dominated subwatersheds. SGFs were largely constant across the subwatersheds composing the larger watersheds (e.g., all the subwatersheds of the Upper Truckee River watershed had nearly the same SGFs). Across the entire Tahoe Basin, there were fewer than five subwatersheds that had SGFs somewhat inconsistent with their sister subwatersheds, but these were usually associated with other anomalous features such as very small areas or changing soil classes.

As noted above, nutrient concentrations for each land-use category were taken from the LSPC model results for each subwatershed and used directly in the analyses. While soil restoration efforts associated with the Treatment Tiers should result in smaller nutrient loadings from any particular land-use category, the only reduction allowed in the FUSCG modeling approach was the reduced runoff associated with improved infiltration rates from soil restoration. Thus, the nutrient loading reductions estimated here are overly conservative and will require further analysis if land-use-based nutrient concentrations in runoff become available from future research. This latter aspect is of acute importance to prescribed burn sites. The FUSCG developed regression equations to calculate infiltration/runoff rates and SY on the basis of soil type, land slope and treatment level/land condition. With information from the LSPC model about soil type, land slope and land use, the FUSCG can assign a treatment level/functional condition class and calculate infiltration rate and SY (or soil *erodibility*, as defined in the Water Erosion Prediction Project (WEPP) model) from regression equations. The same regression equations were used to calculate loading for the five EP land-use categories developed by Simon et al. (2004), which represent a composite of the effects of geology, soil type, land use or cover, average land slope, and elevation (precipitation level). However, to incorporate the soil-and slope-based regression equations, slope was disaggregated from the EP land-use categories on the basis of the slope intervals assigned by Simon et al. (2004, Table 6-6).

Infiltration rates are generally greater in granitic soils as compared to volcanic soils and vary within a particular soil type. *Native* soil conditions and incorporation (tilling/ripping) treatments have the greatest infiltration rates as compared to bare or simply grass-covered soils. As a result, lower gradient (slope) areas, which tend to have greater soil development generally have higher infiltration rates as compared to steeply sloping areas of the watershed. Grismer and others found that infiltration rate was a weak inverse function of slope at small slopes and leveled off at nearly similar values at larger slopes. Such inverse relationships between infiltration rates and slopes for the different soil types and treatments was employed here so as to characterize the decreased runoff rates expected with improved soil tilth. The recently completed Tahoe Basin Soil Survey (USDA-NRCS 2006) provides a wealth of useful soil classification information and shows that there can be great diversity within soil types found in the Tahoe Basin (e.g., depth, percent coarse fragments). However, the resolution/scale of this analysis (subwatersheds) made it impractical to evaluate soil physical characteristics at any finer scale than parent material. Additionally, the large number of RS plot studies has enabled the FUSCG to determine an equivalent range of erodibilities associated with the various soils in the Basin.

Examples of the volcanic soil regression equations for SY as a function of slope and treatment level/functional condition are illustrated in Figure 4-3. Note that the regressions have a range of R^2 values indicating the relative *strength* of the equation *fit* to the observed data. A perfect fit results in an R^2 value of 1.0, though most larger field data sets are generally well-represented by R^2 values greater than ~0.5. A small R^2 value implies that the independent variable (slope) provides little information about the dependent variable (SY). However, during a more extensive statistical analysis of the data Grismer et al. (2007) confirmed the significance (> 95 percent) of the exponential SY vs. slope relationship. The scatter of the data about the regression lines gives a sense of the relative uncertainty that might be encountered with use of the regression equations for determination of a sediment load; however, this uncertainty is relatively small in comparison to that associated with the limited hydrologic function knowledge of soils type and actual cover conditions found in the subwatersheds. The SY equations developed by Grismer et al. (2007) were grouped by soil type and then land use, or soil conditions (e.g., disturbance regime, cover) and smoothed. For example, a set of infiltration rate and SY equations, each as a function of slope, were developed for both granitic and volcanic, sparsely covered ski run soils. Similar pairs of equations were developed for highly erodible unpaved roads and low-erodibility forest soils from the RS results across the Basin. Two additional sets of equations were interpolated from the RS equations to represent the EP3 and EP4 level land-use equivalents.

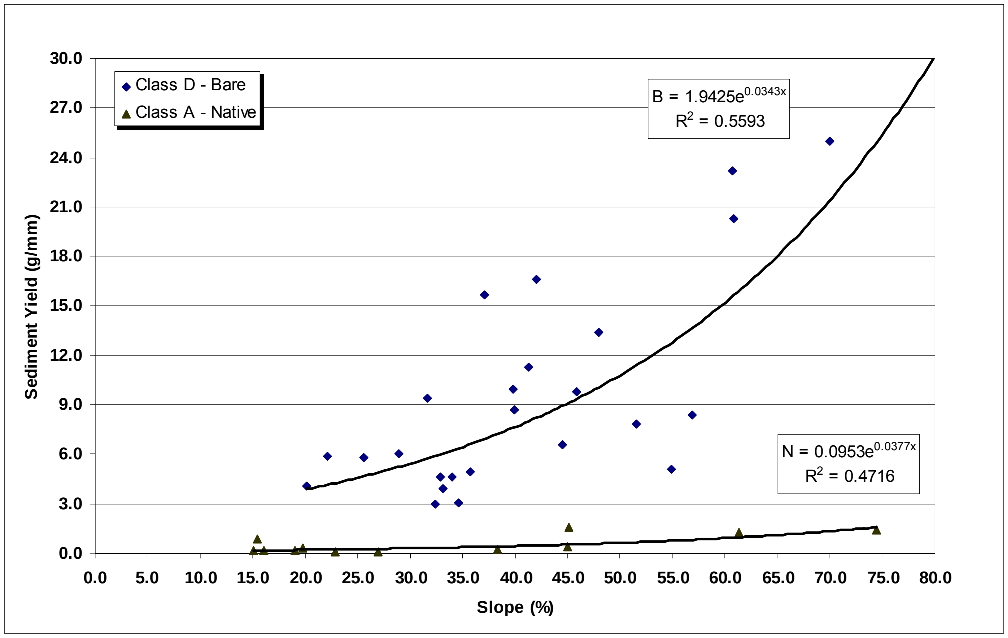


Figure 4-3. Example sediment yield (SY) versus slope regression equations for two treatment levels/functional classes on volcanic soils.

Particle-Size Data

Grismer and others also developed data sets relating SY to particle-size distribution parameters such as the less-than-30% particle-size (D_{30}) silt and clay fractions (%) of the sediment in the runoff. D_{30} is a widely used particle-size parameter in engineering analyses of soil hydraulic conductivity and stability. Figure 4-4 illustrates the dependence of the silt and clay particle sizes on SY for runoff from volcanic soils. The regressions for inverse particle-size as a function of SY are generally quite good and highly significant (> 99 percent). Note that they are independent of treatment; that is a function of soil type only.

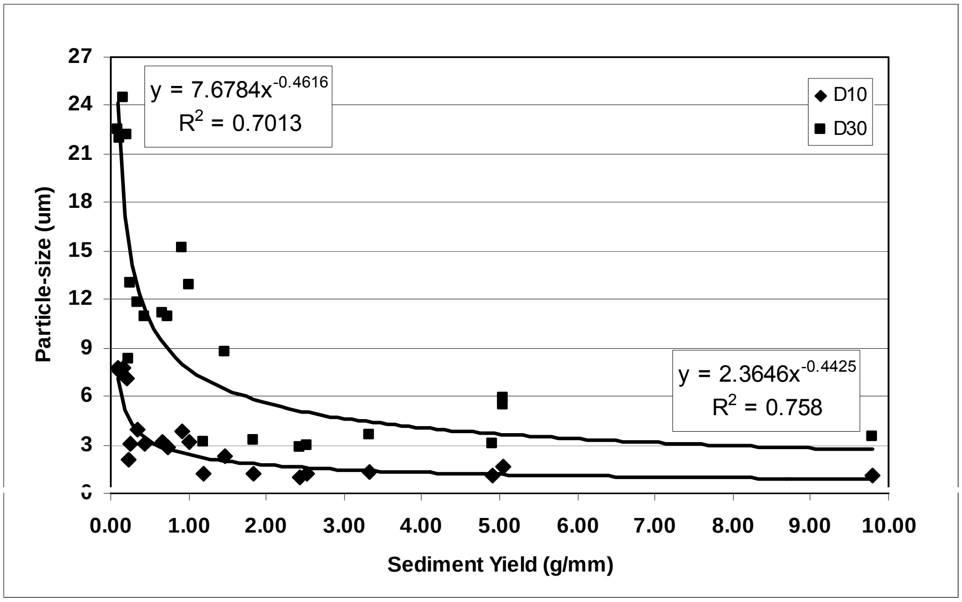


Figure 4-4. Dependence of silt and clay fractions on SY for runoff from volcanic soils.

The silt fraction (%) of the runoff sediment is directly correlated to the D_{30} particle size as shown in Figure 4-5. Again, the regressions for inverse silt or clay fraction as a function of D_{30} are generally quite good and highly significant (> 99 percent). However, note that here they are independent of both treatment and soil type and are function of particle-size distribution only. This observation simplifies estimation of silt and clay fractions from any of the soil types found in the Basin.

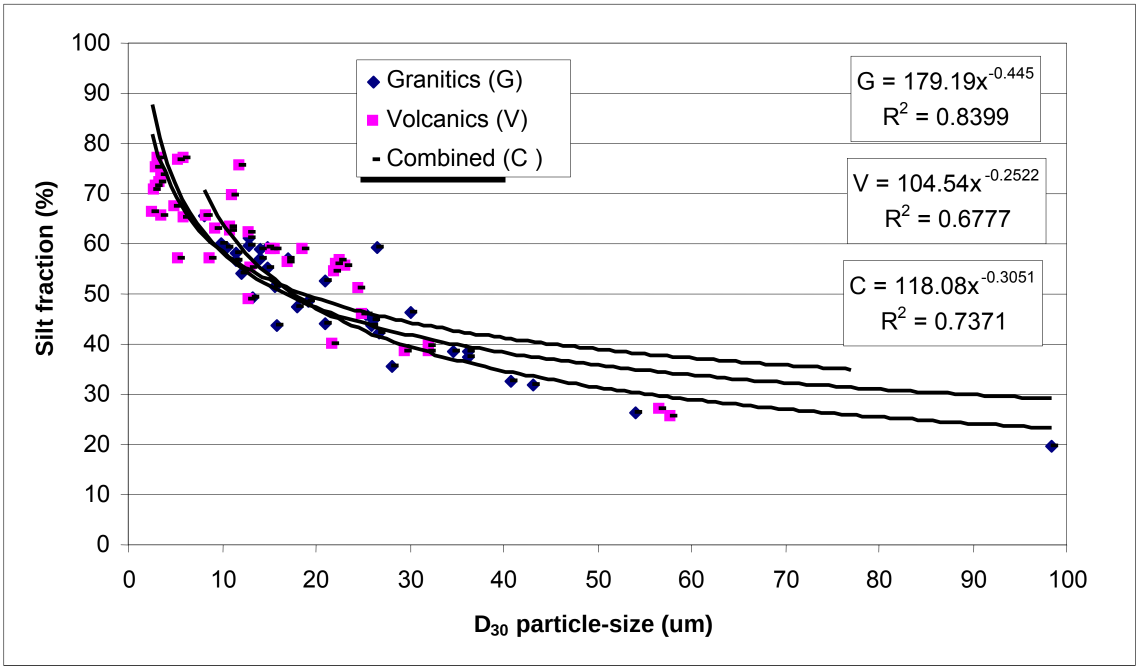


Figure 4-5. Dependence of silt fraction on D_{30} particle size for runoff from all soils.

Nutrient Loading Data

Nutrient loading estimates were determined from the product of surface runoff volume and nutrient concentrations for each land-use category within each subwatershed. Surface runoff volumes were taken from the LSPC model for the baseline level and then as calculated as a function of slope, soil type and treatment level/functional condition in each land-use category for the Treatment Tiers. Nutrient concentrations estimated in the LSPC model for each of the land-use categories within a subwatershed are highly variable between subwatersheds, reflecting the calibration of the LSPC model to LTIMP stream water quality data. Clearly, restoring soil function will result in lower nutrient mobility than that estimated here for each Treatment Tier; that is, nutrient load reductions estimated here are much smaller than those likely following soil rehabilitation as only the effects of reducing surface runoff (via greater infiltration capacity) on nutrient loading were considered in this analysis. Much more research is needed to relate runoff nutrient concentrations to soil conditions, land management practices, and type/level of disturbance (e.g., compaction, burns, loss of cover) or treatment.

Load Reduction Estimates

All FUSCG loading analyses were conducted at the subwatershed scale, because that is the scale employed in the LSPC model. Average slope, geology/soil type (volcanic, granitic, and mixed soils), area and annualized runoff data for each of the 20 land-use categories of each subwatershed identified in the LSPC model was used to determine baseline and Treatment Tier surface flows and loadings for each land-use category and were then summed to determine the total for each subwatershed. For land-use categories not subject to treatment by the FUSCG (e.g., residential, paved roads), flow and load data were taken directly from the LSPC model such that an overall subwatershed flow and load could be determined for later LSPC analyses. Figure 4.6 illustrates the calculation process in a flowchart and provides examples of the base data used to estimate sediment and nutrient loading values for each Setting-Treatment Tier combination.

To set *baseline* conditions in each subwatershed, the relative soil functional condition class of each land-use category was established on the basis of the land-use category descriptions and familiarity with the erosion conditions likely to be associated with each category. Table 4-5 describes the soil conditions that are associated with each soil functional condition class (A–F). Class A soils represent fully functional forest soils having very limited erodibility, if any. Class F soils are drastically disturbed, non-functional and highly erosive. Each soil functional condition class was assigned a corresponding regression equation (developed from extensive RS research in the Lake Tahoe Basin) used to predict runoff, sediment, and nutrient loading. Regression equations were only very slightly modified (with the exception of Class F, for which a new regression equation was created to capture loading estimates for unpaved roads) to better reflect LSPC baseline loading estimates for each land-use category.

Table 4-5. Descriptions for soil functional condition classes

Functional condition class	Description
A	Fully functional forest soils—limited erodibility, high-infiltration rates and sustainable, soil nutrient conditions.
B+	Approaching functional soil conditions as per class A; might not yet be sustainable or are limited by available soils and slope.
B	Functional surface soil protection and initiation toward hydrologic functionality; long-term condition uncertain.
C	Disturbed sites with surface treatment (e.g., hydroseeding or erosion-control fabric) that provide temporary cover but little functional erosion control.
D	No protective surface cover and limited infiltration capacity due in part to dispersed soil aggregates.
F	Compacted bare soil conditions; highly erodible.

The Class C regression equation was developed from RS on surface-treated, grass-covered hillslopes (primarily ski runs and road cuts) around the Basin and seemingly represents the minimum level of treatment following land disturbance. Practices such as hydroseeding with little or no follow-up treatment, nonnative grass reestablishment and temporary straw covers are typically associated with this level of functional condition. The Class B regression equation includes a number of tested, erosion-control treatments that involve some effort at rehabilitating the soil that establishes a functional surface cover of grasses, forbs, and mulch (such as pine needles or tub-ground wood chips). More intensive erosion-control/restoration treatments aimed at restoring soil function are described by the Class A regression equation. These treatments include such practices as incorporation of coarse, organic amendments into the soil profile, soil loosening, and restoration of functional surface cover including vegetation and mulch.

Table 4-6 summarizes the functional classes assigned to the baseline condition and Treatment Tiers associated with each Setting. Again, the determination of suitable functional condition classes for each Setting-Treatment Tier combination (as well as baseline) was based on professional judgment and familiarity with erosion conditions and treatment performance throughout the Tahoe Basin.

Table 4-6. FUSCG Setting-Treatment Tier matrix showing functional condition classes

Treatment Setting	Land-use category	Baseline condition	Treatment Tier 1	Treatment Tier 2	Treatment Tier 3
A	Roads_Unpaved	F	C	B	A
B	Veg_unimpacted EP5	D	C	B	B
	Ski_Runs-Pervious	C	C	B	A
	Veg_Recreational	C	C	B	A
C	Veg_Burned	C	C	B	A
	Veg_Harvest	C	C	B	A
	Veg_unimpacted EP4	C	C	B	B+
	Veg_unimpacted EP3	B	B	B	B+
	Veg_unimpacted EP2	B+	B+	A	A
	Veg_unimpacted EP1	A	A	A	A

The modeling analysis for each Setting-Treatment Tier combination was identical and involved the following steps (refer to Figure 4.6 for the flowchart version):

1. Baseline loading conditions were determined using annualized surface flows generated from the LSPC model and the appropriate infiltration rate and SY equations for each land-use category (and soil type), as outlined in Table 4-6. These equations are used to estimate sediment loading as the product of SY, runoff depth, and land-use area. The silt-fraction equation is a function of sediment loading and soil type and is used to determine silt (fines) loading as a fraction of the overall sediment load. Finally, nutrient loading was determined from the LSPC-based nutrient concentrations per land-use category and the calculated surface runoff volumes, which were adjusted for increased infiltration (decreased runoff) associated with certain treatments.

2. The baseline sediment, silt (fines) and nutrient loads from each land-use category were summed for each subwatershed and compared to LSPC model predictions to determine the soils-geology scaling factor for each subwatershed. The scaling factor was optimized for each subwatershed to obtain identical overall subwatershed loading estimates between the FUSCG and LSPC modeling efforts.

3. The sediment, silt and clay (fines), and nutrient loads for each Setting-Treatment Tier combination were then calculated using the regression equations that correspond to the soil functional condition classes assigned to each Setting-Treatment Tier combination (Table 4-6).

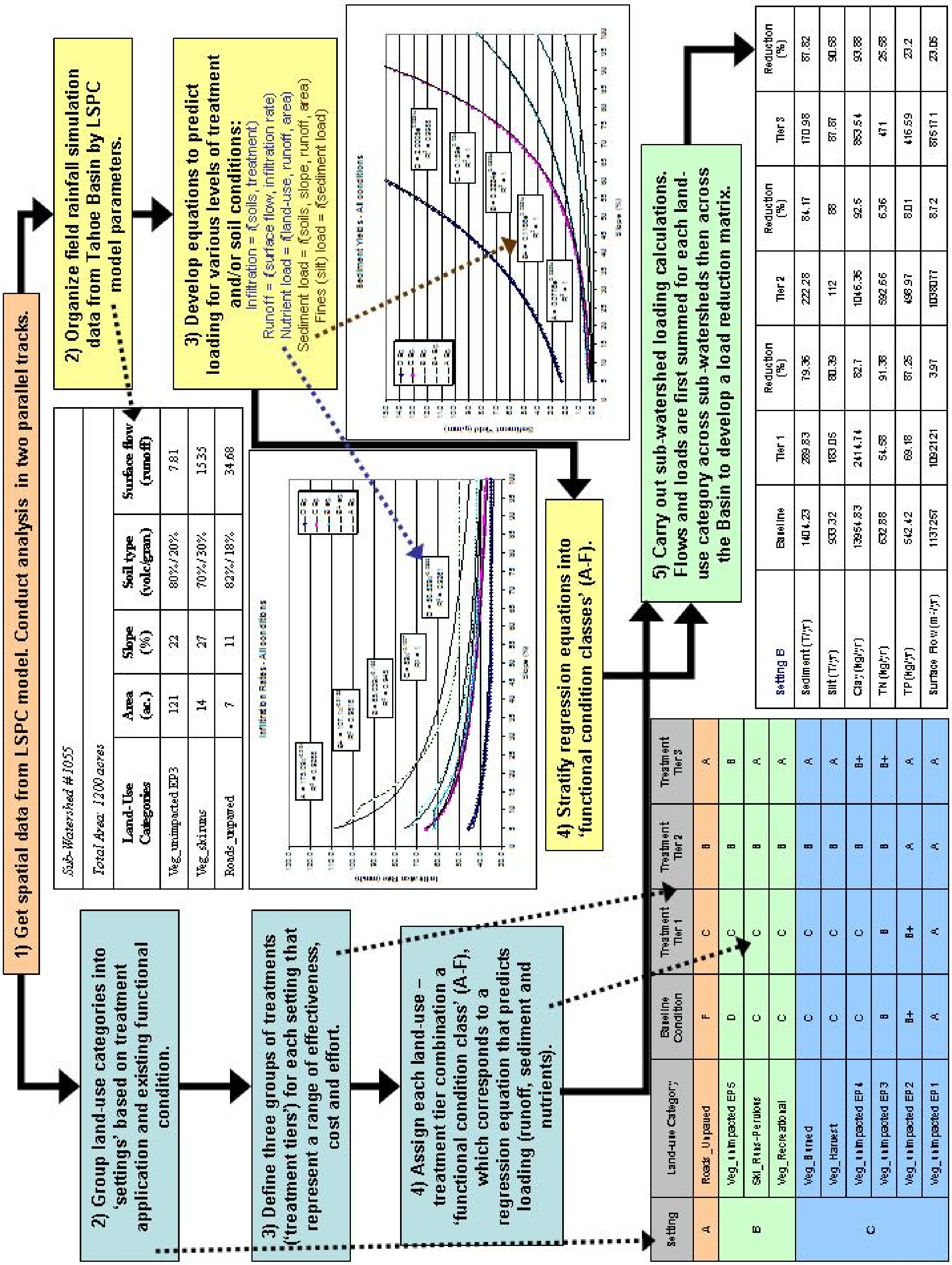


Figure 4-6. Flow chart illustrating FUSCG load reduction analysis process.

Cost Estimates

Cost estimates for a wide range of PCOs were obtained from field practitioners, the California Tahoe Conservancy (CTC), the USFS-LTBMU, forestry contractors, ski resort operations managers, and others. On the basis of the extremely wide range of cost estimates gathered from different sources, the FUSCG assumes that the true cost of a practice or treatment would be most appropriately reflected by a private contractor's cost. For this reason, agency cost estimates were cross-referenced with private contractor cost estimates and the FUSCG's own contracting experience to derive the most realistic cost estimates possible. The functional life expectancy of each treatment was derived from a combination of observed and measured performance in the field, local agency estimates, and the FUSCG's collective experience and best professional judgment.

The table of cost estimates (Table 4-14) includes capital cost per acre, Basin-wide capital cost, annualized O&M costs, and functional lifetime of treatments for each Setting-Treatment Tier combination. For treatments that are not expected to be self-sustaining, retreatment costs were annualized and added to annualized O&M costs. Cost estimates were calculated for each Treatment Tier within each Setting and then summed for the total area (acres) of each Setting across the Basin to derive Basin-wide cost estimates.

4.7. Results

This section includes load reduction estimates, cost estimates and a discussion of uncertainty for all forested upland Settings and Treatment Tiers. In addition to Basin-wide results, load-reduction estimates are also presented for the east and west sides of the Basin, because each side is generally associated with different soil types (granitic and volcanic/mixed, respectively), which are important to consider in assessing and prioritizing opportunities to reduce loading throughout the Tahoe Basin.

Load-Reduction Estimates

Table 4-7 summarizes the total land area (acres) of each FUSCG Setting for the Basin as well as for the east and west sides of the Basin. Three main load-reduction tables are presented in this section. Table 4-8 summarizes load reduction estimates for the primarily granitic-based soils of the 122 subwatersheds of the Basin's east side, largely in Nevada (subwatersheds 1000–5079). Table 4-9 summarizes load reduction estimates for the 62 remaining volcanic and mixed soil type subwatersheds of the Basin's west side, primarily in California. Table 4-10 provides the overall load reductions for the Lake Tahoe Basin as a whole.

Table 4-7. Total land areas (acres) of forested upland Settings for the east side, west side and the entire Basin

	East side	West side	Basin	% of forested uplands
Setting A	143.7	167.1	310.8	0.2%
Setting B	746.6	1,131.3	1,877.9	1.1%
Setting C	92,387	70,252	162,639	98.7%
Total	**93,277**	**71,550**	**164,828**	

The most noteworthy observation when comparing the relative size of different FUSCG Settings is how little area Settings A and B (e.g., unpaved roads and ski runs) account for in comparison to Setting C (forested areas), which is roughly 100 times larger than the combined area of Settings A and B. None of the Settings are particularly concentrated on either side of the Basin. However, Settings A and B are more abundant on the west side of the Basin, while the east side has the majority of the undeveloped forested land.

The following three tables summarize sediment and nutrient loading for all Settings and Treatment Tiers for the east side, west side, and the entire Basin. All percent reduction estimates are relative to baseline conditions (which are exactly the same as baseline conditions from the calibrated LSPC model). All results are presented in metric tons (MT) and cubic meters (m^3) over time.

Table 4-8. Load reduction summary for subwatersheds 1000–5079, roughly approximating the east side of Lake Tahoe[4]

	Baseline	Tier 1	Reduction (%)	Tier 2	Reduction (%)	Tier 3	Reduction (%)
Setting A – 143.7 ac.							
Sediment (MT/yr)	28.20	24.97	88.54	27.43	97.27	27.83	98.7
Silt (MT/yr)	14.85	13.55	91.2	14.60	98.31	14.74	99.24
Clay (MT/yr)	0.24	0.23	94.31	0.24	99.23	0.24	99.69
TN (MT/yr)	0.087	0.026	29.54	0.026	30.2	0.047	54.4
TP (MT/yr)	0.038	0.012	29.85	0.012	31.11	0.021	53.78
Surface Flow (m3/yr)	26,224	7,794	29.72	7,933	30.25	14,396	54.9
Setting B – 746.6 ac.							
Sediment (MT/yr)	56.13	46.87	83.51	45.27	86.48	48.81	86.97
Silt (MT/yr)	34.01	27.72	81.51	29.38	86.4	30.62	90.04
Clay (MT/yr)	0.68	0.56	81.65	0.63	92.43	0.64	93.64
TN (MT/yr)	0.061	0.0031	0.05	0.0165	0.27	0.019	31.87
TP (MT/yr)	0.018	0.0009	0.05	0.0155	0.86	0.006	32.15
Surface Flow (m3/yr)	109,066	55	0.05	285	0.26	31,790	29.15
Setting C – 92,387 ac.							
Sediment (MT/yr)	1907.35	0	0	677.95	35.54	1434.47	75.21
Silt (MT/yr)	870.49	0	0	383.29	44.03	707.63	81.29
Clay (MT/yr)	10.73	0	0	5.97	55.61	9.47	88.25
TN (MT/yr)	2.622	0	0	0.007	0.29	0.495	18.9
TP (MT/yr)	0.489	0	0	0.002	0.58	0.087	17.87
Surface Flow (m3/yr)	12,140,727	0	0	30,292	0.25	2,354,209	19.39

[4] The largest watersheds of significance that cross state lines are the Trout and Upper Truckee River systems on the Lake's south shore (subwatersheds 5XXX). For this analysis, they have been included in the east side summary table (Table 4-8).

Table 4-9. Load reduction summary for subwatersheds 6000–9060, roughly approximating the west side of Lake Tahoe.

	Baseline	Tier 1	Reduction (%)	Tier 2	Reduction (%)	Tier 3	Reduction (%)
Setting A – 167.1 ac.							
Sediment (MT/yr)	325.36	288.13	88.56	317.22	97.5	321.21	98.73
Silt (MT/yr)	109.65	100.06	91.25	107.95	98.45	108.85	99.26
Clay (MT/yr)	1.91	1.81	94.42	1.90	99.3	1.91	99.71
TN (MT/yr)	0.383	0.101	26.36	0.115	29.91	0.175	45.71
TP (MT/yr)	0.576	0.146	25.31	0.175	30.39	0.24	41.78
Surface Flow (m^3/yr)	115,856	30743	26.54	34,880	30.11	53,175	45.9
Setting B – 1131.3 ac.							
Sediment (MT/yr)	1366.56	1082.63	79.22	1151.84	84.29	1200.56	87.85
Silt (MT/yr)	490.71	394.27	80.35	432.10	88.06	444.60	90.6
Clay (MT/yr)	7.25	6.00	82.75	6.70	92.51	6.80	93.9
TN (MT/yr)	0.572	0.025	4.38	0.04	7.01	0.143	24.91
TP (MT/yr)	0.525	0.023	4.38	0.044	8.25	0.12	22.9
Surface Flow (m^3/yr)	1,028,192	45082	4.38	98,897	9.62	230,297	22.4
Setting C – 70,252 ac.							
Sediment (MT/yr)	7671.93	0	0	2922.40	38.09	5891.08	76.79
Silt (MT/yr)	2970.07	0	0	1336.65	45	2433.79	81.94
Clay (MT/yr)	33.37	0	0	18.35	54.97	29.43	88.17
TN (MT/yr)	6.916	0	0	0.042	0.61	0.996	14.4
TP (MT/yr)	1.894	0	0	0.025	1.29	0.242	12.77
Surface Flow (m^3/yr)	31,064,382	0	0	172,285	0.55	4,615,443	14.86

Table 4-10. Basin-wide load reduction estimates.

	Baseline	Tier 1	Reduction (%)	Tier 2	Reduction (%)	Tier 3	Reduction (%)
Setting A – 310.8 ac.							
Sediment (MT/yr)	353.56	313.09	88.56	344.65	97.49	349.05	98.73
Silt (MT/yr)	124.51	113.60	91.25	122.55	98.44	123.59	99.26
Clay (MT/yr)	2.15	2.03	94.42	2.14	99.3	2.15	99.71
TN (MT/yr)	0.47	0.127	26.95	0.141	29.97	0.222	47.32
TP (MT/yr)	0.614	0.157	25.59	0.187	30.43	0.261	42.52
Surface Flow (m^3/yr)	142,079	38,535	27.12	42,812	30.13	67,570	47.56
Setting B – 1877.9 ac.							
Sediment (MT/yr)	1422.69	1129.50	79.36	1197.11	84.17	1249.37	87.82
Silt (MT/yr)	524.72	421.99	80.39	461.49	88	475.23	90.58
Clay (MT/yr)	7.93	6.55	82.7	7.33	92.5	7.44	93.88
TN (MT/yr)	0.633	0.025	3.98	0.04	6.36	0.162	25.58
TP (MT/yr)	0.542	0.021	3.96	0.043	8.01	0.125	23.2
Surface Flow (m^3/yr)	1,137,257	45,136	3.97	99,180	8.72	262,086	23.05
Setting C – 162,639 ac.							
Sediment (MT/yr)	9579.28	0	0	3600.35	37.58	7325.55	76.47
Silt (MT/yr)	3840.56	0	0	1719.94	44.81	3141.43	81.81
Clay (MT/yr)	44.10	0	0	24.31	55.11	38.89	88.18
TN (MT/yr)	9.538	0	0	0.049	0.52	1.492	15.64
TP (MT/yr)	2.383	0	0	0.027	1.14	0.329	13.82
Surface Flow (m^3/yr)	43205109	0	0	202,577	0.47	6,969,652	16.13

Sediment, Silt and Clay Loading

East versus West—Soil Type and Geography

In general, sediment, silt, and clay loading from the east shore, granitic subwatersheds is a small fraction of that from the remaining volcanic subwatersheds on the west and north shores of the Basin, despite covering 30 percent more area. For example, the combined sediment and silt loads from Settings A and B in 122 east shore subwatersheds of 84 (sediment) and 49 (silt) MT/year are less than 5.9 percent of that generated from the remaining 62 subwatersheds and less than 5.5 percent of the overall Basin loads. Soil treatments that result in improved infiltration rates can dramatically affect surface runoff rates, especially from very disturbed or highly erodible soils (e.g., unpaved roads, EP5) and is reflected in decreased surface flows of 20–50 percent at the full soil restoration level (Tier 3). It is expected that this translation of surface to subsurface flows will result in greater and more sustained stream base flows and some deeper groundwater recharge, but will have little effect on the overall subwatershed annual total discharge. However, higher base flows and decreased peak flows in the subwatershed stream channels should allow for more efficient stabilization of the channels as part of stream restoration efforts. This aspect is very important toward assessing the overall benefits of upland soils restoration that is not included in the costs or load reductions estimated as part of this analysis.

Settings A and B

Loading results for Settings A and B indicate that substantial sediment and fines load reductions of greater than 80 percent are possible at the Tier 1 treatment level with reductions exceeding 90 percent at Tier 3 treatment level. Predicted reductions in sediment and fines loading from unpaved roads are quite dramatic, approaching 99 percent in the upper Treatment Tiers. While these reductions are quite large, the land area that Settings A and B represent is relatively small relative to other land uses in the Basin. Tables Table 4-11 and Table 4-12 summarize baseline and load reduction estimates on a "MT/ac/yr" basis, which might be more helpful in assessing the Basin-wide loading impacts of various Setting-Treatment Tier combinations. Still, the reductions presented here might seem quite large, perhaps unrealistic. However, unpaved roads (Setting A) have extremely high baseline loading because of bare, compacted soils and poor infiltration capacity. These estimated reductions are the result of significantly increased runoff diversion, infiltration, and BMP maintenance frequency at Tier 2 and full obliteration and functional restoration of roads at Tier 3. For Setting B (ski runs), loading reductions in the upper-80-percent range are a result of increased soil cover, reduced soil density, and increased infiltration rates following functional restoration of drastically disturbed soils. The soil restoration treatments that have been investigated and on which the runoff and erosion equations employed here are based are not in common use in the Basin, and they represent the current state of knowledge related to functional restoration of disturbed soil and long-term erosion control. For example, traditional straw mulch, erosion-control fabric and hydroseeding-type covers result in limited, short-term erosion control but not at the levels associated with the soil-based restoration efforts described in the upper Treatment Tiers, which include elements such as tilling and incorporation of coarse organic materials, and essentially restore disturbed sites to the same level of functional condition as undisturbed sites.

It is important to underscore here that computation of these large reductions are based on the extensive RS studies conducted across the Basin during the past 4 years. In many cases in these studies, some soil restoration treatments result in little or no runoff such that there are SY values of zero. These zero runoff plots were not included in the development of the erosion equations used here, resulting in an equation bias toward those plots yielding runoff. In addition, results from the small plot scale employed in the RS studies are expected to dramatically overestimate actual runoff and erosion rates at the subwatershed scale as a result of variations in topography and soil conditions across the landscape. In the FUSCG modeling here, this was indeed the case, particularly for the east-side, granitic subwatersheds in which the SGF was approximately 0.1. On the other hand, this factor for the west-side, volcanic subwatersheds was roughly 1.0. In either case, the sediment and fines load reductions suggested here are indeed possible and have been demonstrated in field studies; their implementation and effects at the subwatershed scale remain to be seen. For a table of SGFs for each subwatershed, see Table A-2 in Appendix FUSCG-A.

Setting C

Loading results for undeveloped forested areas (Setting C) suggest that standard forest management practices associated with thinning and fuels reduction in the Tahoe Basin, coupled with existing BMP technology (Tier 1), will have no effect on existing sediment and nutrient loading rates at the subwatershed scale.[5] This is largely because most forest soils are in a state of reasonably high hydrologic function as compared to those of the other two Settings, which have far greater soil disturbance. Additionally, ground-based mechanized logging has been limited on USFS and state lands to relatively low gradient (slope) areas, which have deep soils with high-infiltration capacities. The USFS relies primarily on CTL harvesting systems and hand crews for thinning in the vast majority of the Tahoe Basin. Compared to conventional logging techniques, CTL systems have relatively low ground pressure, minimal landing footprints and operate over a slash mat, which further buffers the soil from disturbance.

[5] Note: Effects of fire on soil function and sediment/nutrient loading were not considered in this analysis primarily because of a lack of relevant supporting data and information.

Conventional logging (*skidding*) is limited to only the most accessible, low-angle, resilient areas, because the impacts on soil and vegetation resulting from this technique can be far greater than CTL systems (Powers et al. 1999; Hartsough et al. 1997; Lanford and Stokes 1995). Unfortunately, there is still very limited directly measured data available on the effects of different fuels reduction treatments on runoff, sediment and nutrient yield, particularly in the Tahoe Basin. While some equipment can compact soils and reduce infiltration capacities, modern, wide-track crawlers and rubber-tire equipment appear to have minimal effects on soil function. For example, well-supervised mastication treatments that employ excavator-type equipment could result in some soil improvements associated with addition of mulch layers to the soil surface, despite limited track compaction of some soil during the operation (Hatchett et al. 2006).

At greater erosion-control and soil-restoration efforts (Tier 2), forest soils on steeper mid-slopes, which tend to have shallower depths and greater runoff potential, can be improved such that runoff and erosion rates are reduced by roughly 50 percent relative to existing (baseline) levels. There is, however, an upper limit to reducing EP from steeply sloping, thin soils on which some logging or thinning can occur. This reality is reflected in
Table 4-6 in that the EP3 and EP4 land-use categories were improved only from functional class B to B+ (rather than to functional class A) between Tier 2 and Tier 3 treatment levels, as the steeper slopes and shallower soils associated with these areas make them more susceptible to erosion than lower-slope areas. Tier 3 level treatments represent a full restoration of soil function in areas disturbed by planned thinning and fuels reduction treatments as well as full restoration of legacy roads and trails, abandoned landings and other areas impacted by past logging practices, which are common in forested areas throughout the Tahoe Basin. Most legacy roads and trails are not mapped and are not easily visible from the air, yet they are very efficient at transporting runoff and sediment downslope. Obliteration of legacy roads and trails in the Tahoe Basin has the greatest potential to efficiently reduce loading from forested areas, especially if conducted at the same time as planned forest management treatments.

Nutrient Loading

Nutrient loading summarized in Table 4-8, Table 4-9 and Table 4-10 is based on the runoff nutrient concentrations employed in the LSPC model for each subwatershed and reductions are notably smaller than those associated with sediment. As described above in the Analysis Methodology section (Section 4.6), nutrient loading reductions occur only as a result of decreased runoff associated with soil restoration treatments. Further reductions are likely as a result of soil-vegetation cycling of nutrients, but this aspect has not been quantified and is not considered here. Nutrient concentrations in the LSPC model are dependent on individual land-use categories and subwatersheds and, not surprisingly, vary widely across the Basin. As a result, the percentage reduction in nutrient concentrations within a subwatershed is directly proportional to the reductions in surface runoff. However, when summed across the Basin, this direct proportionality is not precisely related to the summed reductions in surface flows, and these values tend to differ by less than one percent.

Loading Per Acre

From a practical perspective, estimates of loading per unit land area for each Setting might be valuable in prioritizing and efficiently allocating resources for possible treatment across the Basin. Table 4-11 summarizes the loading rates per acre for each Setting-Treatment Tier combination across the Basin. Loading rates are greatest from unpaved roads (Setting A), followed by ski runs (Setting B) then forested areas (Setting C). Although unpaved roads represent a tiny fraction of forested upland land uses in the Basin, annual per acre sediment/silt/clay loading rates from unpaved roads are roughly double that from ski trails and 20–40 times greater than loading rates from undeveloped forested areas. Figure 4-7 provides a visual representation of the great disparity in sediment loading rates across all Settings and Treatment Tiers.

Table 4-11. Basin-wide sediment, silt and clay loading per acre per year for each Setting-Treatment Tier combination

	Baseline	Tier 1	Tier 2	Tier 3
Setting A – 310.8 ac.				
Sediment (MT/ac/yr)	1.138	0.130	0.029	0.015
Silt (MT/ac/yr)	0.40061	0.03508	0.00629	0.00296
Clay (MT/ac/yr)	0.00693	0.00039	0.00005	0.00002
Setting B – 1877.9 ac.				
Sediment (MT/ac/yr)	0.758	0.156	0.120	0.092
Silt (MT/ac/yr)	0.27942	0.05470	0.03367	0.02635
Clay (MT/ac/yr)	0.00422	0.00073	0.00032	0.00026
Setting C – 162,639 ac.				
Sediment (MT/ac/yr)	0.059	0.059	0.059	0.014
Silt (MT/ac/yr)	0.02361	0.02361	0.02361	0.00430
Clay (MT/ac/yr)	0.00027	0.00027	0.00027	0.00003

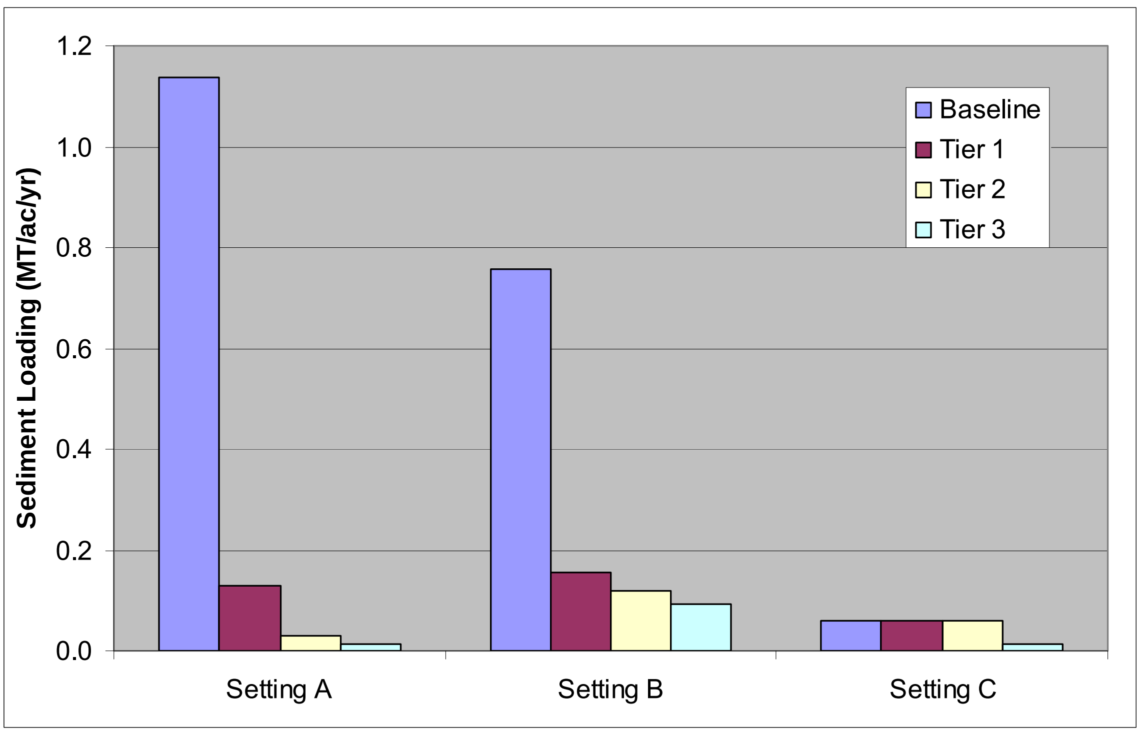


Figure 4-7. Sediment loading per acre per year for all Settings and Treatment Tiers.

In formulating management strategies directed at reducing loading to the Lake, treatment efforts that achieve the greatest reduction in loading per unit land area could be the most desirable with limited capital available. Table 4-12 summarizes sediment and fines loading reductions per acre associated with improving the functional condition of Settings A and B from baseline (existing conditions) to Tier 1 and Tier 3 treatment levels. Reductions in nutrient loading were not considered here because the relative confidence in the treatment effects on nutrient loading is quite low. Results indicate that tremendous sediment loading reductions per acre are possible in the west-side subwatersheds as compared to the east-side subwatersheds. It is also evident that the incremental improvement in loading reductions associated with full soil restoration (Tier 3) as compared to surface-cover type treatments and standard road BMPs (Tier 1) is relatively small for Settings A and B. However, the goals of full soil restoration include one-time recapitalization and long-term sustainability, whereas Tier 1 treatments have short functional lives and typically require ongoing, repeated treatments.

Table 4-12. Change in annual sediment loading reduction per acre for different Treatment Tiers for Settings A and B

Subwatershed grouping	East side (1000-5079)		West side (6000-9060)		Basin	
Loading parameters	Baseline to Tier 1	Baseline to Tier 3	Baseline to Tier 1	Baseline to Tier 3	Baseline to Tier 1	Baseline to Tier 3
Sediment (MT/ac/yr)	0.237	0.259	2.681	2.984	1.609	1.788
Silt (MT/ac/yr)	0.131	0.144	0.947	1.044	0.590	0.651
Clay (MT/ac/yr)	0.00233	0.00253	0.01612	0.01743	0.01003	0.01088

Table 4-13 summarizes sediment and fines loading reductions per acre associated with improving the functional condition of forested areas (Setting C) from baseline (existing conditions) to Tier 2 and Tier 3 treatment levels. Treatment Tier 1 was not considered here, because no changes in loading from baseline conditions are expected at that level of treatment. Load reduction opportunities for Setting C are generally greatest in the subwatersheds on the west side of the Basin. For example, at the Tier 2 treatment level there is a nearly 600 percent difference in sediment reductions per acre between east- and west-side forest soils; that is, sediment reductions of ~0.042 MT/ac/yr are likely from the west-side forests as compared to ~0.007 MT/ac/yr from the east side forests. Similar trends are shown with respect to silt and clay loading. In contrast to Settings A and B, the incremental improvement in loading rates is roughly double between Tier 2 and Tier 3 in forested areas. This is because at the Tier 3 treatment level, erosion *hot spots* such as old logging roads, trails, and abandoned landings are restored to full functional condition, whereas Tier 2 treatments are focused only on areas impacted by planned thinning and fuels reduction treatments. In any case, these reductions in loading per acre from forested areas are substantially smaller than those predicted from Settings A and B, as shown in Table 4-12.

Table 4-13. Change in annual sediment loading reduction per acre for different Treatment Tiers for Setting C

Subwatershed grouping	East side (1000-5079)		West side (6000-9060)		Basin	
Loading parameters	Baseline to Tier 2	Baseline to Tier 3	Baseline to Tier 2	Baseline to Tier 3	Baseline to Tier 2	Baseline to Tier 3
Sediment (MT/ac/yr)	0.00734	0.01553	0.04160	0.08386	0.02214	0.04504
Silt (MT/ac/yr)	0.00415	0.00766	0.01903	0.03464	0.01058	0.01932
Clay (MT/ac/yr)	0.00006	0.00010	0.00026	0.00042	0.00015	0.00024

Cost Estimates

Cost estimates for all Setting-Treatment Tier combinations are presented in Table 4-14. A 40-year cost comparison is presented in Figure 4-8.

Table 4-14. Cost and treatment lifetime estimates for all Setting-Treatment Tier combinations

		Treatment Tier 1				Treatment Tier 2				Treatment Tier 3			
Setting	Total area (acres)	Capital cost ($/ac)	Basin-wide capital cost ($)	Annualized O&M costs ($/ac)	Functional lifetime of treatment (years)	Capital cost ($/ac)	Basin-wide capital cost ($)	Annualized O&M costs ($/ac)	Functional lifetime of treatment (years)	Capital cost ($/ac)	Basin-wide capital cost ($)	Annualized O&M costs ($/ac)	Functional lifetime of treatment (years)
A	311	17,424	5,415,205	3,432	Infinite	26,136	8,122,807	4,356	Infinite	119,790	37,229,534	n/a	Infinite
B	1878	2,500	4,694,800	2,833	3	8,000	15,023,360	3,000	8	108,900	204,505,488	n/a	Infinite
C	162,639	1,000	162,639,000	n/a	Infinite	8,712	1,416,910,968	n/a	Infinite	17,968	2,922,297,552	n/a	Infinite
Total	**164,828**	**20,924**	**172,749,005**	**6,265**		**42,848**	**1,440,057,135**	**7,356**		**246,658**	**3,164,032,574**		

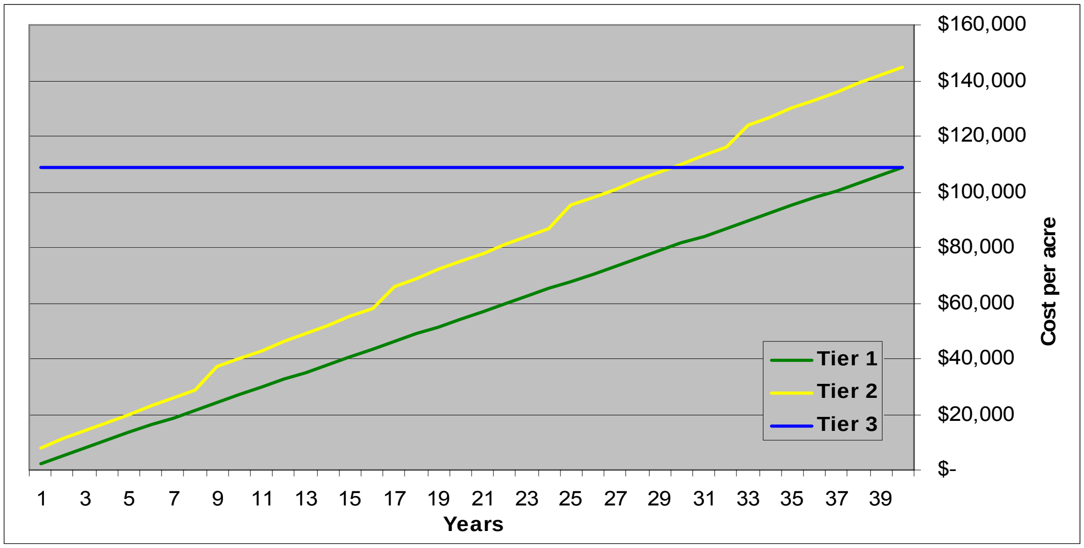


Figure 4-8. 40-year total cost per acre comparison of Treatment Tiers 1-3 for Setting B.

As shown in Table 4-14, Tier 1 cost estimates are the lowest with costs increasing at Tier 2 and the highest costs associated with Tier 3, both on a per-acre and Basin-wide basis for all Settings. Tier 3 capital costs are significantly higher than Tier 2 capital costs. However, there are no O&M or retreatment costs associated with Tier 3 treatments, which aim to restore those ecosystem functions (e.g., infiltration capacity, nutrient cycling) that lead to sustainable, long-term sediment source control, whereas Tier 1 treatments (as well as most Tier 2 treatments) have short functional lives and typically require ongoing maintenance and/or repeated treatments. The scale of each Setting is also important in considering costs. Although the estimated capital costs per acre for Setting C are substantially lower than those for Settings A and B, the Basin-wide capital cost is much higher because of the large land area that Setting C represents (nearly two orders of magnitude more land than Settings A and B combined).

The concept of one-time, permanent recapitalization treatments versus temporary surface treatments makes estimating costs more challenging. An example 40-year total cost projection for Treatment Tiers 1–3 for Setting B is shown in Figure 4-8. Capital cost, O&M costs and retreatment costs (same as capital costs) were summed annually over a 40-year period to derive a 40-year total cost per acre estimate. No discount rate was used to account for inflation in this example. This cost projection is simply presented to offer a longer-term perspective on assessing the *true* costs of achieving load reduction targets. In this example, while the Tier 3 capital cost is several orders of magnitude higher than the other Treatment Tiers, it is roughly equal to Tier 2's total cost (including re-treatment and O&M) after ~30 years and Tier 1's total cost after ~40 years. To maintain the desired performance of Tier 1 and 2 treatments, regular maintenance and retreatment will need to be conducted in perpetuity. Additionally, these cost estimates do not account for the high downstream costs (externalities) of capturing and treating runoff from forested areas.

Assumptions

As mentioned earlier in the report, estimates of costs and treatment lifetimes for a range of treatments and Settings are very difficult to generalize. The main assumptions that are built into these cost estimates are described below.

Setting A – Unpaved Roads

- Annual maintenance will be performed on waterbars, rock-lined ditches and road surface (Tiers 1 and 2).
- Treatments are based on highly disturbed soil conditions typical of unpaved roads. If soil is not highly disturbed, treatment costs would be lower.
- Functional life of Tier 1 and 2 treatments is *infinite*, as long as regular maintenance is performed.
- Functional life of Tier 3 treatments is *infinite*, as long as treatments are properly implemented and treated areas are not re-disturbed.

Setting B – Ski Runs

- Annual maintenance will be performed on waterbars and ski run surface (Tiers 1 and 2).
- Treatments are based on highly disturbed soil conditions typical of most ski runs. If alternative run clearing techniques are employed that minimize disturbance or displacement of the soil profile, treatment costs would be lower.
- Functional life of Tier 3 treatments is *infinite*, as long as treatments are properly implemented and treated areas are not re-disturbed.

Setting C – Undeveloped Forested Areas

- The cost of thinning and fuels management treatments are not included in the cost estimates for Setting C, because these treatments do not have an effect on loading at the scale of this analysis. Only the costs of BMPs and restoration of previously disturbed sites are included in these cost estimates.
- Assume tilling/ripping treatments will be done using mechanized equipment. If done by hand crews, costs will increase.
- Assume thinning treatments are done using CTL systems. BMPs for conventional *whole-tree* logging would be more expensive, as the extent and intensity of soil impacts are generally greater. BMPs for areas thinned by hand crews would be less expensive.
- For Tier 2, assume 10 percent of treatment area is disturbed by thinning/fuels reduction activities to a degree that requires full BMPs (tilling, mulching). While disturbance associated with CTL operations is generally greater than 10 percent of the treatment area, soil impacts in most disturbed areas are minimal (e.g., light compaction, soil profile still intact, mulch/debris left on surface) and do not warrant the *full BMP* package. Areas requiring full BMPs are primarily landings and temporary roads, which are estimated to account for ~10 percent of a treatment area. In other words, the costs per acre presented here account for treatment of 10 percent of every acre, not the entire acre.
- For Tier 3, assume an additional 5 percent of every acre treated has abandoned roads, trails, landings or other erosion *hot spots* that are obliterated/fully restored. As stated above, the costs per acre presented here account for treatment of 5 percent of every acre, not the entire acre.
- Functional life of all treatments is *infinite*, as long as treatments are properly implemented and treated areas are not re-disturbed.
- For Tiers 2 and 3, assume wood chips or other coarse organic materials needed for soil restoration treatments will be generated from fuel reduction efforts or otherwise available in close proximity to treatment areas.

General Assumptions for All Settings

- Slope angle—Treatments on steeper slopes generally require a higher level of effort than lower slope angles. Constructed features that are designed to capture and convey or infiltrate water (e.g., rolling dips, infiltration swales) are typically built at shorter intervals as slope angle increases.

  - The FUSCG assumed moderate slope angles (10-20 degrees) for these estimates. In general, steeper slopes require a higher level of effort, making treatments more expensive.

- Level of disturbance—There is a considerable difference in the level of effort and cost required to treat an area that has been drastically disturbed (graded, compacted, topsoil removed/buried – e.g., road cut) and an area that has simply been compacted. When the full soil profile (including topsoil) is intact, compaction can be removed by ripping or tilling and very few other inputs are required. Areas that have been drastically disturbed require a much higher level of treatment effort to restore infiltration capacity, nutrient cycling and other critical functions that provide long-term sediment source control. For example, a Tier 2 treatment might be able to achieve the same results as a Tier 3 treatment if topsoil is still present. For a discussion restoration techniques and disturbance associated with various forest management practices, see the Literature Review in Appendix FUSCG-C.
  - In estimating costs for Settings A and B, the FUSCG assumed that all ski runs and roads are in drastically disturbed condition.

- Road access—where road access is poor, mechanized treatment is often not a viable option. These areas are likely to be treated using hand crews. The farther a crew has to hike in to a job site and the distance they have to haul the fuels ranges quite a bit throughout the Basin. Likewise, for mechanical operations that have easy road access, costs will be far lower than operations that require road improvements or long travel distances.
  - In estimating treatment costs, the FUSCG assumed reasonable access to treatment areas for all Settings.

- The *true* cost of restoration—Once standard practices and desired outcomes (success criteria) are consistently defined, true costs of treatments can be calculated. Estimated costs for road obliteration varied by more than 500 percent in this analysis. Treatment cost estimates gathered from local agencies tended to be exceptionally low compared to private contractor cost estimates, because they either reflect practices that are not achieving the desired outcomes or certain costs are not included. The FUSCG found that overhead, fixed costs, and even costs for personnel that might already be on staff (for instance a fire fighting crew that is on standby and is being used for thinning and fuels treatments) are not always accounted for.
  - For cost estimates provided here, the FUSCG assumed that the true cost of a practice or treatment would be most appropriately reflected by a private contractor's cost. For this reason, agency cost estimates were cross-referenced with private contractor cost estimates and the FUSCG's own experience to derive the most realistic cost estimates possible.

Confidence in Results

Load Reduction Estimates

With general watershed analyses of flows, sediment, and nutrient loading, there is considerable uncertainty associated with the modeling process and the fundamental data sets used in the models as described in Section 4.6. This uncertainty is exacerbated by even greater uncertainty about the effects of various land management practices on soil function and, ultimately, stream loading. In the FUSCG analyses, the relative range of treatment effects is bounded by the available field research information that suggests a lower limit in loading associated with fully functional forest soils in the Basin, as well as something of an upper limit in loading associated with bare disturbed granitic or volcanic soils. Noting that the starting point of the FUSCG modeling effort was the same baseline loading values determined from calibration of the LSPC model, the relative confidence in loading estimates at the baseline level is relatively high, presuming such confidence in the LSPC model output exists. Sediment and fines loading estimates at the lower and upper treatment levels is reasonably high on the basis of the local research used to generate the load reduction estimates. Relative confidence in the nutrient loading estimates is comparatively poor for the different soil treatment levels as there is little supporting research information necessary to establish these values. Table 4-15 summarizes the relative confidence levels (scale of 1–5) in loading estimates for the FUSCG Settings and Treatment Tiers.

Table 4-15. Relative confidence in load reduction estimates of sediment, fines and nutrient loading (using Confidence Rating System)

	Baseline	Tier 1	Tier 2	Tier 3
Setting A (unpaved roads)				
Sediment (MT/yr)	4	3	2	3
Silt (MT/yr)	4	3	2	3
Clay (MT/yr)	3	3	2	3
TN (MT/yr)	3	2	2	2
TP (MT/yr)	3	2	2	2
Setting B (ski runs)				
Sediment (MT/yr)	4	3	2	3
Silt (MT/yr)	4	3	2	2
Clay (MT/yr)	3	3	2	2
TN (MT/yr)	3	2	2	2
TP (MT/yr)	3	2	2	2
Setting C (forested areas)				
Sediment (MT/yr)	3	3	2	3
Silt (MT/yr)	3	3	2	3
Clay (MT/yr)	3	3	2	3
TN (MT/yr)	2	2	2	2
TP (MT/yr)	2	2	2	2

Cost Estimates

Treatments costs are subject to such a wide array of site-specific conditions and factors that they will always be difficult (if not impossible) to estimate accurately on a Basin-wide scale. Until clear treatment standards are defined and interpreted consistently across the Basin, costs estimates will vary widely from agency to agency and public sector to private sector. Furthermore, most of the Tier 3 treatments proposed here have yet to be embraced and practiced by most agencies, ski resorts, or contractors because they require a shift in the entire approach to controlling erosion and, in this case, reducing sediment and nutrient loading to Lake Tahoe.

Conclusions

The modeling effort completed here as part of the Lake Tahoe TMDL assessment for the Tahoe Basin provided considerable insight into where the greatest EP could occur, the relative levels of sediment and nutrient load reduction possible and general corroboration of the LSPC modeling effort conducted at the subwatershed scale. This analysis was conducted using the annualized runoff and loading output from the

LSPC model for each land-use category of each subwatershed and therefore results in annualized loading estimates for each subwatershed and the Basin as a whole for the three Treatment Tiers. The primary conclusions reached by the FUSCG are summarized below:

- The greatest load reductions possible on a per acre basis are associated with disturbed soils of volcanic origin on the north and west sides of the Basin, such as unpaved roads, recreational and ski run areas (Settings A and B).
- While undeveloped forested areas (Setting C) represent the largest source of loading as a result of having the greatest area, potential reductions in loading per acre from forested areas are an order of magnitude smaller than those predicted from Settings A and B.
- Obliteration of *legacy areas*, such as old logging roads, trails, abandoned landings and other erosion *hot spots*, has the greatest potential to efficiently reduce loading from forested areas, especially if conducted in combination with planned thinning and fuels reduction treatments.
- Further modeling analyses are required at a finer resolution with greater hydrologic routing detail to determine possible load reductions at scales that are realistic for treatment implementation. Refined spatial scale modeling efforts will require additional quantitative data that does not exist about the impacts of various land management practices on erosion. However, this analysis provides a rough first-cut assessment of what levels of load reduction might be possible and at what cost across the Basin.
- Cost estimates generated here are largely best professional judgment as there is limited cost information at the scale of application being considered for the Basin as well as the longer-term effectiveness of some treatments or management practices in terms of their effects on Basin soils and loading processes. On the other hand, large-scale application of some restoration efforts could result in development of scale-appropriate technologies that reduce the treatment costs per unit area from those estimated here.
- The effects of fire on runoff, sediment and nutrient yield in the Basin is a topic that requires additional research and focused analyses beyond those considered here, though the analysis framework developed here could be applied to future fire analysis.

Recommendations

The analyses presented in this report should be considered a *first-cut* approximation of the level of effort that will be required to reduce loading across the Tahoe Basin. The following recommendations are suggested:

- There remains the need for considerable research in the Tahoe Basin[6] relative to the following:
    1. Quantification of the effects of various land-use practices on Basin soils, especially as it relates to erosion, runoff and soil *health*
    2. Upscaling and expanding existing RS generated data
    3. Analyses of nutrient transport from disturbed and treated soils
    4. More refined modeling of subwatershed hydrologic processes within particular subwatersheds
- Targeted assessment of the plot and watershed-scale impacts of various forest management practices on runoff and erosion processes in the Tahoe Basin. Undeveloped forested areas compose approximately 80 percent of the Basin and, while there is a great deal of research underway focusing on the water quality impacts of forest management practices, there is still very little useful data to help predict sediment and nutrient loading from these areas. As new data becomes available, it can (and should) be included in more refined modeling efforts.

[6] The recent Comprehensive Science Plan for the Tahoe Basin (Tahoe Science Consortium 2007) contains many of the suggested research areas outlined above.

- This analysis does not consider wildfire or controlled-burn effects on subwatershed, hydrologic dynamics and subsequent stream loading. Continued investigation into the water quality impacts of prescribed fire in a range of Tahoe Basin conditions should be considered a top priority.
- Refine modeling scale to something on the order of a one-hectare scale when additional measured data become available (perhaps using WEPP hillslope profile case in part) should greatly improve local estimates of loading and how specific land management practices affect loading. In many cases, preliminary modeling (WEPP or equivalent hillslope) at the local scale could be valuable toward identifying specific research needs with respect to model parameterization. Additionally, a more refined modeling scale would allow for highly useful spatial data from Basin agencies (such as USFS-LTBMU road water quality risk levels, road access for fuels reduction, 5-year management plans) to be incorporated into future load reduction modeling efforts. In particular, incorporation of the USFS water quality risk levels for unpaved roads (which are a composite of connected length, gradient, proximity to waterways, and so on.) would allow for greater accuracy in modeling loading and load reductions from unpaved roads.
- Disaggregate trails and unpaved roads using road and trail inventory data from the USFS-LTBMU. This would allow for a separate evaluation of the impacts and load reduction opportunities associated with trail-based recreation, which occurs throughout many upper watersheds in the Tahoe Basin. Additionally, it would allow for refined evaluation of the road improvements made by the USFS-LTBMU in the past several years as part of their Access and Travel Management Plan.
- More accurate cost accounting for treatments should be conducted to assess the long-term costs and cost-effectiveness of various Treatment Tiers. This cost analysis should include more thorough, long-term cost projections and cost per unit reduction calculations for pollutants of concern.
- There is a general need to define terms and establish clear, quantitative success criteria for different treatments and PCOs within the Basin. One important reason that costs were so difficult to generalize is that some treatments are poorly defined or defined very differently from agency to agency, contractor to contractor. A good example of this is the term obliteration, typically used to describe the process of decommissioning and restoring a road. In most cases, roads are simply ripped, seeded and mulched then written off as removed coverage. While this sort of treatment could increase infiltration rates and reduce runoff in the short-run, it does not help rebuild the soil structure or increase nutrient levels and, therefore, is not sustainable. Many of these obliterated roads are barely recognizable, have well-established trees and shrubs and were signed off as removed coverage by Basin agencies, yet the soil is still just as compacted as roads that are still in use. Several FUSCG members have first-hand field experience measuring high soil density and runoff rates on such roads, which are presumed to be *restored*.

Next Steps

Originally, the FUSCG modeling effort and research was directed at providing the information necessary for LSPC modeling of Basin-wide load reductions to be improved. Here, annualized runoff and loading data from the LSPC model was employed to generate Basin-wide load reduction estimates directly such that further LSPC modeling might not be required unless information about possible temporal variations in annual loading are desired. The load reduction tables presented in this document provide planners with *first-cut* estimates from which further policy development or research can be directed. However, as noted in the recommendations above, several additional steps should be considered to improve the load-reduction estimates here.

1. Refine the LSPC modeling grid for each subwatershed to the smallest scale feasible, perhaps the one-hectare scale described above.

2. Disaggregate the Veg_unimpacted land-use categories EP1–EP5; information about soil, slope, and type of vegetated cover per hectare grid cell is adequate. Incorporate the CSTAR vegetated cover survey of the Basin—consider using other spectral layers that might be available from CSTAR or Dr. Susan Ustin's group at UC-Davis.

3. Run the LSPC model for each subwatershed on the finer grid scale suggested here, without the EP1–EP5 land-use categories, using SY and particle-size equations similar to those employed here to determine runoff, sediment, and fines loading rates under actual climate conditions as originally used to develop the annualized data employed here. These new modeling results should be validated against the LTIMP data as done previously in developing the LSPC model for the Basin.

4. Verify land-use category loading rates and nutrient concentrations employed in the LSPC model within each subwatershed and across the Basin and attempt to clarify the differences.

5. Refine the hillslope modeling within each subwatershed to include possible runoff/sediment routing across the actual landscape as proposed originally by the FUSCG. This could be accomplished through repeated application of the WEPP hillslope profile and summed across the subwatershed. Erodibility and cover-related factors included in WEPP would be replaced by SY and particle-size equations similar to those employed here.

6. Review cost estimates and develop appropriate economic analyses of the present value of future costs associated with continued maintenance and/or re-treatment as compared to the initial capital costs of self-sustaining soil restoration approaches. Determine acceptable return periods (e.g., 20–40 years), discount rates (e.g., 3–8 percent) and other factors pertinent to such economic analyses.

4.8. References

Burcar, S.W., W.W Miller, S.W. Tyler and R.R. Blank. 1997. Moist- and dry-season nitrogen transport in Sierra Nevada soils under forested and meadow conditions. *Soil Sci. Soc. Amer. Proc.* 61:1774–1780.

Caldwell, T.G., D.W. Johnson, W.W. Miller, and R.G. Qualls. 2002. Forest floor carbon and nitrogen losses due to prescription fire. *SSSA Journal* 66:262-267.

Carroll, E. M., W.W. Miller, D.W., Johnson, L.S. Saito, R.G. Qualls, and R.F., Walker. 2007. Spatial Analysis of a High Magnitude Erosion Event Following a Sierran Wildfire. *J. Environ. Qual.* 36:1105–1111.

Cummings, J. 2003. Using process-oriented parameters to assess degradation. *Ecological Management and Restoration*. 4:S79–S82.

Grismer, M.E. In-press a. Erosion Modeling for Land Management – Scaling from plots to small forest catchments in the Tahoe Basin. *J. Environ. Management*. Submitted.

Grismer, M.E. 2008 Submitted a. Erosion Modeling for Land Management – Scaling from plots to small forest catchments in the Tahoe Basin. *J. Environ. Management*.

Grismer, M.E. 2007. Soil Restoration and Erosion Control: Quantitative Assessment in Rangeland and Forested Areas. ASABE Transactions 50(5): in-press b.

Grismer, M.E., and A.L. Ellis. 2006. Sediment Particle-size Distributions in Runoff from Disturbed Soils in the Lake Tahoe Basin. *California Ag*. 60(2):72–76.

Grismer, M.E., A.L. Ellis, and A. Fristensky. 2007. Runoff Sediment Particle-sizes associated with Soil Erosion in the Lake Tahoe Basin. *Land Degradation & Dev*. In-press a.

Grismer, M.E., and M.P. Hogan. 2004. Evaluation of Revegetation/Mulch Erosion Control Using Simulated Rainfall in the Lake Tahoe Basin: 1. Method Assessment. *Land Degradation & Dev*. 13:573–588.

Grismer, M.E., and M.P. Hogan. 2005a. Evaluation of Revegetation/Mulch Erosion Control Using Simulated Rainfall in the Lake Tahoe Basin: 2. Bare Soil Assessment. *Land Degradation & Dev.* 16:397–404.

Grismer, M.E., and M.P. Hogan. 2005b. Evaluation of Revegetation/Mulch Erosion Control Using Simulated Rainfall in the Lake Tahoe Basin: 3. Treatment Assessment. *Land Degradation & Dev.* 16:489–501.

Grismer, M.E., C. Schnurrenberger, R. Arst, and M.P. Hogan. In press c. Integrated Monitoring and Assessment of Soil Restoration Treatments in the Lake Tahoe Basin. *Environ. Monitoring & Assessment*.

Guerrent D.G., W.W. Miller, C.N. Mahannah, and R. Narayanan. 1991. Site-specific erosivity evaluation of a Sierra Nevada forested watershed soil. *J. Envir. Qual.* 20(2):396–402.

Hartsough, B.R., E.S. Drews, J.F. McNeel, T.A. Durston, and B J. Stokes. 1997. Comparison of mechanized systems for thinning ponderosa pine and mixed conifer stands. *Forest Products Journal*. 47(11/12):59–68.

Hatchett, B., M.P. Hogan, and M.E. Grismer. 2006. Mechanized Mastication Effects on Soil Compaction and Runoff from Forests in the W. Lake Tahoe Basin. *California Ag.* 60(2):77–82.

Hogan, M.P. 2005. *The Sediment Source Control Handbook*. (Draft) Prepared for the Sierra Business Council and the California Alpine Resorts Environmental Cooperative (CAREC).

Johnson, D.W., J.D. Murphy, R.B. Susfalk, T.G. Caldwell, W.W. Miller, R.F. Walker, and R.F. Powers. 2005. The effects of wildfire, salvage logging, and post-fire N fixation on the nutrient budgets of a Sierran forest. *Forest Ecology and Management* 220:155–165.

Johnson, D.W., R. Susfalk, R. Dahlgren, T. Caldwell, and W.W. Miller. 2001. Nutrient fluxes in a snow-dominated, semi-arid forest: Spatial and temporal patterns. *Biogeochemistry*. 55:219–245.

Johnson, D.W., R.B. Susfalk, T.G. Caldwell, J.R. Murphy, W.W. Miller, and R.F. Walker. 2004. Fire effects on carbon and nitrogen budgets in forests. *J. Water, Air, and Soil Pollution* 4:263–275.

Lanford, B.L., and B. J. Stokes. 1995. Compaction of two thinning systems: Part 1. Stand and Site Impacts. *Forest Products Journal* 45(55):74–79.

Loupe, T.M., W.W. Miller, D.W. Johnson, E.M. Carroll, D. Hanseder, D.S. Glass, and R.F. Walker. 2007. Inorganic N and P in Sierran Forest O Horizon Leachate. *J. Environ. Qual*. 36:498–50.

Marcus, J.A., W.W. Miller, and R.R. Blank. 1998. Inorganic and suspended/dissolved-organic nitrogen in Sierra Nevada soil core leachates. *J. Environ. Qual.* 27(4):755–760.

Miller, W.W., D.W. Johnson, C. Denton, P.S.J. Verburg, G.L. Dana, and R.F. Walker. 2005a. Inconspicuous nutrient laden surface runoff from mature forest Sierran watersheds. *J. Water, Air, and Soil Pollution* 163:3–17.

Miller, W.W., D.W. Johnson, T.M. Loupe, J.S. Sedinger, E.M. Carroll, J.D. Murphy, R.F. Walker, and D. Glass. 2006. Nutrients flow from runoff at burned forest site in Lake Tahoe Basin. California Agriculture 60:65-71.

Merritt, W.S., R.A. Letcher and A.J. Jakeman. 2003. A review of erosion and sediment transport models. *Environmental Modelling & Software* 18:761–799.

Murphy, J.D., D.W. Johnson, W.W. Miller, R.F. Walker, and R.R. Blank. 2006. Prescribed fire effects on forest floor and soil nutrients in a Sierra Nevada ecosystem. Soil Science. 171:181-199.

Murphy, J.D., D.W. Johnson, W.W. Miller, R.F. Walker, E.F. Carroll, and R.R. Blank. 2006. Wildfire effects on soil nutrients and leaching in a Tahoe Basin watershed. J. Environ. Qual. 35:479-489.

Naslas, G.D., W.W. Miller, G.F. Gifford and G.C.J. Fernandez. 1994a. Effects of soil type, plot condition and slope on runoff and surface erosion of two Tahoe Basin soil types. *Water Resour. Bull.* 30(2):319–329.

Naslas, G.D., W.W. Miller, R.R. Blank and G.F. Gifford. 1994b. Water quality of surface runoff from two Tahoe basin soil types. *Water Resour. Bull.* 30(3):409–417.

Rhea, S.A., W.W. Miller, R.R. Blank, and D.E. Palmquist. 1996. Presence and behavior of colloidal N and P in a Sierra Nevada watershed soil. *J. Envir. Qual.* 25(6):1449–1451.

Simon, A., E.J. Langendoen, R.L. Bingner, R. Wells, A. Heins, N. Jokay, and I. Jaramillo. 2004. *GIS Analysis of Erosion Potential from Upland Areas in Lake Tahoe Basin Framework Implementation Study: Sediment Loadings and Channel Erosion*. Research Report. No. 39. U.S. Department of Agriculture–Agricultural Research Service, National Sedimentation Laboratory, Washington, DC.

Schaller, F.W., and P. Sutton (eds). 1978. *Reclamation of Drastically Disturbed Lands*. American Society of Agronomy. Madison, WI.

Tahoe Science Consortium. 2007. *Comprehensive Science Plan for the Lake Tahoe Basin: Conceptual Framework and Research Strategies*. Prepared for U.S. Environmental Protection Agency by Tahoe Science Consortium, Washington, DC.

Tetra Tech. 2005. *Hydrologic Modeling and Sediment and Nutrient Loading Estimation for the Lake Tahoe Total Maximum Daily Load Project*.Prepared for the Lahontan Regional Water Quality Control Board, Fairfax, VA, by Tetra Tech, Inc.

USDA-NRCS (U.S. Department of Agriculture–Natural Resource Conservation Service). 2006. *Soil Survey of Tahoe Basin Area, CA and NV*. U.S. Department of Agriculture–Natural Resource Conservation Service, Washington, DC.

5. Stream Channel Sources

5.1. Source Discussion

Streams convey pollutants that originate from their bed and banks as well as from sources other than the stream channel, such as connected upland areas. Stream and floodplain deposits form sinks that extend retention time or provide long-term storage of pollutants from several sources. The role of stream channel conditions on pollutant sources other than the channel itself is beyond the scope of this SCG's analysis. However, interaction of stream channel conditions with other pollutant sources and their Pollutant Control Options (PCOs) is a topic that requires integration within the overall Lake Tahoe Total Maximum Daily Load (Lake Tahoe TMDL).

Prior studies have established that stream channel erosion has a much larger effect on total and fine sediment loads than on the nutrient loads (Lahontan and NDEP 2007; Simon et al. 2003; Simon 2006). Previous work has also provided a great detail of information about the location and magnitude of stream channel erosion, using consistent methods Basin-wide (Simon et al. 2003; Simon 2006). These factors and data resources influence the approach to analysis, and affect the cost/benefits of stream channel PCOs relative to nutrient constituents.

Fine Sediment

The primary focus of the Stream Channel SCG analysis is fine sediment (considered < 0.063mm *silts and clays*) generated by streambank erosion. Phase One Lake Tahoe TMDL studies have calculated that fine sediment from streambank erosion represents about 27 percent of the total fine sediment loading to Lake Tahoe (Lahontan and NDEP 2007).

Lake Tahoe TMDL Phase One investigations included a significant effort to quantify sediment loads from all 63 Tahoe watersheds by personnel from the U.S. Department of Agriculture (USDA) Agricultural Research Service–National Sedimentation Lab (ARS–NSL). Reconnaissance level geomorphic evaluation of more than 300 sites and detailed geomorphic and numerical modeling investigations of representative watersheds was performed to quantify watershed and stream channel contributions of sediment to Lake Tahoe (Simon et al. 2003). These estimates of fine-sediment contributions from streambank erosion used measured changes in channel geometry along five streams and numerical simulations with the conservational channel evolution and pollutant transport system (CONCEPTS) model on three key streams (Langendoen 2000; Landendoen et al. 2001).

Additional data from several earlier studies of flow, suspended sediment, and channel characteristics of Lake Tahoe tributaries (Hill et al. 1988; Jorgensen et al. 1989; Hill et al. 1990; Nolan and Hill 1991; Rowe et al. 1998; and Rabidoux 2005), allowed Simon (2006) to quantify fine sediment loadings for each of the 63 contributing Tahoe Basin watersheds, including the following:

- Total average, annual fine sediment load (< 0.063mm) in metric tons per year (MT/y);
- Streambank contributions to average, annual fine sediment load (< 0.063mm) (MT/y) and,
- Number of fine sediment particles (< 0.020mm) average, annual load in number of particles per year (n/y).

The Lahontan Water Board and NDEP (2007) calculations of total fine particle (< 0.02mm) flux inputs by watershed, and estimates of fine particle flux specifically from streambank erosion suggest that just 4 percent of the fine particle flux to the Lake originates from stream channel erosion. Therefore, this analysis focuses on streambank fine sediment (< 0.063mm) because the watersheds with high-streambank, fine-sediment sources also have some of the highest streambank, fine-particle (< 0.02mm) fluxes (Simon 2006; Lahontan and NDEP 2007), and there are few streambank or channel treatment options that are capable of targeting treat to the smallest sediment size fractions.

Fine sediment generated from streambanks in the top three source watersheds composes 96.0 percent of the Basin-wide total, and that from the top five source watersheds constitutes 97.9 percent of the Basin-wide total load to the Lake (Table 5-1). The recent loadings/flux estimates by watershed have, therefore, provided data supporting geographic priorities for the study of potential load reduction from stream channel erosion.

Table 5-1. Watersheds with largest streambank fine sediment (< 0.063mm) loads (MT/y) to Lake Tahoe

Watershed*	Streambank fine sediment load (MT/y)	Percent of streambank fine sediment load (%)
Upper Truckee River	2,259	60.0 %
Blackwood Creek	873	23.2%
Ward Creek	485	12.9%
General Creek	48	1.3%
Third Creek	23	0.6%
Total of all 63 watersheds	3,768	100.0%

Source: Lahontan and NDEP (2007)

Field surveys and sampling throughout all watersheds in the Lake Tahoe Basin conducted by the NSL in 2002, 2004, and 2006 provide detailed information about channel and bank geomorphic conditions for specific sites and continuous reaches along numerous tributaries (Simon et al. 2003 and Simon 2006). In addition to providing Basin-wide information that informs one about key source watersheds, the data collected along each stream are used in the SCG load-reduction analysis to prioritize treatment areas within each of the key watersheds.

The results of qualitative surveys and quantitative analysis of bed and bank samples on streams throughout the Basin have indicated that fine sediments are not found in measurable quantities on streambeds (Simon et al. 2003). Therefore, bed erosion is assumed to be an insignificant source under present stream channel conditions and is not specifically analyzed further in this load-reduction analysis.

Nutrients

The current Lake Tahoe pollutant loading budget attributes less than 1 percent of the annual total nitrogen (TN) and total phosphorus (TP) loading to the Lake, to stream channel erosion (Lahontan and NDEP 2007). Tahoe Basin stream bank sediments contain such a small amount of TN that no specific estimates of TN loads generated from in-channel bank erosion have been made (Ferguson 2005; Ferguson and Qualls 2005). Therefore, the stream channel erosion load-reduction analysis does not perform estimates related to TN.

Phosphorus is present in measurable concentrations within the volcanic and granitic geologic materials of the Tahoe Basin. Additionally, TP in the stream suspended sediment of Lake Tahoe tributaries is relatively high (average of 2.9 µg/mg sediment) compared to studies in other regions (Ferguson 2005), as is the percent of bioavailable phosphorus (BAP) (average 21 percent). While these relatively high TP and BAP values have been reported for the suspended sediment, phosphorus associated with stream channel erosion has been shown to be minor.

Water quality data from Tahoe streams demonstrate that in-stream relationships between total suspended sediment (TSS) and TP reflect more than just the channel margin sediment sources. On average, TP composes 0.311–0.530 percent of TSS load in water from four of the five largest stream sediment sources to Lake Tahoe—Upper Truckee River, Ward Creek, Blackwood Creek, and General Creek (Appendix SCSCG-A). These TP:TSS ratios are much larger than the ratio of 0.01–0.02 percent measured for Tahoe stream bank sediments (Ferguson 2005; Ferguson and Qualls 2005). The large difference between bank sediment and in-stream TP:TSS ratios and the large magnitude of upland TSS sources compared to stream channel TSS sources (16,900 MT versus 5,500 MT) suggest that other phosphorus sediment sources dominate the in-stream TP signal, primarily upland surface runoff and urban stormwater or enriched interflow or both. On the basis of these data, the stream channel load reduction approach and methods focuses on producing estimates of fine sediment loads associated with eroded bank sediment rather than on TP or BAP.

5.2. Analysis Overview

Approach

The assessment builds on the knowledge base of Lake Tahoe TMDL Phase One findings, other ongoing research and project-related studies, implementation experience, and monitoring results throughout all steps. Specifically, the stream channel erosion load reduction approach (1) compiles geographically relevant pollutant source data along with geographic data that could affect PCO selection, effectiveness, and cost; (2) conducts new bank stability modeling of PCO effectiveness using a Bank Stability and Toe Erosion Model (BSTEM) in specific Tahoe Basin stream sites; (3) integrates available empirical data on PCO effectiveness with new modeling results; (4) produces estimates of loads for each of three intensively studied streams from extrapolation of modeled site data; (5) extrapolates from the three intensively studied streams to produce estimates for the fourth and fifth largest source watersheds throughout the Basin; and (6) provides locally valid cost estimates for PCO implementation.

Stream Channel Sources of Fine Sediment

Because prior studies have identified a few streams as major contributors of fine sediment load from stream channel erosion, this effort focuses on three streams that together compose 96 percent of the load from this source. The three largest source streams, Blackwood Creek, Upper Truckee River, and Ward Creek were intensively studied during Phase One of the Lake Tahoe TMDL and have been assessed individually for potential ecosystem restoration projects. The individual watershed studies and design reports provide information on pollutant source locations, possible treatments, and costs that are considered in this analysis. The individual watershed studies provide site-specific information used to refine decisions about where treatment is needed and which PCOs might be appropriate.

For the three key watersheds, GIS overlays of the field and analytical data from Simon et al. (2003) and Simon (2006), recently updated Natural Resource Conservation Service (NRCS 2007) soils maps, Tahoe Regional Planning Agency (TRPA) land ownership, the watershed-specific inventories of problem sites/reaches, and proposed treatment alternatives are used to track characteristics of reaches or sites on each stream. These specific associated existing conditions are used to help guide various estimation, modeling, and extrapolation steps.

Settings

The Settings evaluated for the stream channel erosion load reduction analysis are those few large streams that have been identified as composing the overwhelming majority of the Basin-wide source: the Upper Truckee River; Blackwood Creek; and Ward Creek. Because these key streams compose such a large percentage of the identified source, quantitative load-reduction estimates for them will establish load-reduction estimates for the entire Basin directly. The watershed Settings vary in proportions of public and private land ownership, surrounding land uses, and some basic geologic, soils and topographic parameters. Within each of these watersheds, the severity of the source problem—rather than a random or stratified sampling—is the basis for selecting treatment areas. The treatment areas along each of the key streams are locations that were rated as *high* or *moderate* sources of streambank fine sediment by Phase One studies (Simon et al. 2003).

The spatial scale for results are the watershed Settings, but two smaller spatial scales (sites and reaches) are important in the source data set, in modeling representative locations, and for proposed treatment areas.

Pollutant Control Options

A wide range of possible PCOs was initially identified from literatures searches of international stream stabilization and restoration science and practice. These were refined to develop a realistic set of functionally unique, specific PCOs and to use terminology consistent with other efforts in the Tahoe Basin.

PCOs that are well defined and already part of standard stream engineering practice, have high-performance certainty, and are considered appropriate for use over a range of spatial scales were preferred for inclusion in Treatment Tiers. However, some PCOs are not applicable to address system-wide instability. These and other PCOs that have varied characteristics, low-performance certainty, or lack established design standards were not expected to be major components of Treatment Tiers. For the purposes of this evaluation, PCOs selected for quantitative analysis cover a wide range of techniques (e.g., hard engineering , biotechnical methods), represent contrasting approaches to stream and channel instability solutions (e.g., process restoration, channel reconstruction), and have quantitative effectiveness data sources. The selected PCOs were featured in varied proportions as part of each Treatment Tier for the quantitative load estimates.

PCO Effectiveness

The approach incorporates available quantitative estimates of PCO effectiveness for sediment load reductions from scientific literature sources, emphasizing regionally collected or regionally valid data. Because of the limited quantitative information available from existing literature sources, new quantitative modeling using the BSTEM developed by the USDA-ARS, National Sedimentation Laboratory (Simon et al. 1999, 2000) was performed to represent existing conditions and the selected PCO treatments.

PCO effectiveness is simulated for seven moderate to critical source areas on the three key streams. While limited in number, the locations are representative within each stream and reflect both moderate and high fine sediment sources. BSTEM locations include the range of typical and critical streambank configurations (e.g., height, angle) and materials (e.g., sediment layers, size distributions, and vegetation) that have been specifically observed, measured, and sampled throughout Tahoe Basin streams during USDA-ARS-NSL field investigations since 2002.

Time and resource constraints and the assumptions and limitations of BSTEM as a modeling tool restrict the ability to simulate all PCOs. However, a range of protection, reconstruction, and vegetation-modification PCOs are modeled. These data and interpolation of PCO effectiveness using literature sources of quantitative PCO effectiveness data and best professional judgment (BPJ) informed the final PCO effectiveness values used in calculations.

Load Reduction Calculations

The Stream Channel SCG load reduction analysis is conducted outside the Loading Simulation Program C++ (LSPC) watershed model because the geographic distribution of the sources and likely treatment locations are concentrated in just a few watersheds, and supplemental analytical modeling outside LSPC is needed to estimate PCO effectiveness.

The BSTEM modeling of fine sediment loading and PCO effectiveness required simulating hydrologic conditions known to produce bank erosion (for calibration) and that would test PCO effectiveness . Therefore, the simulated period (1995 and January 1997 storm) is an *above average* to *critical* condition, rather than an *average* year. BSTEM results are extended to entire stream lengths for the three key source streams using treatment area characteristics based on the prior Basin-wide and stream-specific inventories. By modifying the PCOs applied to the treatment areas on each stream, fine sediment loads associated with each Treatment Tier on each stream are estimated.

The stream-specific load reduction estimates for the top three stream sources of streambank fine sediment (Blackwood Creek, Upper Truckee River, and Ward Creek) are a nearly complete Basin-wide estimate, based on the high percentage of source they represent. However, the consistency of the PCO effectiveness modeling results and the availability of treatment areas characteristic data from prior inventories (Simon et al. 2003),allowed extrapolation to the next two largest source streams (General Creek and Third Creek). This Basin-wide extrapolation step provided an opportunity to examine the usefulness of predictive modeling of both PCO performance and cost-effectiveness to inform implementation priorities.

The estimates of fine sediment loads for each Treatment Tier on each stream are used to produce a rough estimate of the corresponding TP loads using average TP content of Tahoe Basin streambank sediments (~0.15 percent) (Ferguson 2005; Ferguson and Qualls 2005).

Cost

Cost estimates for stream channel erosion PCOs are compiled from existing recent construction costs for similar work in the Basin. The cost estimates are expressed in 2008 dollars and reflect construction, operations, and maintenance costs over a ~20 year lifespan. The cost estimates are calculated for standardized implementation lengths and include scaling adjustments for both channel and floodplain width for PCOs that require increased space to function. Costs estimated from recent completed projects were also compared to current planning-level cost estimates presented in watershed-specific studies as a cross-check.

Data Sources and Relevance

Data sources for the stream channel load reduction analysis include the following:

- Field and laboratory inventory data describing existing conditions of stream channels and identified sources of fine sediment from streambanks, performed Basin-wide using consistent methods (Simon et al. 2003; Simon 2006)

- Stream and ecosystem assessments, restoration alternatives, and design descriptions from various stream-specific studies of the three key watersheds
- Peer-reviewed literature and local practice knowledge of possible PCOs
- Peer-reviewed literature and local project monitoring data regarding PCO effectiveness
- Modeled estimates of existing and future loads
- Construction costs for recently implemented stream projects in the Tahoe Basin
- Planning cost estimates for proposed stream projects in the Tahoe Basin

5.3. Pollutant Control Options

There are diverse approaches to reducing stream channel erosion varied by the nature of the driving factors, state of the stream system, and site conditions in addition to complex ecological, engineering, logistic, and financial considerations. A general list of stream erosion PCOs covers the full range of possible treatments from site-specific streambank stabilization through comprehensive process-based ecosystem restoration (Appendix SCSCG-B). The potential PCOs are described with terminology and categories as consistently as possible with international river engineering and stream restoration practices, while reflecting stream and wetland restoration projects in the Lake Tahoe Basin and strategies identified by the Pathway Technical Working Groups (TWGs).

PCO Selection and Screening

Initial PCO Screening

All the identified PCOs (Appendix SCSCG-B) are potentially functional components of modern stream rehabilitation/restoration practice. They variously have multiple ecosystem benefits including water quality improvement. Some are suitable for both site or reach scale application (e.g., bank lowering or angle reduction, bank strengthening or protection), others are applied only at site scales (e.g., channel constriction removal, grade control), and some are typically implemented over multiple reaches (e.g., peak flow regulation).

A few of the general PCOs are not suitable for the key streams in Tahoe Basin (e.g., peak flow regulation). A few are experimental and there is limited data, design standards, or modeling results to inform performance estimates (e.g., anchored Large Woody Debris [LWD]). These PCOs were screened out from further use in the Treatment Tiers and load-reduction analysis (screening rationale is provided for each PCO in Appendix SCSCG-B). Passive PCOs (e.g., removal of incompatible land uses or fill within floodplains, restrictions on in-stream/streamside uses)—while beneficial as preventive measures or part of comprehensive river restoration projects—are not likely to be effective in reducing loads from degraded streambanks without combining them with active PCOs (e.g., channel reconstruction, bank protection, flow regulation). The load reduction estimates are focused on, and largely estimated from, the associated active PCOs.

On the basis of available data resources and analytical tools, screening of PCOs considered their suitability for the streams analyzed, viability, available performance data, and whether other similar PCOs could have performance data for analysis. The rationale for screening, available empirical performance data, and screening results of preferred PCOs are listed in SCSCG-Appendix B.

Data for PCO Analysis

Quantitative Data Resources

There is a general lack of quantitative information in scientific literature predicting performance of stream channel PCOs, either as individual elements or when combined in treatments. Even stream rehabilitation and restoration manuals that provide detailed design guidance lack quantitative information to predict effectiveness (FISRWG 1999; Watson, et al. 1999; River Restoration Centre 2002).

Design Standards

To the degree that they are available, design standards provide effectiveness for engineered PCOs, typically expressed in a *pass/fail* context—if specifications were met, the PCO would be assumed to function for its expected life. For example, guidelines for stone bank armor have been analyzed by research and practical application (Watson et al. 1999). There are similar levels of design/performance information available for other direct bank protection. However, most design guidance data for biotechnical and mixed material treatments are empirically based (Larson et al. 2001; D'Aoust and Millar 2002; Micheli and Kirchner 2002a; Micheli and Kirchner 2002b). There are no formal or widely tested criteria exist for indirect protection (e.g., dikes, retards, vanes), and there is limited guidance for use of flow regulation (Watson et al. 1999). Design standards are typically expressed in relation to maintaining the bank stability, assumed to serve water quality, but not documented in terms of percent of sediment load reduction.

Empirical Studies

Efforts towards long-term water quality and ecosystem monitoring have increased (Palmer et al. 2005), but there is still limited guidance for expected *effectivity* of stream stabilization PCOs from empirical data. The National River Restoration Science Synthesis (NRRSS) is an effort to analyze the extent, nature, scientific basis and success of stream/river restoration projects nationwide, with California as one of the seven regional nodes (Kondolf et al. in press). . However, little or no quantitative data exists from the appraisals to verify the effectiveness of specific PCOs or combinations of PCOs relative to water quality performance.

Effectiveness monitoring of stream projects in Tahoe, as elsewhere, has been conducted with reference to project-specific objectives (qualitative and/or quantitative) and at project-level spatial scales (EDAW 2006). Few projects have long or readily available monitoring records, or specific parameters related to fine sediment. Some projects have at least a few years' post-construction data, which were reviewed as part of the current study for guidance on PCO effectiveness. Project owners and sponsors that have ongoing baseline or post-project performance monitoring (e.g., California Department of Parks and Recreation (CSP), U.S. Geological Survey (USGS), U.S. Forest Service, and California Tahoe Conservancy (CTC)) are a source of data for the initial PCO effectiveness rating. For example, some local monitoring results used to screen PCOs and develop effectiveness ratings include the following:

- Post-restoration monitoring of the Trout Creek Stream Restoration and Wildlife Habitat Enhancement Project (since 2001) has included a range of parameters (River Run 2006; Swanson Hydrology and Geomorphology 2004a; Wigart 2003; and Herbst 2003). Several components of the monitoring results provide qualitative and quantitative guidance for estimating effectiveness of process-oriented full channel restoration and some site specific treatments (e.g., sod revetment bank protection). However, no water quality data or quantitative sediment data is available, precluding development of quantitative load reduction estimates from the monitoring data.
- Post-restoration monitoring associated with the 2003 reconstruction of lower Rosewood Creek provides some seasonally and event-varied data of changes in suspended sediment loads (Susfalk 2006). These data provide quantitative indications of effectiveness for similar channel reconstruction/rehabilitation and some site-specific treatments (e.g., stone bank toe protection, grade control). However, only the first two seasons' data are available, and they cover widely varied performance ranging from successful reductions to temporary load increases.
- Suspended sediment sampling in the Upper Truckee Marsh on a functional stream (Trout Creek) and an impacted, incised channel (Upper Truckee River) by Stubblefield et al. (2006) identifies

improved sediment retention on the portion of marsh with better floodplain connectivity. These data provide one of the few quantitative indications of PCO effectiveness for restoration/reconstruction and improved floodplain connectivity (valid at least in similar very low-gradient stream and marsh reaches).

Many of the stream restoration projects in Lake Tahoe have a wide range of project objectives. Without required uniform evaluation techniques (e.g., modeling simulations) or reliable treatment effectiveness monitoring data, pre-project alternatives evaluations have largely been subjective, relative/ranking, with some use of hydraulic modeling to generate semi-quantitative results (e.g., EDAW and ENTRIX 1999; TRCD 2003; Swanson Hydrology + Geomorphology 2004a; EDAW & ENTRIX 2005; Mainstream Restoration 2005; ENTRIX 2006). These analyses incorporate criteria that are proxy indicators of expected water quality improvements, such as the following:

- Improved floodplain connectivity and resultant increased overbanking frequency
- Increased channel length and inundation area from frequent overbanking (without high floodplain velocities or shear stress)
- Reduced bank erosion (reduced channel length of high, erodible, and eroding banks)
- Increased streamside riparian vegetation
- Control of channel incision (grade control)

These proxy data are useful as qualitative guidance but do not provide quantitative performance information that can inform the PCO effectiveness rating relative to fine sediment or nutrient loads. However, these data are used in analyzing results and developing recommendations.

PCO Effectiveness Data Options

An indication of how the load reduction potential of each preferred PCO can be quantified is listed in Table 5-2. For some PCOs, such as direct bank protection, standard engineering design performance guidelines suggest complete effectiveness (~100 percent) if they are designed, installed, and maintained. However, such engineering guidelines are not necessarily met in as-built conditions. Furthermore, the empirical data on performance is dominantly qualitative and ranges from evidence of complete success to complete failure.

Because of the limited amount of adequate empirical data, predictive, process-based numerical modeling of bank stability (BSTEM) is used to quantify performance of a few important PCOs for use in this analysis.

In addition, the likely effectiveness for a few other PCOs is estimated by interpolation using BSTEM results for similar PCOs and comparison to the available empirical performance ratings.

Table 5-2. PCO effectiveness data options for preferred PCOs

PCO	Standards	Empirical	BSTEM	Interpolation
Floodplain constriction/fill removal	N	Y	N	?
Channel constriction removal	Y	?	N	?
Bank Protection—stone	Y	?	Y	Y
Bank Protection—flexible geotech mattresses	Y	?	N	?
Bank Protection—LWD/rootwad revetment	Y	?	N	?
Bank Protection—stacked sod revetment	N	Y	N	Y
Bank Strengthening—wet meadow vegetation	N	Y	Y	Y
Bank Strengthening—woody riparian vegetation	N	Y	Y	Y
Grade Control Structure—nonporous material	Y	Y	N	Y
Grade Control Structure—porous rock material	Y	Y	N	?
Channel fill with bank toe stabilization	N	N	Y	Y
Bank lowering + floodplain excavation	N	Y	?	?
Bank lowering + angle reduction	N	Y	?	?
Channel reconstruction	N	Y	Y	Y
Channel restoration	N	Y	N	Y

? indicates a possible data source but would have less certainty than those labeled as Y.

There are several aspects of the data resources that affect the SCG's ability to quantify PCO effectiveness, including the following:

- Lack of quantitative, tested, and reliable means to predict effectiveness of PCOs from empirical data–as designed, constructed, and maintained in practice. Therefore, the SCG must rely on model simulations.
- The available modeling tool for bank stability, while of critical usefulness to generate quantified load reduction estimates, has limitations for adequately representing all preferred PCOs or to simulate complex channel response to PCOs over space and time.
- Modeled performance at a the site scale might, or might not, reflect performance of a PCO over a long reach of stream—depending on how sensitive the PCO is to various driving factors and channel adjustment processes

Some of the data limitations reflect the management context of PCO installation and maintenance and are difficult to predict or control but can cause variation in actual performance relative to designed or modeled performance. Finally, there is little information available with which to predict how the PCOs performance could be affected by driving trends and cycles in weather and climate, including conditions that can control initial and long-term performance of PCOs.

Selected PCOs

A subset of the *preferred PCOs* (Appendix SCSCG-B) were selected as the principal treatments to be combined in the Treatment Tiers for load reduction analysis (Table 5-3). The selected PCOs cover a range of approaches and methods and include techniques whose effectiveness can be estimated either by empirical data, BSTEM modeling, or reasonable interpolation.

Table 5-3. Selected stream channel erosion PCOs for Treatment Tiers

General PCO	Description
Bank Protection—stone	Install rigid stabilization covering bank toe
Bank Protection—LWD/Shrub revetment	Install flexible stabilization covering bank
Bank Strengthening—wet meadow vegetation	Restore streambank vegetation herbaceous (via soil improvements, soil moisture increases) wet meadow *sod* growing on banks
Bank Strengthening—woody riparian vegetation	Restore streambank vegetation woody (via soil improvements, soil moisture or stream dynamics-seed beds)
Channel fill with bank toe stabilization	Recreate hydrologic connectivity in streams, meadows, and wetlands—raise streambed elevation within incised channel
Bank lowering + floodplain excavation	Recreate hydrologic connectivity in streams, meadows, and wetlands—excavate bank to create connected active floodplain
Bank lowering + angle reduction	Recreate hydrologic connectivity in streams, meadows, and wetlands—excavate and contour bank to reduce angle and/or improve bank vegetation
Channel reconstruction	Restore natural geomorphic characteristics through construction; Decrease channel slope/increase sinuosity of degraded streams; Maintain hydrologic connectivity in streams, meadows, and wetlands
Channel restoration	Restore natural geomorphic characteristics through restored processes; Decrease channel slope/increase sinuosity of degraded streams; Maintain hydrologic connectivity in streams, meadows, and wetlands

5.4. Settings

Spatial Resolution for Stream Channel Erosion Analysis

This study employs several spatial scales that are commonly applied in hydrology and geomorphology: *sites*; *reaches*; *streams*; and, *watersheds*. These terms, while accepted and widely used, do not have specific absolute dimensions associated with them. Watersheds are areas, defined by the topographic boundaries of land surfaces that drain to a common outlet and can range widely in size. There are 54 identified watersheds draining to Lake Tahoe via defined stream channels (Lahontan and NDEP 2007).

The sites, reaches, and streams are linear surface water channel features within watersheds. This analysis considers a site to generally range in length from a few meters to several hundred meters long. Sites are typically the scale of *hot spot* bank erosion problems and the scale at which the modeling of individual PCO effectiveness is conducted. The site is a common scale for many bank and bed stabilization PCOs but it is too short to be suitable (in terms of function or cost-effectiveness) for reconstruction/restoration PCOs. Reaches are generally more than several hundred meters long and up to a few thousand meters long. Channel instability and bank erosion often occur at the reach scale, and PCOs must be applied at this scale to address system-wide problems. Reconstruction and restoration PCOs are typically implemented at the reach scale, and combinations of bank and bed stabilization PCOs can be effective at the reach scale.

This study uses the term *stream* to refer to the mainstem channel of the tributary watersheds to Lake Tahoe. Although there are additional channels forming tributaries or headwaters in the watersheds, streambank fine sediment sources are largest along the main channel and detailed site and reach level data is readily available for the main channels.

Settings

The Settings for this analysis are the watersheds that contribute the largest amounts of fine sediment from streambanks to Lake Tahoe. Specifically, they are the top three watersheds that compose 96 percent of the Basin-wide total (Upper Truckee River, Blackwood Creek, and Ward Creek) and the next two largest source watersheds (General Creek and Third Creek) that account for another 1.9 percent of the Basin-wide total.

The watersheds identified as major sources are large and have somewhat varied geology, soils, elevation, landownership, and land uses. The stream lengths for these watersheds range from less than 10 km to more than 20 km (Table 5-4), with the Upper Truckee River having about three times the total length of the other top source streams.

The pattern and proportion of urbanization along the stream corridors in the watershed is fairly consistent for all five streams. Each has urbanized areas typically in its downstream reaches where major highways and roadways cross but is rural in the headwaters. Third Creek and the Upper Truckee River have somewhat higher urbanization along the channel in the middle reaches. Land ownership (as a percent of stream length) along the stream channels is dominantly public on the top four streams, with varied mix of federal, state, or local government versus private land. Land ownership along Blackwood Creek is dominantly federal (87 percent), with remainder equally shared by state government and private parties. About half of the Ward Creek stream is under state ownership (49 percent), over a third is federal (38 percent), and the remainder is private. Along the Upper Truckee River, federal and state government each own about a third (32 percent and 37 percent, respectively), local government control just under 10 percent, and more than 20 percent is private (22 percent). Much of the mainstem and nearly all the important tributaries of the top four streams are in conservation and recreation areas, with some suburban residential sections and a few locations with industrial and commercial activities.

Table 5-4. Stream channel erosion pollutant control Setting characteristics

Stream	Total channel length[a] (km)	Percent of banks failing (%)	Length of high & moderate bank source of fines (km)	Percent of high & moderate bank source of fines (%)
Upper Truckee River	24.2	20.2%	11.4	47.2%
Blackwood Creek	8.3	15.8%	7.0	83.8%
Ward Creek	6.6	3.8%	3.2	48.4%
General Creek	8.1	5.0%	2.9	35.8%
Third Creek	8.1	9.1%	0.6	7.4%

[a]*Total* main channel length as analyzed with comprehensive, consistent geomorphic inventory (Simon et al. 2003; Simon 2006). These channel lengths might not include some headwater portions of main channel or headwater tributaries.

The potential treatment areas within the watersheds are locations that have failing banks and are rated as moderate- to high-severity locations generating fine sediment from streambanks. The absolute length and proportion of these characteristics vary among the watersheds (Table 5-4) but are large in comparison to other watersheds Basin-wide that produce less streambank fine-sediment loads.

Setting Data Sources

The selection of the Settings and treatment areas has been based on prior Basin-wide data that can provide consistent, systematic information across all the various tributaries to the Lake (Simon et al. 2003; Simon 2006; Lahontan and NDEP 2007).

The relative rating of reaches as sources of fine sediment from bank erosion (High, Moderate, Low) is based on Simon et al. (2003) and Simon (2006), which used consistent field methods and ratings across all Tahoe Basin streams. These ratings are based on a combination of Rapid Geomorphic Assessments (RGAs) at sites and continuous stream observations conducted at the reach and stream scale across the Lake Tahoe Basin. The RGAs and stream walks evaluated relative stability and stage of channel evolution. RGA techniques use diagnostic criteria of channel form to infer dominant channel processes and the magnitude of channel instabilities. They have been used successfully in a variety of physiographic environments to rapidly determine system-wide geomorphic conditions of large fluvial networks. Because they provide information on dominant channel processes rather than only channel form, they can be used to identify disturbances and critical areas of erosion and deposition.

The reach scale Settings have a variety of physical, ecological, and socioeconomic characteristics that are spatially tracked to support PCO application in the Tier analysis and to support extrapolation of BSTEM modeling from sites to reaches and streams. The sources of these data include geospatial and database information from the USDA-ARS-NSL, newly released Tahoe Basin Soil Survey data (NRCS 2007), and watershed-specific assessments: Blackwood Creek (Swanson Hydrology + Geomorphology 2003, 2007), Upper Truckee River (EDAW/ENTRIX 2003, 2006; TRCD 2003; ENTRIX 2006, 2007; Camp Dresser & McKee 2005; Swanson Hydrology + Geomorphology 2004b; River Run Consulting 2006), and Ward Creek (Hydro Science and River Run Consulting 2007) are the key data sources combined to produce reach-level and site-specific data tables for cross-referencing in extrapolation.

5.5. Treatment Tiers

The selected PCOs (Table 3-2) are applied to the treatment areas in each watershed Settings (Table 4-1). Each Treatment Tier features the same treatment areas (*high* and *moderate* streambank sediment sources. While the locations and length of treatments do not vary between Tiers, the types of PCOs differ in each of three Treatment Tiers. The proportions of selected PCOs in each Tier allow a wide range of approaches to channel rehabilitation/restoration to be depicted. The Tiers include two *bookends* that characterize diverse approaches (Tiers 1 and 3) and an intermediate, mixed Treatment Tier (Tier 2). Having two extreme Tiers allows simplification of the approaches to suit the modeling methods and produces results that help define reasoned *upper* limits for water quality performance and costs that can be used in interpolation. However, Tiers 1 and 3 have very different ecological and land use issues associated with them (i.e., *non-water quality* cost/benefit considerations) that must be evaluated before making implementation decisions. The mixed Treatment Tier has a consistent spatial scale (same Settings and treatment areas) as the other two Tiers, but it is more indicative of the types of multiple objective stream projects and range of treatment approaches already used in the Basin. The three Treatment Tiers could be implemented over various time frames or in phases, and could have varied effectiveness during early stages or initial stages of implementation. However, all the Tiers are described and evaluated as if they are in place and fully functional across their spatial extent .

The most distinctive components for each Treatment Tier are highlighted below, prefaced by a description of similar parameters for baseline (existing/recent) conditions.

Baseline

Baseline conditions are those recent stream channel and hydrologic conditions, generally the late 1980s to present. This period includes the years of measured streamflow and sediment discharge (1995 and 1997) used in BSTEM modeling and validation, and is the time frame of the USDA-ARS-NSL field observations (Simon et al. 2003; Simon 2006) and repeat surveys used to calibrate prior estimates and modeling of existing conditions. In this analysis, the baseline conditions are not a Treatment Tier, they are the present channel and streambank conditions in the Settings that result in *existing* values in the load estimates.

Generally, the channels are too deep (i.e., *incised* or *entrenched*) and too wide, so that the channel capacity is large enough to prevent overbank flow except in very large storm events (e.g., > 20-year event) (Figure 5-1). The high banks are often steep and may be overhanging. The steep bank angles and large channel capacity increase hydraulic force on the bank, bank toe, and bed relative to idealized or pre-disturbance conditions. Groundwater is deep and summer moisture content in adjacent terrace surfaces is limited, with decreased riparian vegetation density and survival. These are the key features that decrease channel stability and increase bank erodibility. Additional description of baseline conditions relative to processes that affect nutrient sources and sinks is provided in Appendix SCSCG-A.

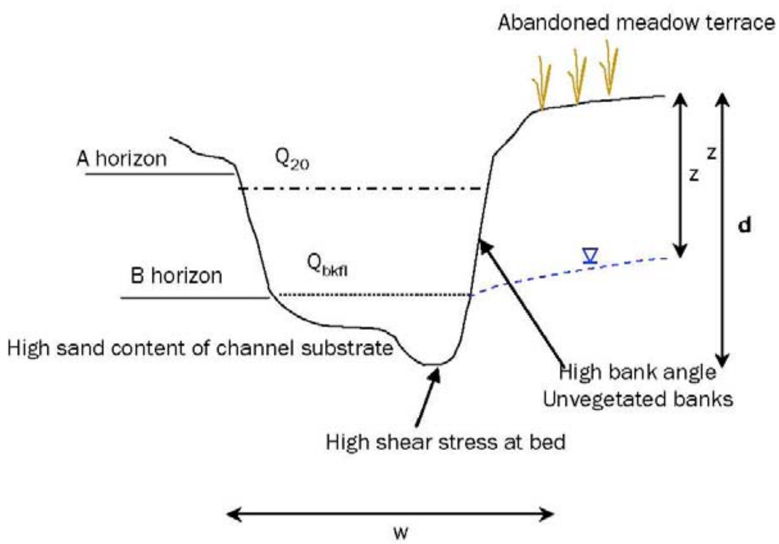


Figure 5-1. Schematic representation of Tahoe Basin stream channel characteristics under the baseline (existing) conditions

Tier 1—Channel Restoration

Tier 1 represents a treated condition where reach scale treatment has modified the existing unstable stream's planform, increased its length and sinuosity, and decreased its slope. The treatment could have occurred rapidly through *reconstruction* or gradually via modified processes, but the result is a *restored* condition. Allowing the stream access to appropriate valley floor width for natural channel dynamics and floodplain ecosystem processes is prioritized over potential land use/infrastructure conflicts.

Generally, the channels are connected to the adjacent valley floor (floodplain/meadow/marsh), and the channel width/depth are adjusted to slope and sediment transport. The channel capacity is small enough to allow overbank flow in modest, relatively frequent storm events (e.g., ~1 to 2-year events) (Figure 5-2), while the floodplain width and capacity are large enough to accommodate large storm events (e.g., ~20-year event) without excessive depth and velocities. The bank heights are modest, but bank angles may still be steep, at least on outer bends. The low banks and frequent overbanking decrease hydraulic force on the bank, bank toe, and bed similar to idealized or pre-disturbance conditions. Groundwater is nearer to the surface and summer moisture content in adjacent floodplain surfaces supports high riparian vegetation density and survival. These are the key features that increase channel stability and decrease bank erodibility. Additional description of Tier 1 conditions relative to processes that affect nutrient sources and sinks is provided in Appendix SCSCG-A.

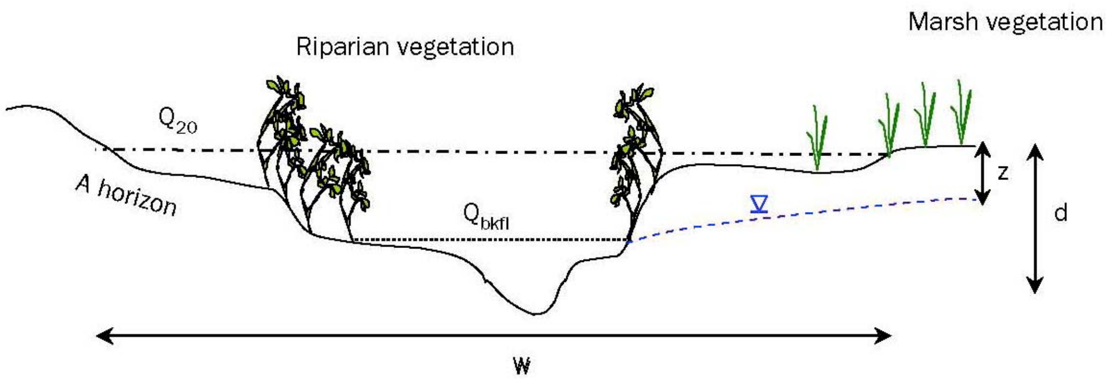


Figure 5-2. Schematic representation of Tahoe Basin stream channel characteristics under the Tier 1-channel restoration conditions

Tier 2—Mixed Treatment

Tier 2 represents a treated condition where reach scale treatment has modified the existing unstable stream in the same problem areas as in Tiers 1 and 3, but some areas would have PCOs providing restored conditions and other areas would have PCOs providing bank protection. Cost-effective water quality improvement is still a high-priority objective, so PCO choices favor those with higher load-reduction cost/benefits.

Where land ownership is suitable and land use/infrastructure conflicts are resolved, the channel planform is modified, length and sinuosity are increased and slope is decreased. Where land ownership is private and/or land use/infrastructure conflicts are more restrictive, the banks are protected, but the channel dimensions and slope are not modified. In transition reaches, or in combination with the geotechnical and restoration PCOs (where overbanking or groundwater improvements allow), vegetative PCOs would be implemented. The treatment might have occurred rapidly or gradually, but the result is a *rehabilitated* condition of mixed treatments.

Tier 3—Bank Protection

Tier 3 represents a treated condition where reach scale treatment has modified the existing unstable streambanks without changes to the channel planform, length, sinuosity, or slope. As needed, reaches with unstable stream beds would also have had grade control installed along with bank treatments. The treatment may have occurred rapidly and concurrently, or gradually in phases, but the result is a *protected* condition. No additional access to valley floor width for natural channel dynamics and floodplain ecosystem processes is required. Stabilization of the banks in place allows land use/infrastructure conflicts to be avoided.

Generally, the channel dimensions are as for existing (baseline) conditions, with high banks and adjacent terraces rather than active floodplains (Figure 5-3). The channels are too deep (i.e., *incised* or *entrenched*) and might be too wide, but the installed bank toe protection (and in some cases streambed protection for grade control) have reduced channel capacity slightly. Overbank flow would still only occur in relatively large events (e.g., < 20-year event) but perhaps slightly more often than under existing conditions. The high banks could still be steep, but installation of bank toe protection would have been combined with removing overhanging banks. While the bank angles and channel capacity are still high and the channel slope has not been reduced, hydraulic resistance of the bank toe has been increased. Groundwater is deep and summer moisture content in adjacent terrace surfaces is limited, with riparian vegetation density and survival similar to the baseline conditions. The channel stability and bank protection is dominantly provided by the installed geotechnical materials and does not require or depend upon vegetative strengthening. Additional description of Tier 3 conditions relative to processes that affect nutrient sources and sinks is provided in Appendix SCSCG-A.

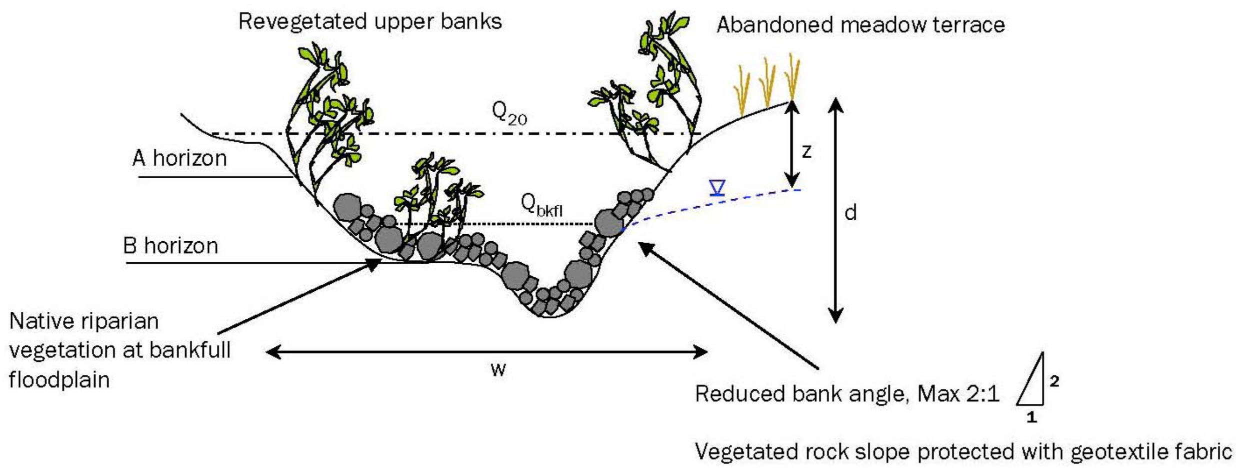


Figure 5-3. Schematic representation of Tahoe Basin stream channel characteristics under the Tier 3-bank protection conditions

Treatment Tier Comparisons

The key components for each Treatment Tier are summarized in Table 5-5. As described above, the Tiers have similar spatial scales and patterns of implementation, with consistent mixtures of sites and reaches for treatment that have been selected on the basis of the background inventory of severity of the existing sources. Key distinctions between Tiers are the contrasting priorities represented by the extreme water quality objective weighting exhibited in Tier 3 versus the multiple ecosystem-based objectives targeted in both Tier 1 and Tier 2. Another distinction is in how the treatment decisions are made for each reach Settings. Tier 1 assumes that a process-based approach selects the suitable PCOs for all treatment locations. Conversely, Tier 3 assumes that predictive modeling selects the most suitable PCOs for all treatment locations. Tier 2 uses iterations of predictive modeling, along with consideration of socioeconomic factors (e.g., land ownership, land use), to assign PCOs to treatment locations.

Table 5-5. Summary of stream channel erosion Treatment Tier features

Component	Group	Description	Tier 1 Channel Restoration	Tier 2 Mixed Treatment	Tier 3 Bank-Protection
Spatial Scale					
	Sites	~10 to 1,000 meters	■	■	■
	Reach	~1000 to 5,000 meters	■	■	■
Spatial Pattern					
	Severity Based	High and moderate fine streambank sediment reaches	■	■	■
Treatment Type					
	Design Approach	Process-based, multi-objective	■		
		Iterative-based, multi-objective		■	
		Predictive-based-WQ priority objective			■
	Selected PCOs				
		Bank Protection		45%	~100 %
		Bed (grade) Stabilization	*	*	*
		Bank Strengthening		10%	
		Channel Fill + Toe Stabilization		5%	
		Bank Lowering + Angle Reduction		5%	
		Channel Reconstruction/ Restoration	~100%	35%	

■ A distinctive aspect of the Tier.

* Streambed (grade) stabilization features would likely be a component of all Tiers, at transitions between treated and non-treated reaches within Tier 1 and 2, and likely at locations within the treated reaches in Tier 3. The potential cost of grade control is incorporated in costs of the other PCOs where they are expected to be combined.

Treatment Tier Examples

The following descriptions for the Upper Truckee River Setting provide an example of the way the generalized Tier descriptions were interpreted.

Tier 1—Channel Restoration Example

Project planning boundaries would be discontinuous but based on type and severity of sediment sources and consideration of the space needed to allow for desired ecosystem processes and functions. Design objectives and criteria elevate ecosystem benefits, including water quality/bank stability to the highest priority. These objectives override other land use considerations and conflicts with other major land use/infrastructure needs (e.g., airport or golf course would be relocated/removed as needed for full restoration). Modifying planform and grade would reroute pipelines or make changes to road fill/bridge crossings (but not completely eliminate these land uses). Channel restoration project boundaries might not coincide with present property ownership/infrastructure and would require coordinated decision-making for implementation.

Treatment types would be composed of PCOs to reconstruct/reoccupy channel(s) with appropriate bed elevation, slope, size, and shape to support floodplain connectivity with existing terraces and would be consistent with and supportive of ecological and dispersed recreation objectives. The primary PCOs would be channel reconstruction or channel restoration that reestablishes channel and floodplain processes. For the purpose of simplification in the analysis, little or no other PCOs are *required* to represent the Tier. In practice, some additional PCOs can be used to provide bed stabilization between treated and untreated areas, enhance habitat within floodplains, combine stabilization of banks with habitat improvements, or speed up attainment of the restored state. However, for the purpose of analyzing load reduction the key actions would be the reestablished and functioning channel geometry, length, slope, and reduced bank heights of a *restored* channel in virtually each of the identified high and moderate fine streambank sediment source reaches.

Tier 2—Mixed Treatment

Project planning boundaries would be discontinuous but based on type and severity of sediment sources the treatment scale needed to achieve water quality benefits, and cost-benefits of both water quality and other ecosystem and land use objectives, based on iterative predictive modeling. Design objectives and criteria elevate water quality/bank stability benefits but not to the total exclusion of other ecosystem benefits, and adjust treatment types for major land use/infrastructure conflicts (e.g., airport would remain in place).

Treatments that require less planform space are selected in areas with land use conflicts. Mixed Treatment project boundaries might not coincide with present property ownership/infrastructure; again, this would require coordinated decision-making for implementation. Treatment types emphasize water quality performance but use multiple-benefit PCOs with lower water quality effectiveness to support other ecological and recreational objectives in some of the identified high and moderate fine streambank sediment source reaches.

Tier 3—Bank Protection

Planning boundaries would be discontinuous but based on type and severity of sediment sources, the treatment scale needed to achieve water quality benefits, and cost-benefits focused on water quality objectives based on iterative predictive modeling. Design objectives and criteria elevate water quality/bank stability benefits to the highest priority. These objectives would override other ecosystem benefits but do not conflict with land use/infrastructure constraints (e.g., airport would remain in place) because the channel planform position and profile remain essentially as existing.

The treatment PCOs would primarily be PCOs to stabilize eroding banks, along with some additional PCOs to provide bed stabilization within some treated reaches and between treated and non-treated reaches. For the purpose of simplification in the analysis, the bank protection PCOs are assumed to be engineered, rigid material (stone). However, in practice, some other protection PCOs could be applied and the toe protection can be combined with other PCOs to reduce upper-bank angle, improve bank vegetation, adding to water quality effectiveness or habitat value. However, for the purpose of analyzing load reduction, the key actions are limited to the installation of stone material to protect the toe of banks in virtually each of the identified high and moderate fine streambank sediment source reaches.

Treatment Tier Data Sources

The primary sources of spatial data to support assigning PCOs within the subreaches of the streams to represent the Treatment Tiers in modeling are the surveys by Simon (2003, 2006). In addition, Tier 2 selection of types of treatments/alternatives try to incorporate assessments and design reports for the specific key watersheds: Blackwood Creek (Swanson Hydrology + Geomorphology 2003, 2007), Upper

Truckee River (EDAW/ENTRIX 2003, 2006; TRCD 2003; ENTRIX 2006a, 2006b, 2007; Camp Dresser & McKee 2005; Swanson Hydrology + Geomorphology 2004b; River Run Consulting 2006), and Ward Creek (Hydro Science and River Run Consulting 2007). Interim results of the Tiers 1 and 3 load calculations and costs are also a data source used to finalize the locations and PCOs selected for the Tier 2 (i.e., iterative adjustments to PCO assignments for Tier 2 were made after Tier 1 and Tier 3 results were available).

5.6. Analysis Methodology

The following sections describe analysis methods used to quantify PCO effectiveness, formulate fine sediment loads for each Treatment Tier, calculate associated TP loads, and provide costs for the PCOs and Treatment Tiers, including the cost per ton of reduced fine sediment and TP loads.

PCO Effectiveness Analysis

PCO effectiveness data from scientific literature and reported monitoring provide guidance for estimating performance of a few of the identified PCOs (Appendix SCSCG-B). These data are restricted in the scope of PCOs represented and wide ranging in their values, reducing confidence in their application to load reduction estimates. Therefore, new modeling of some preferred PCOs, as applied to the stream conditions at the watershed and reach level Settings in Tahoe Basin, is performed using a deterministic, quantitative model that simulates the processes controlling streambank erosion.

These processes can be modeled using the BSTEM developed by the USDA–ARS–NSL (Simon et al. 1999, 2000). The BSTEM has been previously used successfully in the Tahoe Basin to model the influence of riparian vegetation on bank stability along a reach of the Upper Truckee River (Simon et al. 2006). The BSTEM modeling in support of this load reduction analysis was conducted by the USDA–ARS–NSL. The specific methods and technical background on the model characteristics are described in Appendix SCSCG-C.

The general approach was to simulate fine-sediment loadings from streambank erosion for existing (baseline) conditions and, once the existing conditions results could be validated, to investigate how various PCOs might reduce the sediment loadings. The inventory of site and reach level conditions by USDA–ARS–NSL gathered 2002–2006, provided information from which representative sites were selected for the watershed and reach Settings. The record of USGS LTIMP measured sediment loadings guided selection of a representative year and flood event known to have produced bank erosion as the modeling period for baseline and treatment cases. The results of BSTEM modeling for representative sites on the streams in the watershed Settings under these approximately *worst-case* hydrologic conditions then provide PCO effectiveness data. The BSTEM results are compared from site-to-site, stream-to-stream, and in relation to literature values as part of final quantification of PCO effectiveness.

BSTEM Modeling Sites

Representative sites from all the reach Settings were selected from the three watersheds known to contribute the greatest amounts of fine sediment by streambank processes: Blackwood Creek, Upper Truckee River, and Ward Creek (Simon 2006), all of which have actively eroding streambanks. Site-specific evaluations of representative streambank erosion scenarios within the moderate and high fine sediment source areas include three sites on the Upper Truckee River and two each on Blackwood Creek and Ward Creek (Table 5-6).

Table 5-6. General characteristics of bank stability modeling sites

Stream	River station (km)	Bank height (m)	Vegetation characteristics	Relative bank contribution of fines (H,M,L)	Land use/transect
Blackwood Creek	1.94	3.0	No top of bank vegetation	H	Public; Conservation; Recreation; Suburban fringe—Residential
Blackwood Creek	2.39	2.4	Lemmon's willow (moderate)	M	Public; Conservation; Recreation; Rural
Upper Truckee River	4.51	2.6	Meadow vegetation	H	Private; Agriculture; Conservation; Urban fringe—Commercial/Residential
Upper Truckee River	8.45	1.9	Mixed meadow and woody vegetation	M/H	Public; Conservation; Urban fringe—Industrial/Residential
Upper Truckee River	13.1	2.7	Managed turf with lodgepole pine	H	Public; Conservation; Recreation; Suburban fringe—Residential
Ward Creek	2.48	14.9	Mature conifers at top of slope	H	Public; Conservation; Recreation; Suburban fringe—Residential
Ward Creek	3.60	1.3	Meadow vegetation	M	Public; Conservation; Recreation; Rural

BSTEM Modeling Period

Hydrologic conditions of *years* and *events* that produce erosion where selected from the period of record, and emphasizing larger measured sediment loading years during the relatively recent baseline period (Figure 5-4). On the basis of these considerations, the 1995 annual hydrograph and the January 1997 flood event were chosen to provide the driving, hydraulic forces in BSTEM modeling. 1995 was an above-normal flow year that contained series of high-flow events and long durations. The 1995 sediment loads were between the 75th percentile and maximum annual loads for the period of record. In addition, the rain-on-snow event on January 1–2, 1997, was a major peak event and is known to have generated substantial bank erosion. Using these flows in the BSTEM modeling period includes enough driving force conditions to generate erosion. The SCG can, therefore, assume that PCOs effective during this modeling period would be expected to function at least as well in most other years over a projected 20-year project life.

Mean daily stage data for 1995 from the four USGS gauging stations nearest to the selected modeling sites were simplified into simple rectangular hydrographs of constant stage, over a given duration, to create suitable input to the BSTEM toe-erosion component that tests resistance to hydraulic force on the toe (Figure 5-5). The January 1, 1997 flood event is expressed as a simple rectangular hydrograph with 48-hour duration and the depths ranging from 0.64 m at the Ward Creek site, 1.55 m at the Blackwood Creek sites, and 1.8 m for the Upper Truckee River sites, based on the closest USGS gauging station data. Additional details of the mean flow depths and durations input to BSTEM for each event in the hydrologic period simulated for each site are provided in Appendix SCSCG-C.

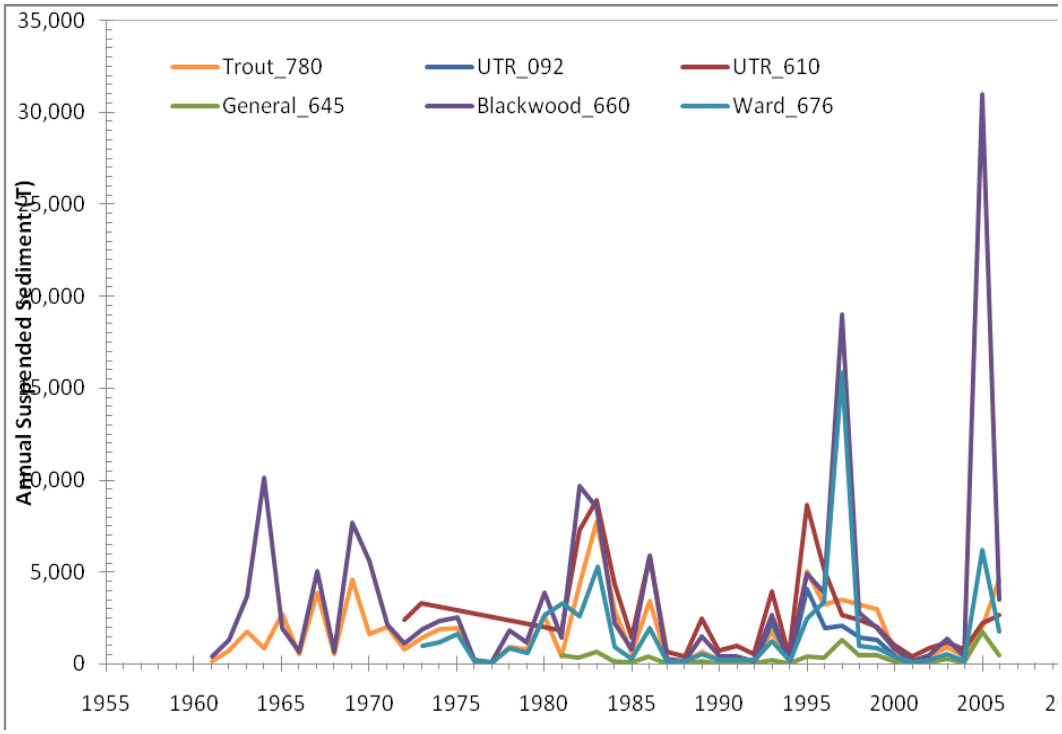


Figure 5-4. Annual suspended sediment (TSS) loads (MT) for major fine sediment source Tahoe streams

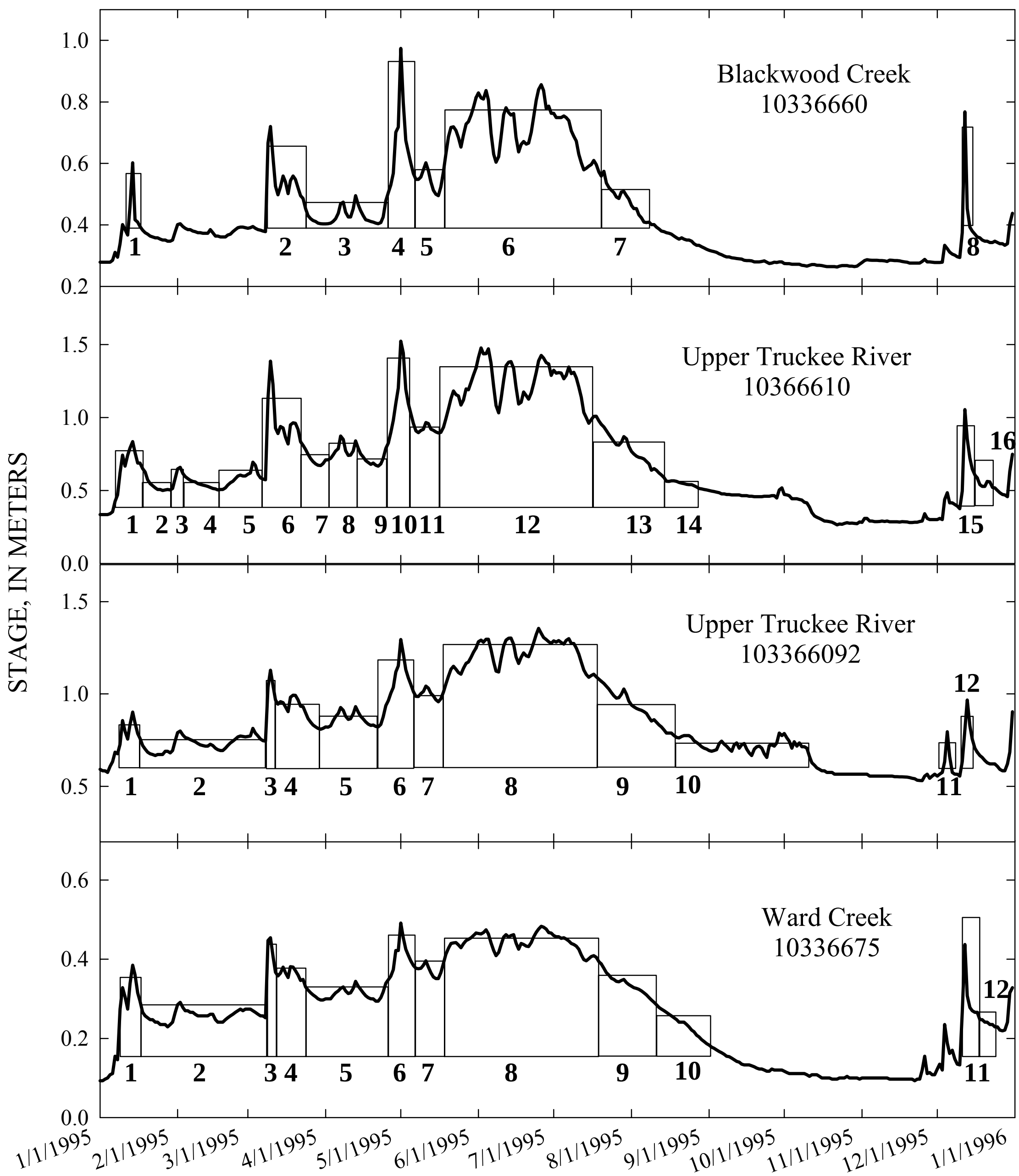


Figure 5-5. Simplified 1995 hydrographs for the four USGS gauging stations with numbered *events* used as input to the toe-erosion sub-model of BSTEM.

Existing Load Calculations

Data collected in 2002 along the Upper Truckee River and Ward Creek and additional data along these streams and Blackwood Creek collected in 2006 was used to assign BSTEM parameters for the existing conditions (Appendix SCSCG-C). For example, topographic survey provided bank height and channel slope, geotechnical observations and measurements provided bank layering, sediment sizes/cohesion, in-situ shear strength, vegetative cover density and root depth, and hydraulic jet-testing allowed erodibility to be measured. These data facilitated the use of the deterministic, process-based BSTEM for all the representative sites within the Settings.

BSTEM modeling, using both the toe erosion and bank stability submodels, and iterative steps to adjust the bank geometry and water table data, was conducted for the representative sites, as detailed in Appendix SCSCG-C.

The volumes of erosion and the number of mass failures simulated by BSTEM over the hydrograph events for each site were summed to produce the totals for the simulation period. The total sediment volumes for the site are converted to estimated fine material volumes using field and laboratory data collected by NSL. Each of the sites modeled with BSTEM thus produce a total and fine sediment load volume for the hydrologic period simulated, which is extrapolated from the modeled representative sites to stream-wide estimates for the three watershed Settings.

The relative magnitude of the BSTEM results for *high* and *moderate* representative sites was used to guide estimated loads for the *low* sites. The total erosion volumes and fines are determined within the spatially discrete calculation worksheet for each stream using field and laboratory characteristics such as the percent of bank failing, total lengths, and the percent fine sediment. The simulated *existing* load calculations are included in each of the spreadsheets used in the load reduction (Appendix SCSCG-D).

BSTEM Validation

The BSTEM results for all three watershed Settings were validated by comparison to USGS LTIMP measurements of total and fine suspended load, and calculated fine sediment load from Simon (2006) for the simulated hydrologic period (1995 annual total plus the two day total for the January 1–2, 1997 storm). The comparison did confirm an order-of-magnitude consistency between the measured and simulated fine sediment loads, and similar relative contributions of streambank fines to total watershed fines (Table 5-7). While this rough validation is not able to support high confidence in the absolute magnitudes, it supports high confidence in using the modeling tool for relative comparison of various alternatives.

Table 5-7. Validation of BSTEM results for streams' existing condition

	Units	Blackwood Creek	Upper Truckee	Ward Creek
Measured fine suspended load[a]				
1995 Annual Total	(MT)	1,927	3,500	1,083
Jan 1-2, 1997 Storm Total	(MT)	8,223	1,958	5,189
Total	(MT)	10,150	5,458	6,272
Simulated fine sediment load				
1995 Annual Total + Jan 1-2, 1997 Storm	(MT)	4,432	5,828	2,953
Relative Contribution of Streambank Fines to Total Fines	(%)	43.7%	106.8%	47.1%
Streambank Fine Sediment Load (Simon 2006)	(MT)	5,179	5362	2,109
Relative Contribution of Streambank Fines to Total Fines (Simon 2006)	(%)	51%	98%	34%

[a]Measured loads from USGS LTIMP stations.

PCO Representation in BSTEM

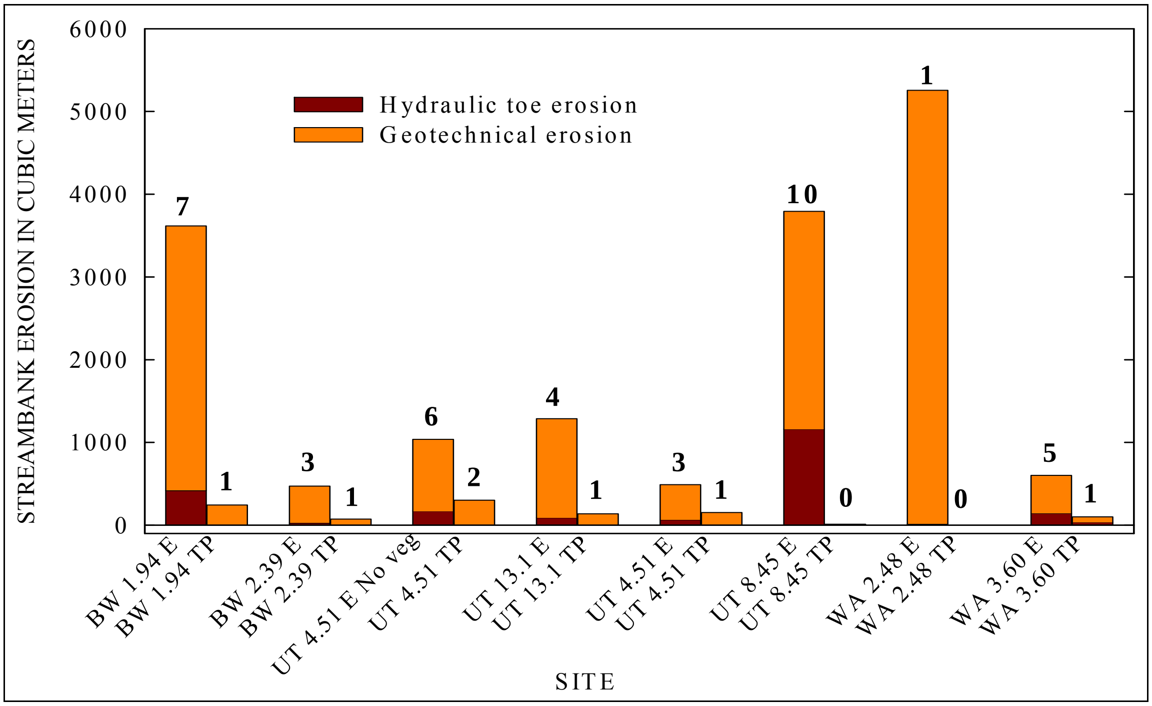
To provide new quantitative PCO effectiveness data without adequate literature values, toe-erosion and bank-stability processes under the *treated* condition are modeled with BSTEM. BSTEM modeling of PCOs for the seven sites was performed using the identical simulated hydrologic period but with input files modified to represent the manner in which the PCOs would affect driving and resisting parameters. The PCOs could affect various driving and resisting parameters. Only selected PCOs are modeled with BSTEM. The limited number of PCOs represented in BSTEM was partially to conserve modeling effort, but also because of the lack of information available with which to validate results from minor variations of different PCOs (Table 5-8). Relatively simplified versions of fairly distinct PCOs are simulated, to help indicate the range of expected effectiveness despite the modeling and validation limitations.

Table 5-8. Selected PCO representations in BSTEM modeling

PCO	Description	Representation within BSTEM
Bank Protection-stone toe	Rigid stabilization of bank toe	Complete: modify physical properties of lower bank to reflect 256 mm boulders placed 1.0–1.5 m up the bank toe.
Bank Strengthening-wet meadow vegetation	Restore streambank vegetation herbaceous (via soil improvements, soil moisture increases) wet meadow *sod* growing on banks	Complete: modify vegetation parameters to increase strength relative to root reinforcement in upper 0.5 to 1.0 m, but adjust for added weight (surcharge) if needed.
Bank Strengthening-woody riparian vegetation	Restore streambank vegetation woody (via soil improvements, soil moisture or stream dynamics-seed beds)	Complete: modify vegetation parameters to increase strength relative to root reinforcement in upper 0.5 to 1.0 m, but adjust for added weight (surcharge) if needed.
Channel reconstruction/ Channel restoration	Restore natural geomorphic characteristics through construction Restore sinuosity to channelized streams Recreate hydrologic connectivity in streams, meadows, and wetlands	Partial: effects of increased sinuosity are simulated by reducing bed slope (~20% reduction, based on concept designs for proposed projects).

The representations of PCOs in BSTEM are not able to fully reflect all elements that control the water quality performance for complex, multicomponent PCOs like channel restoration. However, the core hydraulic and geotechnical driving and resisting forces are simulated. For example, the reduced shear stress from lower channel slope (i.e., from channel lengthening (increased sinuosity), channel fill/grade control, or similar PCOs) can be represented by reducing the modeled channel bed slope. In full restoration, slope reduction would be accompanied by bank height reduction, changes in the soil layers exposed, and vegetation conditions. The possible additive beneficial effects are not included in the BSTEM representation. However, simplification also precludes deterministic representation of, possible offsetting adverse effects such as bank erosion from active channel migration, or changes in sediment transport continuity.

BSTEM modeling of existing conditions and the stone toe bank protection PCO highlighted the important relation between hydraulic erosion at the toe with overall bank erosion. While toe erosion accounts for an average of 13.6 percent of the total streambank erosion magnitude, it steepens bank slopes and contributes to subsequent mass-bank instability which accounts for vast majority of streambank erosion (Figure 5-6). The only exception is in situations where major side slopes like the representative BSTEM site on Ward Creek (WA 2.48 in Figure 5-6). The addition of geotechnical protection (stone toe) virtually eliminates hydraulic erosion at the bank toe, thus reducing total bank erosion by over 80 percent.



Note: BSTEM for a 100-m-long reach for the 1995 annual period, plus January 1-2, 1997 under existing conditions (E), and with toe protection (TP). Numbers in bold refer to the frequency of bank failures for each scenario.

Figure 5-6. Simulated volumes of streambank erosion by hydraulic (toe erosion) and geotechnical (bank failure) processes.

Even the more readily represented PCOs, like stone toe protection, might not have some of their possible additive beneficial effects (e.g., lowered upper bank angles, re-vegetation) or offsetting adverse effects (e.g., increased hydraulic forces in adjoining non-treated reaches) included.

Despite these simplifications and limitations, the BSTEM quantification of PCO effectiveness provides critical data that are compared with literature sources as a *reasonableness* check before load reduction calculations.

Sediment Load Reduction Estimates for Selected PCOs

The limited quantitative data from literature sources about PCO effectiveness in local or similar Settings provide only fairly broad ranges of load reduction percentages (Table 5-9). BSTEM results for representative sites and selected PCOs and provide additional quantitative estimates of the load reduction percentage (Table 5-9).

The BSTEM values are used as the basic input to the load reduction calculations, but for reaches where treatments are combined or have limited BSTEM modeling sites, the literature-based values provided context for the assigned load reduction in the worksheets. Because PCOs have been represented in simplified ways and some of the complex associated water quality benefits or adverse offsetting effects cannot be modeled very well with BSTEM, the literature values were important to review before making calculations. However, there is wide disparity in most literature-based results (Table 5-9). The few quantitative data sources are not able to justify quantitative adjustments to the BSTEM results. In terms of channel restoration, for example, the simulated hydraulic change because of slope reduction probably underestimates the load reduction effectiveness if the additional benefits are considered. However, if the upper bound of such PCO effectiveness is thought to be similar to the empirical data comparing the degraded Upper Truckee River to the more functional Trout Creek system (Stubblefield et al. 2005) it is still not necessarily over 50 percent reduction. Given the difficulty of quantitatively adjusting the estimated effectiveness, the load-reduction estimates used the new modeling results for the quantitative analysis, as documented within each stream and Tier's load and cost calculation spreadsheet (Appendix SCSCG-D).

Table 5-9. PCO effectiveness values for load reduction analysis

PCO	Load reduction percent ranges from literature sources		Load reduction percent estimates from BSTEM modeling		
	Sediment Load Reduction (%)	Reference	BW	UTR	Ward
Bank Protection-stone toe	~100% (design standards)		84.3% 93.3%	70.7% 68.6% 89.4%	83.1% 100%
Bank Strengthening- wet meadow vegetation	90% decrease in failure numbers; 84% decrease migration	Micheli and Kirchner 2002 a and b		52.7%	
Bank Strengthening- woody riparian vegetation	44 to 60% reduction vs agricultural land	Micheli et al. 2004			
Bank lowering +floodplain excavation/ Bank lowering +angle reduction	23 to 91 % 8 to 93%	Phillips 1989; van der Lee et al. 2004			
Channel reconstruction/ Channel restoration	20 to34 % functioning stream vs degraded stream; 51 to 77% functioning marsh vs degraded marsh	Stubblefield et al. 2005		41.9%	53.8%

Load Reductions

Fine Sediment Load Reduction for Key Streams

For each stream, the BSTEM existing conditions calculation worksheet was modified to allow input of varied PCO assumptions for each of the reach Settings on the three largest watershed fine streambank sediment sources (see Blackwood, Upper Truckee, and Ward worksheets in the Appendix SCSCG-D spreadsheets).

The load analysis was performed at the reach scale, using the available data from both Basin-wide studies (e.g., Simon et al. 2003) and available stream-specific studies, to be as realistic as possible. However, there are few ways to validate either the *existing* or *treated* load results at this detailed spatial scale. Adding more spatial resolution or accuracy from inventories and design reports might not necessarily improve the results.

The reach properties were tracked and overlaid using GIS shapefiles and data from the 2002–2006 RGA and stream walks, and associated laboratory data from the USDA–ARS–NSL, the new NRCS soil data shapefile published in 2007, and data for the Upper Truckee River , Ward Creek , Blackwood Creek, and General Creek mainstems. The data sets were intersected to identify reaches and subreaches, and classified them with their corresponding soil type, RGA identification, and hotspot locations. RGA data (e.g., stage of channel evolution, degree of failing banks, sideslope scores, and bankface soil properties for percent fines) were tracked by river kilometer and overlain with the available stream-specific inventories and design reports for each of the three key streams. These overlays were used to help assign PCOs for the mixed Treatment Tier.

Fine Sediment Load Reduction Basin-Wide Extrapolation

Results of the three key source streams for which results are generated represent the overwhelming majority (~96 percent) of all estimated Basin-wide sources of fine sediment from streams (Table 5-1). However, extrapolation to the next two largest watershed sources would account for another ~2 percent of the Basin-wide source, effectively representing the entire basin. The extrapolation was possible in part because of the consistent PCO effectiveness for Tier 3 regardless of stream. Because no BSTEM results are specifically for sites within those two streams, the existing load from banks was estimated using USGS LTIMP measured data and Simon's 2006 relationships of bank fine loads to total fine sediment loads (45 percent for General; 10 percent for Third). Reduced loads were estimated in a simplified approach using the same spatial application pattern (All, High, Moderate and High) and assigning the resultant stream-wide load reduction percentages from the three modeled streams.

Estimated Phosphorus Load Reduction

The stream channel load reduction approach and methods have focused on producing quantitative estimates of fine sediment loads, with little specific analysis of the extremely small nutrient load source attributed to stream channels (See Section 5.1). Estimates of TP or BAP associated with eroded bank sediment were calculated through a simple percentage adjustment to the estimates of sediment loads for the top three source streams.

TP loads are estimated by modifying the total fine sediment load by the average measured TP percent for erodible bank sediment samples reported by Ferguson (2005) and Ferguson and Qualls (2005) (0.0152 percent).

Cost Estimates

Costs of Preferred PCOs

General cost estimates for all the preferred PCOs for stream erosion treatment were prepared for this study by ENTRIX, Inc. (Appendix SCSCG-E) using recent data for construction costs on projects implemented within the Tahoe Basin. Costs include both construction and operations and maintenance (O&M) costs over an assumed 20-year life span. Some PCOs can be considered self-sustaining over even longer periods, but no attempt has been made to quantitatively compare the likely maintenance needs or costs beyond a 20-year planning horizon, partially because of uncertainties regarding how the magnitude of future seasonal peak flows and flood regimes could change in response to climate conditions.

A consistent implementation area or *site* was identified for each PCO, defined as that area required to treat approximately 1,000 linear feet (~305 m) of channel, including any adjacent lands (e.g., floodplain) that directly require or are affected by the PCO. On the basis of this spatial area and the type of features in the PCO, unit costs from the construction cost data sources were reviewed to create an estimate of cost per site and by unit length of channel treated.

The cost estimates are all expressed in 2008 dollars, estimated by applying typical recent regional inflation rate (approximately 10 to 15 percent per year) between the *actual* construction cost year and 2008. While there will also be variation in possible costs depending on the implementing agency and whether competitive bid processes are used, these general cost estimates assume public-bid processes similar to the recently completed projects for which data was available.

The general cost estimates do not make specific modifications or adjustments to reflect impacts of varied construction access issues (ease of access to construct the given improvement). The cost data from recently completed projects (e.g., Lower West Side, Angora SEZ, Erosion Control Projects) was generally within 500 feet of a public right-of-way (paved roadway) and required minor tree removal. However, they all had typical difficulties related to constructing any stream/river restoration in the Tahoe Basin: traffic control and interruption, seasonal limitations, unregulated flows to bypass, and construction-phase water quality standards. There are many variables and a wide range of complications that could affect the costs of a proposed project, but they are difficult to predict, so no access difficulty factor is applied to the general cost estimates.

Stream Size Correction Factor

The available cost data for similar work in the Lake Tahoe Basin region, constructed within the past 10 years, is primarily for small to moderate size stream channels. The general cost estimates based directly on recent projects, therefore, are best applied to channels with a 100-year design flow on the order of 150 and 200 cubic feet per second (cfs).

In contrast, the three key fine sediment source streams (i.e., Blackwood Creek, Upper Truckee River, Ward Creek) are considerably larger (100-year flows of 4,820 cfs, 7,650 cfs, and 2,670 cfs, respectively). Streams of this size have not yet had significant restoration/repair/enhancement performed within the Lake Tahoe Basin. Some of the PCO features and construction efforts are not significantly affected by the channel size, floodplain width or peak flow magnitudes (e.g., bank toe protection of consistent height, bank top vegetation treatments or protective measures), so no scaling adjustment is made. However, the costs of some PCOs are scaled up to reflect additional land, material, or effort that would be required for the PCO to function (e.g., floodplain excavation or floodplain land acquisition, channel reconstruction). In a few cases (e.g., grade-control structures), there are offsetting costs in the unit site assumption (e.g., more structures per unit length needed in smaller, steeper streams but fewer required in lower gradient large streams), so the total cost is not scaled up. The scaling factor, where necessary, is estimated to be 10 percent of the difference in 100-year flow magnitude from the small/moderate sized streams. This factor is based on professional judgment, but the resulting costs compare well with recent planning and conceptual design reports cost estimates for the three large Tahoe Basin streams of interest as noted in the Appendix SCSCG-E.

5.7. Results

The spreadsheet calculations of load reductions for all treatment areas in each Setting are provided in Appendix SCSCG-D and discussed below. The quantitative load reduction estimates are presented, followed by the cost estimates. There is also discussion of cost/benefit factors that were not specifically quantified, and description of the SCG's confidence in the results and highlights some qualitative considerations. Conclusions regarding the results and are also provided, followed by recommendations on anticipated use of results and means to refine and improve the analysis.

Fine Sediment Load Reduction Estimates

Quantitative results from the fine sediment load reduction calculations (Appendix SCSCG-D) for all Tiers and streams analyzed are summarized in Table 5-10 at the watershed level, with sub-totals for the top three source streams (~96 percent of the identified basin source) and totals for the top five source streams (~98 percent of the identified basin source). The top three watersheds have existing loads about 25 to 50 times larger than loads from the next two watersheds, so results of all the Tiers have predictably large differences between these two groups of streams.

Because the Treatment Tiers are consistent in their spatial extent (all Tiers treat the same reach Settings), variation in PCO effectiveness (Table 5-9) has a strong effect on the range of load reductions, but the actual bank conditions, percent fines, and simulated bank processes for each stream reach do affect the results.

Bank Protection (Tier 3) consistently has the greatest load reduction (more than 80 percent) and Channel Restoration (Tier 1) consistently has the least load reduction (40–50 percent), but all the Tiers are estimated to produce substantial reductions from existing conditions. These estimates are just based on the core components of PCOs, rather than combinations of PCOs that integrate multiple and possibly additive water quality benefits. However, the calculated existing loads and reduced loads are for the simulated period (1995 and January 1997 storm) that represent conditions when driving hydrologic forces are known to be great enough to produce bank erosion, rather than for an *average* year. Because some bank erosion processes are not typically initiated below a minimum threshold of hydrologic/hydraulic driving force, this is a reasonable first choice for simulation period. The resulting loads, however, are likely larger than the *average* annual loads. The percent load reduction estimates can, however, be compared across PCOs, Treatment Tiers and streams consistently.

The load reduction potential under both Tier 1 and Tier 3 for General and Third creeks is very low, as a function of the low existing loads (Table 5-10). Given the small loads and lack of detailed information with which to select treatment area PCOs for Tier 2, no estimates were produced for these two creeks under the intermediate Tier.

Table 5-10. Summary of stream channel fine sediment load reduction results for all Tiers

	Existing	Tier 1-channel restoration		Tier 2-mixed treatments		Tier 3-bank protection	
Stream	Fine-sediment load (MT)	Fine-sediment load (MT)	Load reduction (%)	Fine-sediment load (MT)	Load reduction (%)	Fine-sediment load (MT)	Load reduction (%)
Blackwood Creek	4,432	2,593	41.5%	1,275	71.2%	732	83.5%
Upper Truckee River	5,828	2,812	51.7%	2,094	64.1%	1,103	81.1%
Ward Creek	2,953	1,746	40.9%	919	68.9%	525	82.2%
Top Three Sub Total/Averages	13,213	7,152	44.7%	4,288	68.1%	2,360	82.3%
General Creek	117	69	42.1%	N/A	N/A	21	82.4%
Third Creek	133	74	44.7%	N/A	N/A	23	82.4%
Top Five Totals/Averages	13,463	7,294	44.0%	N/A	N/A	2,404	82.3%

Note: Details provided in Appendix SCSCG-D. All load calculations are for the same modeled hydrologic period, the full 1995 annual hydrograph and the January 1-2, 1997, storm event. The load values should not be inadvertently considered *average* annual values (they represent *above average* to *critical* driving hydrologic conditions).

Phosphorus

TP loads generated from stream channel erosion are estimated by applying the same scaling factor from the measured average phosphorus content of channel sediments (0.0152 percent) for all streams and Treatment Tiers. While there are some stream-specific TP data that indicate slight variations in TP content (Ferguson 2005), the concentrations are so low that no attempt is made to customize the factor by watershed (Table 5-11). These loads, as for the fine sediment loads are for *above average* conditions, so the estimated loads are higher than likely average annual loads, but comparisons between streams and Treatment Tiers are still valid. Because the TP estimates are from a simple multiplier on the fine sediment loads, spatial patterns, relative performance of the PCOs, and results by Treatment Tiers and streams inherit the same patterns as for the fine sediment loads, discussed above.

Table 5-11. Summary of stream channel TP load reduction results

	Existing	Tier 1—channel restoration		Tier 2—mixed treatments		Tier 3—bank protection	
Stream	TP load (MT)	TP load (MT)	Load reduction (%)	TP Load (MT)	Load reduction (%)	TP Load (MT)	Load reduction (%)
Blackwood Creek	0.7	0.4	41.5%	0.2	71.2%	0.1	83.5%
Upper Truckee River	0.9	0.4	51.7%	0.3	64.1%	0.2	81.1%
Ward Creek	0.4	0.3	40.9%	0.1	68.9%	0.1	82.2%
Top Three Sub Total/Averages	2.0	1.1	44.7%	0.7	68.1%	0.4	82.3%

Note: Details provided in Appendix SCSCG-D. All load calculations are for the same modeled hydrologic period, the full 1995 annual hydrograph and the January 1-2, 1997 storm event. The load values should not be inadvertently considered *average* annual values (they represent *above average* to *critical* driving hydrologic conditions).

Cost Estimates

PCO Costs

A summary of costs associated with selected PCOs that are included in Treatment Tier representations in the load reduction estimates is provided in Table 5-12, and all PCO cost estimates, assumptions and rational for scaling, are attached in Appendix SCSCG-E. The cost of PCOs featured in the Treatment Tiers varies widely in the unit costs for typical Tahoe Basin streams (small- to moderately sized). The cost of PCOs also varies by watershed because some of the costs must be scaled up to reflect required channel dimension or floodplain area construction and O&M costs.

Table 5-12. Costs of PCOs selected and used in Treatment Tiers for load reduction analysis[a]

	Typical Tahoe Basin streams[b]	Large Tahoe Basin streams[c]		
Selected PCOs	"Small to moderate" Tahoe streams total 20-year cost per meter (2008 $value/m)	Ward Creek total 20-year cost per meter (2008 $value/m)	Blackwood Creek total 20-year cost per meter (2008 $value/m)	Upper Truckee River total 20-year cost per meter (2008 $value/m)
Bank Toe Protection-stone	700	700	700	700
Bank Protection-anchored shrub/brush revetment	342	864	942	1,495
Bank Strengthening- wet meadow vegetation	336	336	336	336
Bank Strengthening- woody riparian vegetation	336	336	336	336
Bank lowering +floodplain excavation/	1,601	4,044	4,409	6,997
Bank lowering +angle reduction	268	676	737	1,170
Channel reconstruction (slope reduction +other measures)	2,718	6,867	7,487	11,882

Source: Appendix SCSCG-E (ENTRIX, Inc.)
[a] A site is defined as ~1,000 linear feet (~305m) of channel and any associated off-channel areas, if required for each PCO.
[b] Available costs of recently constructed Tahoe Basin projects are primarily from small to moderate channels (e.g., Angora Creek, Trout Creek, Incline Creek), so *typical* cost estimates are associated with streams of similar size.
[c] Cost scaling relative to channel and floodplain size is only for those PCOs affected by flow magnitudes and channel or floodplain dimensions, using 10 percent of the difference in 100-year flood flow magnitudes as the scaling factor.

Cost of Fine Sediment Load Reduction by Tier

The total costs and cost per MT of reduced fine sediment by Treatment Tier and stream (Table 5-13) display a large range that reflects of the wide cost range for the selected PCOs featured in the *bookend* Treatment Tiers (Table 5-12). A consistent pattern in the unit costs per load reduction is that these costs could underestimate cost/load reduction on an *average* annual basis, because the estimated loads are simulated for *above average* conditions.

Total costs and costs per MT of reduced fine sediment are much higher for channel restoration than for the other Tiers. The planform changes, slope reduction, and floodplain reconnection to achieve restoration requires expensive PCOs. The measures provide a wider meander belt and make modifications to channel sizes and lengths, conduct revegetation on floodplains or former terraces, and filling existing channels. Although the distribution of public and private lands varies somewhat within each of the focus stream areas, the unit costs for Tier 1 assume the lower cost situation that all the restoration can be accomplished on public land or without land acquisition. The total costs of this full restoration Tier in all the reach Settings are probably fairly represented. However, the costs per ton reduced fine sediment are probably inflated, because the PCO effectiveness (Table 6-4) only captures some of the primary aspects of channel restoration (slope reduction), and could underestimate load reduction. The empirical data for fully functioning streams indicates that perhaps another 10 to 20 percent load reduction could be possible, but without additional verification, the SCG is unable to provide better refinement of the cost per MT of reduced load.

As could be expected from the high load reduction effectiveness (Table 5-9), low unit costs (Table 5-12), and the limited need for cost scaling by stream size for bank protection PCOs, the estimated total cost and cost per MT of reduced fine sediment are lowest for Tier 3 (Table 5-13). The bank protection total costs are estimated to be about 10 percent of the amount for Tier 1, and about a third the amount of Tier 2. Total costs for Tier 3 could be somewhat underestimated because (like Tier 1) it is a simplified, extreme version of treatments that assumes no other PCOs would be used, when some more costly and less-effective PCOs would likely be incorporated. It is possible that the water quality effectiveness for the bank protection PCOs is overstated, but even if it is 10 to 20 percent less effective, the cost per MT of reduced load would still be much less than Tier 1. For Tier 1, only Ward Creek has an estimated unit cost under $20,000/MT, while all three top source streams have unit costs under $8,000/MT for Tier 2 and under $2,000/MT for Tier 3 (Table 5-13).

The pattern of costs by stream is fairly consistent from Tier to Tier, with the Upper Truckee River having the highest total cost for all Tiers, followed by Blackwood and Ward. This is a direct function of the treatment lengths on each stream because the reach Settings are consistent. General Creek has a similar treatment length as Ward Creek, and therefore, treatment cost. Third Creeks' treated length and cost is very small. Because the Tier 1 and Tier 2 PCOs have more stream-size scaling in their costs, the difference between the Upper Truckee, Blackwood, and Ward costs are greater under Tiers 1 and 2 than under Tier 3, which relies on PCOs that do not have much increase in costs related to stream or floodplain size.

The costs per load reduction reflect the spatial pattern of sources, ability to control sources on each stream, as well as the PCO unit costs by stream. The costs are typically a function of length treated, but the load reduction per stream length is not similar on all the streams because the actual source magnitudes and percent fines vary. Of the three top source streams, the Upper Truckee consistently has the largest unit costs—not surprising for its treatment length and stream/floodplain size requirements compared to Blackwood and Ward Creeks. The unit cost of treating smaller sources like General Creek and Third Creek can escalate (Table 5-13). General Creek has the highest unit cost, and Third Creek has the second highest unit cost for bank protection because the cost of treating the bank toe is not *scaled down* for a small stream. On the other hand, Third Creek's unit cost for channel restoration is less extreme because it does not need to assume a *scaling up* of the PCO costs.

Total and unit costs for Tier 2 are relatively reasonable compared to other Tiers, in part because of that Tier's iterative use of the modeled load reductions and cost calculations for the Tiers 1 and 3 to guide selection of which PCOs to apply to which reach Settings in Tier 2.

Table 5-13. Summary cost of fine sediment load reduction

Stream	Tier 1—channel restoration		Tier 2—mixed treatment[a]		Tier 3—bank protection	
	Total cost ($millions)	Cost per metric ton reduced fine sediment ($/MT)	Total cost ($millions)	Cost per metric ton reduced fine sediment ($/MT)	Total cost ($millions)	Cost per metric ton reduced fine sediment ($/MT)
Blackwood Creek	52.0	28,301	13.60	4,303	4.9	1,315
Upper Truckee River	135.5	44,938	29.6	7,933	8.0	1,690
Ward Creek	21.8	18,042	6.5	3,185	2.2	914
Top Three Sub Total/Averages	**209.3**	**30,427**	**49.7**	**5,140**	**15.1**	**1,306**
General Creek	21.0	436,242			2.1	21,274
Third Creek	1.6	27,221			0.4	3,803
Top Five Totals/Averages	**213.8**	**110,949**			**17.5**	**5,799**

[a]Because of the small existing loads relative to the top three streams and the lack of site-specific data on General and Third Creeks to guide treatment area decisions for Tier 2, only the two *bookend* Tiers have been calculated for General and Third Creeks.

Cost of Phosphorus Reduction

The total and cost per ton reduced load of phosphorus have been calculated, but because TP is such a small percentage of the fine sediment (Appendix SCSCG-A) and the costs for sediment load reductions are relatively high (Table 7-4), the costs for TP reduction linked to streambank erosion sources are extremely high. All TP cost data are included in the Appendix SCSCG-D calculations and results worksheets for reference, but not repeated here.

Qualitative Cost/Benefit Factors

There are several cost/benefit factors that were not quantified in this particular analysis, but are worthy of qualitative discussion to assist with decisions about the use for quantitative results. These also serve as indications of the type of refinements or additional information recommended. Some of these factors relate to water quality alone, but other factors are ecological or socioeconomic aspects of the stream channel treatments.

Water Quality Cost/Benefits

An important water-quality cost/benefit factor that is not directly captured in this analysis is an artifact of the separate analysis being performed for various pollutant *sources* for the Lake Tahoe TMDL load reduction despite ecosystem links between some of the sources and processes affecting them. Some of the streambank PCOs could provide treatment opportunities for pollutant loads that originate with other sources, yet the potential water quality benefit of that load reduction has not been calculated here. For example, any of the preferred and selected streambank PCOs that lower bank heights, increase overbanking frequency, restore channel geometry and floodplain function could also provide opportunities to treat sediment and nutrient loads conveyed from uplands. These characteristics affect the overall benefit of the stream erosion PCOs to nutrient loading of the Lake but are not captured in the evaluation of sediment or phosphorus loading directly linked to streambank sources. The cost/benefit of such PCOs in this analysis only have their direct *streambank source* quantification incorporated. Integration of analysis between source groups could address this factor, but it was beyond the scope of this study. A conceptual framework of the relations between channel morphology, hydrology, erosion, vegetation , soil processes, and the relative sediment and nutrient sources and sinks expected for channel conditions under the stream channel Treatment Tiers have been prepared as part of this analysis (Appendix SCSCG-E) and could support development of overall cost/benefits assessment of stream channel PCOs.

All the Treatment Tiers analyzed implement PCOS in spatially discontinuous patterns along the streams, based on reach Settings severity. The channels potentially will experience response over time to the treated versus not-treated reaches that is not captured in this study. The severity of response could vary with PCO possible adverse water quality effects are probably worse for Tier 3 than for Tier 1. However, the modeling tools in use at this time cannot verify the differences in long-term performance or risk of negative effects ton on-treated reaches. Alternatively, the engineered treatment PCOs in Tier 3 may be more readily monitored and/or managed than the natural process PCOs featured in Tier 1, which presents different management decisions given the channel dynamics included in the PCO's normal function. The long-term performance differences, as implemented and managed remain is difficult to predict.

Another water-quality cost/benefit factor that is not directly captured in this analysis relates to the possible short-term, but realistic possibility of possible adverse effects that could result during early implementation phases of treatments on these relatively large, unregulated rivers. If implementation timing on several reaches happens to be concurrent with adverse weather patterns and extreme runoff, the risk of short term water quality problems increase. While there may be design or construction management options to reduce these short-term risks, the risks are likely higher for Tier 1 and 2 in contrast to Tier 3. Because this analysis focuses on the PCO effectiveness once installed and functional, such considerations are outside of this scope.

Non-Water Quality Cost/Benefits

A couple of diverse, but important non-water quality cost/benefit factors are not captured in this analysis: the value of ecological benefits or lost opportunity costs associated with some PCOs and the socioeconomic values of reducing or avoiding infrastructure or land use conflicts.

Tier 1 PCOs that protect, strengthen, or otherwise reduce bank erosion without hardening of the bank surface (e.g., channel reconstruction, bank lowering and vegetative strengthening) would provide associated riparian and aquatic habitat values that are not reflected in load reduction estimates. Conversely, Tier 3 PCOs that protect, strengthen, or otherwise reduce bank erosion without expanding the area needed for overbanking flows and channel migration or relocation (e.g., bank protection with rigid materials, grade control and bank strengthening) would provide the best preservation of existing land uses or infrastructure that are not reflected in the load-reduction estimates.

Confidence in Results

Data Resources

The excellent data resources regarding stream channel erosion source locations, magnitudes and relative contributions of fine sediment from stream channels and uplands Basin-wide permitted a focused analysis of watershed and reach level Settings that compose the overwhelming percentage of the existing pollutant source.

Additional site-specific data on the key watersheds provided additional spatial information on problem areas, proposed alternative treatments, likely costs and benefits expected, which supported development of realistic/meaningful PCO assignment for Tier 2.

However, the extremely limited supporting quantitative data regarding PCO effectiveness from *any* environmental Setting (let alone from scientifically and regionally appropriate monitoring studies) limited the SCG's ability to do initial screening of PCOs based on quantitative data. This lack of reliable literature-based information required that new modeling be conducted. The limited quantitative water quality PCO data restricted the options to interpolation or extrapolation from the initial modeling results.

PCO Effectiveness Modeling

Despite the limited PCO effectiveness data from literature sources, and the time and funding restrictions that affected which modeling tools could be employed, the quantitative field and laboratory data collected by USDA–ARS–NSL for the Tahoe Basin streams (2002–2006) facilitated pioneering use of a deterministic, predictive quantitative model to generate PCO effectiveness data. A deterministic, predictive tool (BSTEM) that has been developed and tested by leading scientists at the USDA-ARS-NSL, subjected to peer review, and applied to similar problems in other regions was used to simulate bank stability under existing and varied PCO applications for this load reduction study. The local site conditions on key streams were taken as representative of the reach Settings, as established by the prior field and laboratory data. The SCG was thus able to generate verifiable, quantitative load estimates under existing conditions. The same tool was then used to simulate effectiveness of PCOs for quantitative comparison.

Time and resource limitations restricted the number of different hydrologic conditions simulated. The driving hydrology used for all BSTEM modeling is a representative period known to have produced bank erosion (the annual hydrograph for 1995 and the January 1–2, 1997 storm). This is a valid approach to ensure that bank failures under existing condition would be modeled and the various PCOs might be compared, by site and stream to establish relative, but quantitative, load changes.

Validation of the BSTEM modeling was possible at the stream scale and for existing conditions, but there are few options to calibrate site-level results (which would require water quality data, observed bank failure events, rates or volumes).

Little data are available to accurately reflect near bank groundwater conditions during and between flow events. Consequently, iterative and conservative assumptions were made during the BSTEM simulations to reduce this modeling disadvantage. Time and funding limited options to sensitivity test various possible conditions in the absence of observations.

Treatment Tier Data

The professional experience of the SCG lead working on Tahoe Basin stream project planning (vis-à-vis, implementation and factors controlling project success), along with the detailed data sources about the local conditions from stream-specific studies was crucial in identifying major components of Treatment Tiers for steam channel erosion reduction measures. The difficulty was that data resources with quantitative PCO effectiveness are so limited that BSTEM and the load calculation methods may not be able to reflect subtle differences or complex, multi-faceted PCOs. Therefore, the Treatment Tiers were set up to be fairly simplistic to cover a range of possible approaches and methods.

Refined spatial data regarding source severity and percentages of fines could be useful in making the Settings very realistic, but this improvement is probably not important unless modeling tools are also updated.

Load Calculations

Load calculations for stream channel erosion did have spatially discrete and process-driven inputs that allow reasoned and realistic values to be generated. However, the availability of spatially detailed data for reaches and sites was greater than the performance data with which the SCG could calibrate the model and calculation results. A potentially important variable in the existing calculations that could be refined or sensitivity tested would the percent fine content in the banks. The data used to-date numerous actual field samples. However, because these data represent spot samples from specific depth, a sensitivity analysis using ranges from depth integrated soils data in addition to the existing data would allow us to see how this variable modifies the output. Unfortunately, this was outside the scope of work.

Another potentially important variable in existing calculations that could be refined or sensitivity tested would be validation of BSTEM output with the stream total at their downstream gauges. The SCG needed to assume that the resulting loads are distributed along the RGA and stream-walk surveyed lengths of the main channel only. Additional lengths of the mainstem channels and some tributary lengths (as noted and assumed by Simon 2006) could also be contributing fine sediments but were not accounted for in the rough validation of the modeled year (1995) and event (January 1–2, 1997). The SCG did not have the time, resources or data sets needed to test whether and to what extent the absolute load numbers generated from the BSTEM site modeling, and the stream-wide extrapolations, overestimate or underestimate actual loads from the portion of the mainstem associated with it. However, the validation at stream-wide scale demonstrated consistency with measured loads that supports use of the method to perform calculations and make comparisons.

Costs and Cost-Effectiveness

Cost information used in this analysis is locally based, recent, and includes a range of implementing agencies, locations and types of projects. However, the primary challenge is that no local projects of the size and scale that could be part of the PCOs on the larger key streams have been constructed in the vicinity and within the last few years—only planning cost estimates are available for comparison. The existing approach to scale some of the PCOs to reflect larger stream costs is a first cut and could be improved with additional research from outside of the region comparing projects of equal size to known Tahoe projects. Many variables can affect the costs, in both the positive and negative direction, and are difficult to predict. Additional information and sensitivity testing would improve on, and perhaps narrow some of the cost estimates. It might be crucial to have funding and implementation agency assumptions clarified to determine whether projects will occur under public bidding processes or if those cost assumptions could be changed.

Confidence Summary

On the basis of the various aspects of data resources, modeling tools and options, the professional judgement to set up and verify Treatment Tiers, and data available to validate the load estimates, the SCG’s estimated confidence in the results (Table 5-14) is highest for the baseline conditions, which have been well documented with local data, by experts, and have data available for model result validation. The largest challenges with the data set, modeling tool, or calculation methods are common to each of the Tiers. But if differences are known that affect confidence in the results, it is indicated in Table 5-14. The SCG is also generally more confident for Tier 2 than either of the *bookend* Tiers, because Tier 2 iteratively benefits from the Tier 1 and 3 results, as well as from the reach-specific geographic data sets from other studies.

Table 5-14. Stream channel erosion confidence rating table

Setting	Baseline	Tier 1	Tier 2	Tier 3
Stream-Specific	4	3	4	3
Blackwood	4	4	4	3
Upper Truckee	4	4	3	4
Ward	4	3	4	3
Basin-Wide	4	3	4	3

The primary issue affecting confidence in these results is that the absolute values (loads) are likely high relative to *average* annual amounts for all PCOs and Tiers. Additionally, there are varied possible *over* and *under* estimations of particular PCO effectiveness. The cost data is local and reliable, and relative patterns by Tier and stream should all be valid for interpretation and decision making.

Conclusions

A large amount and high percentage load reduction of fine sediment from streambank sources could be achieved using bank protection (Tier 3), at low cost per unit load reduction. However, even this low-cost treatment is not likely to be cost effective except the top three source streams, and perhaps a high source, small-size stream like Third Creek. The uncertainty about PCO effectiveness for Tier 3 could overestimate load reductions and underestimate costs. The cost/benefit information available for Tier 3 does not include non-water quality benefits related to land use constraints, or the non-water quality costs of lost opportunities to achieve other ecosystem functions or additional water quality treatment.

A large amount and moderately high percentage load reduction of fine sediment from streambank sources could be achieved using channel restoration (Tier 1) but at very high total and unit cost. This high-cost treatment might not be cost effective if evaluated just in terms water quality control of streambank sources, even on the top three source streams. However, uncertainty about PCO effectiveness for Tier 1 could underestimate load reductions and overestimate costs. Additionally, the cost/benefit information available for Tier 1 does not include possible water quality benefits of treating pollutants from upland sources. If these load reductions were considered jointly, the cost per unit load reduction would decrease, even if the total cost of implementation would not. The non-water quality benefits that would be associated with channel restoration could include habitat and passive recreation resources, but these are not expressed in the water quality study. There could also be non-water quality costs that relate to land use trade-offs, acquisitions, or easements.

Tier 2 PCO assignments were made iteratively, so it was possible to apply knowledge of the site/reach scale conditions, and prior studies' opportunities/constraints data or alternatives evaluations to help pick which treatment area should have which selected PCO. Therefore, the mixed treatments (Tier 2) is able to achieve greater load reduction than Tier 1 at fairly feasible total and unit cost. Uncertainty about PCO effectiveness for Tier 2 could variously underestimate or overestimate load reductions. The full water quality and non-water quality cost/benefits for Tier 2 have not been incorporated in this analysis and would include a mixture of the considerations listed above for Tiers 1 and 3.

The estimates and the analytical tools/calculation spreadsheets developed for this study are an initial but important and useful step that integrates existing pollutant source data, generates new quantitative estimates of PCO performance, documents regionally valid PCO cost estimates, and applies both to specific stream reaches using data for *real* landscape positions on locations totaling more than 96 percent of the Basin-wide source. The load and cost estimates developed in this study establish a framework and initial quantifications for comparing expected performance and costs for stream channel erosion PCOs, Treatment Tiers, and streams.

There are limitations to the results provided in that not all preferred PCOs, including some of the complex, multi-objective ones, could be accurately quantified or validated with existing models and data. Quantitative results are not available for all PCOs, and there is limited data to support adjusting the BSTEM output using BPJ, although interpretation and use of the results must be tempered by BPJ.

The load modeling with deterministic, process-based methods, required use of driving hydrology above average conditions, so the quantities should not be considered *average annual* values. The best use of the quantitative load results is comparative by stream and Tier and proportionally as part of the Basin-wide source.

Good, site-specific data guided the watershed Setting and treatment area decisions, but there is still uncertainty in the magnitude of fine sediment sources and the length-weighting and incomplete knowledge of differences in main channel versus tributary contributions to loads.

The water quality performance of some stream channel PCOs might be underestimated by BSTEM modeling with respect to other sources of pollutant loads, and it could be possible to achieve substantial treatment of loads from other sources concurrently with the treatment of loads from stream channel erosion.

Improvements and sensitivity analysis could be made using the same general approach and methods. The existing spreadsheet calculation tools can be used iteratively and could be modified to represent other water quality, or even non-water quality decision criteria, if data and criteria can be agreed upon.

Streams contain and convey pollutants that originate from sources other than the stream channel (e.g., bed and banks), and stream and floodplain deposits form sinks that extend retention time or provide long-term storage of pollutants from several sources. The role of stream channel conditions on pollutant sources other than the channel itself is beyond the scope of this SCG's analysis. However, interaction of stream channel conditions with other pollutant sources and their PCOs is a topic that requires integration within the overall Lake Tahoe TMDL.

The stream-specific load reduction estimates for the top three stream sources of fine sediment from channels (Blackwood Creek, Upper Truckee River, and Ward Creek) can be considered a nearly complete Basin-wide estimate based on the high percentage of source they represent. However, the consistency of the PCO effectiveness modeling results and the availability of treatment areas and reach characteristic data from prior inventories (Simon et al. 2003), allowed extrapolation to the next two largest source streams (General Creek and Third Creek). This Basin-wide extrapolation provides an opportunity to examine the usefulness of predictive modeling regarding performance and cost-effectiveness to inform implementation priorities.

The three Treatment Tiers could be implemented over various time frames or in phases, and might have varied effectiveness during implementation. However, all the Tiers are described and evaluated as if they are in place and fully functional across their spatial extent (all reach Settings in all the Settings).

Recommendations

Application of this Study

As described above, the use of the quantitative results can guide Lake Tahoe TMDL decisions but should be applied primarily in comparisons between streams and Tiers. The absolute magnitudes are best thought of as an initial estimate of the *above average* loads associated with existing and selected PCOs. The results are valuable in their incorporation of site-specific, reach and stream length-weighted data regarding the existing sources and newly generated PCO effectiveness and cost data developed for the Tahoe Basin.

Future Studies

Data resources

A critical, continuing need is for quantitative water quality monitoring of various stream channel projects (regardless of PCO or approach). Other data sets for improving modeling tools, such as groundwater monitoring near stream banks, bank erosion monitoring, and floodplain sedimentation monitoring would expand the quantitative basis for modeling as well as support for BPJ interpretations of complex, multifaceted PCOs.

Improvements and New Elements

Several possible improvements and refinements to the existing analysis could reduce some uncertainties for specific PCOs, increase the accuracy of the estimates in terms of average annual loads, and provide sensitivity analysis related to some variables for which the SCG lacked adequate validation data (e.g., groundwater, fine sediment percentages).

- The existing BSTEM tool and approach could be applied more rigorously and with additional PCOs parameterized, for additional hydrologic conditions, and for more specific or idealized Tahoe stream sites. This would reduce the uncertainty and create more confident bounds to the expected PCO and Treatment Tier results.
- Improvements to the BSTEM, additional calibration with local surface and ground water conditions, and site-level calibration of the geotechnical/hydraulic properties of some additional PCOs, like stacked sod and anchored LWD, would allow a wider range of treatment options to be compared directly using the same modeling tool and calculation spreadsheets.

New aspects of the analysis, such as increased information about performance over time and process interactions possible within various treated and non-treated reaches could expand the information to guide Lake Tahoe TMDL decisions. These elements would require different modeling approaches, such as use of the CONCEPTS model (Langendoen 2000; Langendoen et al. 2001). CONCEPTS was employed as part of the earlier Lake Tahoe TMDL efforts to simulate existing conditions for a subset of Tahoe Basin Streams . Funding was not available in time to conduct the extensive model setup and runs needed to represent the details of all the Treatment Tiers for the Settings with CONCEPTS for this study.

Stream Restoration Design and Uncertainty Approaches

The iterative use of predictive models in this analysis has illustrated that it is possible and cost effective to combine water-quality priority PCOs at spatially important sources with other multiple objective PCOs in other reaches. However, the understanding of channel process-response between reaches and over time requires further research and application to support informed decisions.

It has been generally acknowledged that long-term effects of stream corridor restoration are not easy to predict, and there are rather high levels of uncertainty associated with design and implementation (FISRWC 1999). The data sets, approaches, and modeling tools used for the Lake Tahoe TMDL process can also lend themselves to support use of a Failure Modes and Effects Analysis (FMEA) (Johnson and Brown 2001) and Design Failure Modes and Effects Analysis (DFMEA) (Niezgoda and Johnson in press) perspective to deal with uncertainty in stream restoration design processes. These approaches systematically identify all possible components that can fail, consequence of failures, likelihood of failures, and difficulty to detect failure and create a framework for compensating for/adjusting to the risks. This approach should be advocated to help decisions on water-quality focused or other multiple objective stream projects in the Tahoe Basin.

5.8. References

Biedenharn, D. S., Elliott, C.M. and C.C. Watson (1997) *The WES Stream Investigation and Streambank Stabilization Handbook*. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Camp Dresser & McKee. 2005. *Upper Truckee Restoration Project: Existing Conditions Report* (Reach between Hwy 50 bridge in the City of South Lake Tahoe and the diversion dam). Prepared for City of Lake Tahoe and California Tahoe Conservancy, South Lake Tahoe, CA, by Camp Dresser & McKee, Tahoe City, CA.

D'Aoust, Stephane G., and R.G. Millar. 2002. Stability of ballasted woody debris habitat structures. *Journal of Hydraulic Engineering* 126:810–817.

EDAW. 2006. *Upper Truckee River Watershed Framework Monitoring Plan Discussion Paper*. Compiled for California Tahoe Conservancy and Upper Truckee River Watershed Advisory Group, Truckee, CA, by EDAW Inc., Stateline, NV.

EDAW & ENTRIX. 1999. *Upper Truckee River and Wetland Restoration Project: Lower West Side Wetland Restoration Project-Concept Summary Report*. Prepared for California Tahoe Conservancy, South Lake Tahoe, CA, by EDAW Inc., Sacramento CA, and ENTRIX, Inc., Sacramento CA.

EDAW & ENTRIX. 2003. *Upper Truckee River and Wetland Restoration Project: Processes and Function of the Upper Truckee Marsh*. Prepared for California Tahoe Conservancy, South Lake Tahoe, CA, by EDAW Inc., Sacramento CA, and ENTRIX, Inc., Sacramento CA.

EDAW & ENTRIX. 2005. *Upper Truckee River and Wetland Restoration Project: Alternatives Evaluation Report*. Prepared for California Tahoe Conservancy and Department of General Services, Real Estate Services Division. EDAW Inc., Stateline, NV, and ENTRIX, Inc., Sacramento, CA.

EDAW & ENTRIX 2006. *Upper Truckee River and Wetland Restoration Project: Final Concept Plan Report*. Prepared for California Tahoe Conservancy. South Lake Tahoe, CA. by EDAW Inc., Stateline, NV, and ENTRIX, Inc., Sacramento, CA.

ENTRIX. 2004. *Sunset Stables Restoration and Resource Management Plan-Final Draft Existing Conditions Report*. Prepared for the California Tahoe Conservancy, South Lake Tahoe,CA, by ENTRIX, Inc., Walnut Creek, CA.

ENTRIX. 2006a. *Upper Truckee River Middle Reach Restoration Project, Reaches 3 and 4: Final Formulation of Alternatives Memorandum*. Project No. 3114101. Prepared for the City of South Lake Tahoe, CA, by ENTRIX Inc., Walnut Creek CA.

ENTRIX. 2006b. *Upper Truckee River Middle Reach Restoration Project, Reaches 3 and 4: Alternatives Evaluation Memorandum*. Prepared for the City of South Lake Tahoe, CA, by ENTRIX, Inc., Walnut Creek, CA.

ENTRIX. 2007. Results of Sunset Stables sub-task 4C1: Supplemental Geomorphic Assessment. Letter report of March 23, 2007, to Joe Pepi, California Tahoe Conservancy, South Lake Tahoe,CA from Brendan Belby, ENTRIX, Inc.

FISRWG (Federal Interagency Stream Restoration Working Group). 1999. *Stream Corridor Restoration: Principles, Processes, and Practices*. National Technical Information Service, Department of Commerce, Springfield, VA.

Ferguson, J.W. 2005. The bioavailability of sediment and dissolved organic phosphorus inputs to Lake Tahoe. M.S. thesis, University of Nevada, Reno.

Ferguson, J.W., and R.G. Qualls. 2005. Biological available phosphorus loading to Lake Tahoe. Prepared for Lahontan Regional Water Quality Control Board., South Lake Tahoe, CA.

Glancy, P.A. 1988. *Streamflow, Sediment Transport, and Nutrient Transport at Incline Village, Lake Tahoe, Nevada, 1970-1973*. USGS Water-Supply Paper 2313.

Hanson G.J, Simon A. 2001. Erodibility of cohesive streambeds in the loess area of the midwestern USA. *Hydrological Processes* 15:23–38

Herbst, D.B. 2003. *Trout Creek Restoration Monitoring: Initial Post-project Assessment Using Benthic Invertebrates as Indicators of Ecological Recovery*. Sierra Nevada Aquatic Research Laboratory, University of California, Mammoth Lakes, CA.

Hill, B.R., J.R. Hill, and K.M. Nolan. 1988. *Sediment Sources in the Lake Tahoe Basin, California-Nevada: Preliminary Results of a Four-Year Study, August 1983–September 1987*. Open-File Report 88-333. U.S. Geological Survey Sacramento, CA. Prepared in cooperation with the Tahoe Regional Planning Agency.

Hill, B. R., J.R. Hill, and K.M. Nolan. 1990. *Sediment-Source Data for Four Basins Tributary to Lake Tahoe, California and Nevada, August 1983–June 1988*. Open-File Report 89-618. U.S. Geological Survey, Sacramento, CA.

Hydro Science and River Run Consulting. 2007. *Ward Creek Watershed Restoration Project: Technical Assessment*. Prepared for California Tahoe Conservancy, South Lake Tahoe,CA, by Hydro Science, Vacaville, CA and River Run Consulting, Truckee, CA.

Jacobson, R.B., and A.L. Pugh. 1998. *Riparian-vegetation controls on the spatial pattern of stream-channel instability, Little Piney Creek, Missouri*. USGS Water-Supply Paper 2494. U.S. Geological Survey, Sacramento, CA.

Johnson, P.A., and E.R. Brown. 2001. Incorporating uncertainty in the design of stream channel modifications. *Journal of American Water Resources Association* 37(5):1225–1236.

Jorgensen, L.N., A.L. Seacer, and S.J. Kaus. 1978. Hydrologic basins contributing to outflow from Lake Tahoe, California–Nevada. Hydrologic Investigations Atlas HA-587. U.S. Geological Survey, Carson City, NV.

Kondolf, G.M., S. Anderson, R. Lave, L. Pagano, A. Merelender, and E. Bernhardt. In press. *Two Decades of River Restoration in California: What can we learn?* http://landscape.ced.berkeley.edu/~kondolf/topics/restore/restore.html. Accessed August 15, 2007.

Lahontan Regional Water Quality Control Board and Nevada Department of Environmental Protection 2007. Lake Tahoe TMDL Technical Report. Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA and Nevada Department of Environmental Protection, Carson City, NV.

Langendoen, E.J. 2000. CONCEPTS–CONservation Channel Evolution and Pollutant Transport System, Research Report 16, U.S. Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS.

Langendoen, E.J., A. Simon, and R.E. Thomas. 2001. CONCEPTS- A process-based modeling tool to evaluate stream-corridor restoration designs. In *Proceedings of the 2001 Wetland Engineering & River Restoration Conference*, Reno, Nevada, D.F. Hayes, ed., ASCE, Reston, VA, on CDROM. <http://www.ars.usda.gov/SP2UserFiles/Place/64080510/AGNPS/Concepts/Doc/werr2001.pdf >.

Langendoen, E.J., R.E. Thomas, and R.L. Bingner. 2002. Numerical simulation of the morphology of the Upper Yalobusha River, Mississippi between 1968 and 1997. *River Flow* 2002, D. Bousmar and Y. Zech, eds., Balkma, The Netherlands. <http://www.ars.usda.gov/SP2UserFiles/Place/64080510/AGNPS/Concepts/Doc/riverflow2002.pdf>.

Larson, M.G., D.B. Booth, and S.A. Morley. 2001. Effectiveness of large woody debris in stream rehabilitation projects in urban basins. *Ecological Engineering* 18:211–226.

Mainstream Restoration, Inc. 2005. *Middle Rosewood Creek: Geomorphic and Riparian Assessment*. Prepared for Nevada Tahoe Conservation District, Stateline, NV, by Mainstream Restoration, Bozeman, MT.

Micheli, E.R., and J.W. Kirchner. 2002a. Effects of wet meadow riparian vegetation on streambank erosion.1. Remote sensing measurements of streambank migration and erodibility. *Earth Surface Processes and Landforms* 27:627–639.

Micheli, E.R., and J.W. Kirchner 2002b. *Effects of wet meadow riparian vegetation on streambank erosion. 2. Measurements of vegetated bank strength and consequences for failure mechanics*. *Earth Surface Processes and Landforms* 27:687–697.

Micheli, E.R., Kirchner, J.W., and E.W. Larsen. 2004. Quantifying the effect of riparian forest versus agricultural vegetation on river meander migration rates, central Sacramento River, California USA. *River Research and Applications*. 20:537-548.

NRRSS (National River Restoration Science Synthesis). 2006. *Post project appraisals for subset of California node*. <http://nrrss.nbii.gov>. Accessed August 15, 2007.

NRCS (Natural Resource Conservation Service). 2007. Tahoe Basin Area Soil Survey. Natural Resource Conservation Service, South Lake Tahoe, CA. <http://websoilsurvey.nrcs.usda.gov>.

Niezgoda, S.L., and P.A. Johnson. In press. Case study in cost-based risk assessment for selecting a stream restoration design method for a channel relocation project. *Journal of Hydraulic Engineering*, *ASCE*, 133(5).

Nolan, K.M., and B.R. Hill. 1991. *Suspended-Sediment Budgets for Four Drainage Basins Tributary to Lake Tahoe, California and Nevada, 1984-1987*. USGS Water-Resources Investigations Report 91-4054. U.S. Geological Survey.

Palmer, M.A., E.S. Bernhardt, JU.D. Allan, P.S. Lake, G. Alexander, S. Brooks, J. Carr, S. Slayton, C.N. Dahm, S.J. Follstad , D.L. Gallat, S.G. Loss, P. Goodwin, D.D. Hart, B. Hassett, R. Jenkinson, G.M. Kondolf, R. Lave, J.L. Meyer, T.K. O'Donnell, L. Pagano, and E. Sudduth 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology* 42:208–217.

Partheniades E. 1965. Erosion and deposition of cohesive soils, *Journal of Hydraulic Engineering*, 91(1):105–139.

Phillips, Jonathan D. 1989. Fluvial Sediment Storage in Wetlands. Water Resources Bulletin. 25(4):867–873.

Pollen, N., and A. Simon. 2005. Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model. *Water Resources Research* 4:W07025.

Rabidoux, A.A. 2005. Spatial and temporal distribution of fine particles and elemental concentrations in suspended sediments in Lake Tahoe streams, California-Nevada. M.S. Thesis, Department of Civil Engineering, University of California–Davis, Davis, CA.

River Run Consulting. 2006. *Upper Truckee River Restoration Project: California Department of Parks and Recreation Reach, Riparian Ecosystem Restoration Feasibility Report*. Prepared for Lake Tahoe Golf Course and California Department of Parks and Recreation, Sierra District Resource Office., by River Run Consulting, Truckee, CA.

River Run Consulting. 2006. *Final Fisheries Monitoring Report: Trout Creek Stream Restoration and Wildlife Habitat Enhancement Project*. Prepared for City of South Lake Tahoe, South Lake Tahoe, CA, River Run Consulting, Truckee CA.

Rowe, T.G., D.K. Saleh, S.A. Watkins, and C.R. Kratzer. 1998. *Streamflow and Water Quality Data for Selected Watersheds in the Lake Tahoe Basin, California and Nevada, Through September 1998.* USGS Water-Resources Investigations Report 02-4030. Prepared in cooperation with the Lahontan Regional Water Quality Control Board, Tahoe Regional Planning Agency, and University of California–Davis.

Simon, A. 2000. Bank Stability and Toe Erosion Model – Static Version 4.1. USDA-ARS National Sedimentation Laboratory.

Simon, A. 2006. Estimates of fine-sediment loadings to Lake Tahoe from channel and watershed sources. USDA-ARS National Sedimentation Laboratory Research Report No. 52. 59 pp.

Simon A, and A.J.C Collison. 2002. Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes and Landforms* 27(5): 527-546.

Simon A, and A. Curini. 1998. Pore pressure and bank stability: The influence of matric suction. In *Water Resources Engineering '98*, eds. Abt, S.R., Young- Pezeshk J., Watson C.C., pp. 358-363. American Society of Civil Engineers, Reston, VA.

Simon, A., A. Curini, S.E. Darby, and E. Langendoen. 1999. Streambank Mechanics and the Role of Bank and Near-Bank Processes in Incised Channels. In *Incised Channels: Processes, Forms, Engineering, and Management*, eds. S.E. Darby and A. Simon. pp. 123–152. John Wiley & Sons, Chichester.

Simon A, A. Curini, S.E. Darby, and E.J Langendoen. 2000. Bank and near-bank processes in an incised channel. *Geomorphology* 35:183–217.

Simon, A. Langendoen, E., Bingner, R., Wells, R., Heins, A., Jokay, N. and I. Jaramillo. 2003. *Lake Tahoe Basin Framework Implementation Study: Sediment Loadings and Channel Erosion*.

Prepared for U.S. Army Corps of Engineers, Sacramento District and U.S. Department of Agriculture, ARS National Sedimentation Laboratory, Oxford, MS.

Simon, A., N. Pollen, and E. Langendoen. 2006. Influence of two woody riparian species on critical conditions for streambank stability: Upper Truckee River, California. *Journal of the American Water Resources Association (JAWRA)* 42(1):99–113.

Susfalk, R.B. 2006. Impact of the Rosewood Creek Restoration Project on suspended sediment loading to Lake Tahoe: Pre-Monitoring and Year 1. In *Proceedings 8th FISC and 3rd FIHMC Joint Federal Interagency Conference*, April 2-6, 2006 Reno, NV p. 304.

Stubblefield, A.P., M.I. Escobar, and E.W. Larsen. 2005. In press. Retention of suspended sediment and phosphorus on a freshwater delta, South Lake Tahoe, California. Wetlands Ecology and Management. Springer Netherlands.

Swanson Hydrology + Geomorphology. 2007. *Blackwood Creek Restoration Project Technical Memorandum: Phase 3: Conceptual Design of Reach 1 and Reach 6 Projects*. Prepared for U.S. Forest Service, Lake Tahoe Basin Management Unit, South Lake Tahoe, CA, by Swanson Hydrology + Geomorphology, Santa Cruz, CA.

Swanson Hydrology + Geomorphology. 2006. *Edgewood Watershed Assessment and Enhancement Plan: Upper Edgewood Creek Watershed; Heavenly Mountain Resort, California and Nevada*. by Swanson Hydrology + Geomorphology, Santa Cruz, CA.

Swanson Hydrology + Geomorphology. 2004a. *Trout Creek Meadow Restoration, 2001-2003 Geomorphic Monitoring*. Prepared for Russ Wigart, City of South Lake Tahoe, South Lake Tahoe, CA, by Swanson Hydrology + Geomorphology, Santa Cruz, CA.

Swanson Hydrology + Geomorphology. 2004b. *Upper Truckee River: Upper Reach Environmental Assessment, Final Report*. Prepared for the Bureau of Reclamation, Tahoe Resource Conservation District, South Lake Tahoe, CA, and Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA, by Swanson Hydrology + Geomorphology, Santa Cruz, CA.

Swanson Hydrology + Geomorphology. 2003. *Blackwood Creek Stream Restoration Project: Final Design Report*. Prepared for U.S. Forest Service, Lake Tahoe Basin Management Unit. Swanson Hydrology + Geomorphology Santa Cruz, CA, in association with Haen Engineering, Hydroscience, River Run Fisheries and Hydrology, Western Botanical Services, Wildlife Resource Consultants, and Ecosynthesis.

TRCD (Tahoe Resource Conservation District). 2003. *Upper Truckee River Reclamation Project Environmental Assessment, Feasibility Report and Conceptual Plans, Final Report*. Prepared for the U.S. Bureau of Reclamation (City of South Lake Tahoe and El Dorado County), by Tahoe Resource Conservation District, South Lake Tahoe, CA.

The River Restoration Centre. 2002. *Manual of River Restoration Techniques, RRC-Web Edition 2002*. The River Restoration Centre, Silsoe Beds MK45 4DT <http://www.therrc.co.uk/manual.php>. Accessed August 15, 2007.

Thorne, C.R., and N.K.Tovey. 1981. Stability of composite river banks. *Earth Surface Processes and Landforms* 6:469–484

Watson, C.C., D.S. Biedenharn, and S.H. Scott. 1999. *Channel Rehabilitation: Processes, Design, and Implementation*. Prepared for the U.S. Army Corps of Engineers, Research and Development Center, Vicksburg, MS.

Wigart, R. 2003. *Trout Creek Stream Restoration and Wildlife Enhancement Project: Monitoring Progress Report*. Prepared for Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.

6. Combined Results: Load Reduction and Cost Tables

Each of the Source Category Groups (SCGs) has provided information related specifically to its source category. These results have been processed to develop a consistent set of tables that summarize overall Basin-wide results in relation to the total pollutant budget. Complete results for each Setting are presented in two types of tables—*load tables* that combine the estimates of potential fine sediment, phosphorus and nitrogen reductions, and *cost tables* that provide several breakdowns of costs associated with the pollutant controls. This chapter also notes important results that are relevant across all source categories and the Lake Tahoe TMDL as a whole.

The results in this chapter will inform the packaging of PCOs from all sources into several potential Integrated Water Quality Management Strategies (Integrated Strategies) to achieve Basin-wide load reduction goals. Therefore, these results must be seen in the context from which they were estimated. Some of the primary considerations include:

- These results are estimates and are expected to be revised and refined through subsequent research and analyses through a formalized adaptive management and continual improvement process.
- These results assume that each Treatment Tier is applied to 100 percent of its applicable area. When considering Integrated Strategies it is usually possible to apply a Treatment Tier to a percentage of applicable area and achieve a proportional load reduction.
- Results did not consider the potential constraints to immediate implementation of all controls.
- In most cases, the SCGs presented average values that represent the wide ranges of many of their estimates.
- Cost estimates are intended for comparative purposes only; they are not suitable for budgeting purposes.

6.1. Processing of SCG Results & Cost Calculations

In some cases information provided by the SCGs required additional processing to provide consistent and comparable results. These calculations were performed by the SCIC and Tetra Tech Project Team. This section describes the processing done to produce the results presented in this chapter.

Fine sediment loads can be expressed as Total Suspended Solids (TSS), fine sediment mass of less than 63 micron particles or the number of fine sediment particles less than 20 microns. The Lake Tahoe Watershed Model provides results as both TSS and mass of less than 63 micron fine sediment. All fine sediment data provided by the SCGs was provided as the mass of particles less than 63 microns. Because Lake Tahoe TMDL Phase One research showed that the number rather than the mass of fine sediment particles was more closely correlated with Secchi depth readings, all mass-based results were converted to particle numbers. A mass to particle number converter used a unique number of less than 20 micron fine particles per metric ton of less than 63 micron fine sediments for each *source category* to convert from fine sediment mass to number of particles. Stream channel and forest sources contained nearly an order of magnitude less particles per metric ton (4.5 and 8.6 x 10^{15}, respectively) than atmospheric or urban sources (66 and 75 x 10^{15}, respectively). These conversions added additional uncertainty to the fine sediment results.

Scaling factors were required to match the SCG results with the Basin-wide pollutant budget. This scaling allowed each SCG to use the best available information and methodologies from their source category while they performed their estimates. The factors were different for each source category and are presented in Table 6-1.

Table 6-1. SCG baseline to pollutant budget load scaling factors

	Fine Sediment Particles	Total Nitrogen	Total Phosphorus
Atmospheric	1.000	1.000	1.000
Urban & Groundwater	1.561	1.242	1.351
Forested Uplands	1.044	1.044	1.044
Stream Channel	1.043	1.000	1.043

The pollutant reductions provided by the stream channel SCG were adjusted to provide an annual average load reduction that was comparable to the other source category results. The stream channel SCG provided a percent reduction of each pollutant for an *above average* flow year that would not be suitable for *average annual* load reduction estimates. A suitable average annual load reduction was estimated by: (1) the stream channel SCG's percent reductions were multiplied by the stream channel portion of the Lake Tahoe TMDL pollutant budget, (2) these results were then adjusted by each stream's portion of the stream channel source category load. This calculation provided the estimate of annual average loads for each stream that is presented in the load tables of Section 6.4.

Atmospheric results provided as inorganic nitrogen were converted to total nitrogen using a factor of 1.5. This conversion allows atmospheric results to be compared to nitrogen reduction results from other source categories and is consistent with this species conversion in the Lake Tahoe TMDL pollutant budget (Lahontan and NDEP 2007, see citation in Section 2.8).

Atmospheric pollutant reduction opportunities have been subdivided into: 1) non-mobile sources consisting of transportation infrastructure (roads) and stationary source reductions (construction sites) and 2) mobile sources consisting of reductions achieved by reducing vehicle miles traveled. This division is useful because sediment and phosphorus reduction opportunities generally fall into the former category, while nitrogen opportunities fall into the latter. Because fine sediment particles are responsible for two thirds of the clarity decline, it is efficient to target these sources for control. Additionally, the non-mobile source controls are much less expensive than the mobile source controls, particularly for O&M expenses.

Tier 3 urban and groundwater is a composite of the Pump and Treat Tier for all concentrated impervious sub-watersheds, supplemented by Tier 2 PCOs on sub-watersheds with dispersed impervious coverage. This adjustment makes innovative or advanced pollutant controls available for the entire urban area of the Basin, and makes this tier comparable to Tier 1 and Tier 2. There is a 2 percent difference between the total area of the Pump and Treat Tier and the total area of concentrated settings. This minor difference in in the comparable area results in much less than 1 percent difference in potential estimated load reductions.

Three cost calculations were completed after the SCGs had provided their results. All costs are provided in 2007/2008 dollars. Specific calculations included:

- In cases where pollutant controls are not expected to last 20 years, additional capital costs were added at the end of the useful life to represent a recapitalization or repetition of the project. Fractional capital costs were not considered when a capital investment extended beyond the 20 year planning horizon.
- Total 20-year costs were calculated by summing capital investments and 20 years of average annual operations & maintenance (O&M) costs necessary to maintain effectiveness of the PCOs at the efficiency used in load-reduction estimates.
- Cost effectiveness values were also calculated to allow for comparison between the various source categories and Treatment Tiers. Cost effectiveness was calculated by dividing the annual 20 year cost for Basin-wide implementation of the Treatment Tier by each load reduction estimate. No attempt was made to separate the cost to control a particular pollutant because most controls contribute to reductions in more than one pollutant.
- Mobile source atmospheric pollutant control opportunities have the potential to generate revenues from user fees. These revenues are not included in the cost analysis.

6.2. Summary Results

Table 6-4 and Figure 6-1 provide the load reductions as percentages of the entire pollutant budget. These percentages are presented for each source category and Treatment Tier. In general, a single Treatment Tier can be selected from each source category and resulting load reductions can be added to estimate a Basin-wide reduction of pollutants from all source categories. Cost information provides key feedback to determine the potential resource limitations that could constrain implementation of pollutant controls. Table 6-4 presents estimated total costs for a 20-year time frame in millions of 2007/2008 dollars (Million $).

These summary results provide a gross estimate of potential pollutant reductions from Basin-wide application of pollutant controls. These results are helpful in making broad comparisons, but it is important to understand their limitations. There are some subtleties found in the Setting level results, presented in Sections 6.4 and 6.5, that provide necessary insights to inform the formation of Integrated Strategies.

Table 6-2. Summary table of estimated potential load reductions as a percent of the total pollutant budget and 20 year total costs

Source Category and Tier	< 20 micron sediment particle reductions	Phosphorus reductions	Nitrogen reductions	Total 20 year cost (Million $)	20 year capital cost (Million $)	Annual O&M cost (Million $)
Atmospheric[4]						
Tier 2 Non-Mobile	3%	3%	0%	$35	$28	$0
Tier 2 Mobile	0%	0%	5%	$2,900	$280	$130
Tier 2 Sub-total	3%	3%	5%	$2,900	$300	$130
Tier 3 Non-Mobile	7%	8%	1%	$88	$74	$1
Tier 3 Mobile	0%	0%	12%	$7,200	$690	$330
Tier 3 Sub-total	8%	8%	13%	$7,300	$760	$330
Urban & Groundwater						
Tier 1	24%	9%	3%	$1,500	$1,400	$3
Tier 2	40%	15%	9%	$3,200	$2,800	$21
Tier 3	44%	16%	6%	$2,800	$2,500	$15
Forested Uplands						
Tier 1	1%	0%	0%	$320	$193	$6
Tier 2	4%	1%	0%	$1,600	$1,400	$7
Tier 3	7%	2%	0%	$3,200	$3,100	$0
Stream Channel						
Tier 1	2%	1%	N/A	$210	$210	$0
Tier 2	2%	1%	N/A	$50	$51	$0
Tier 3	3%	1%	N/A	$15	$15	$0

Notes:
1. These results are based on the assumption that controls are applied to the maximum applicable area.
2. Columns are not summed because Tiers are not additive. Only one Tier can be selected for each source category.
3. Rows are not summed because each represents a different quantity.
4. Atmospheric pollutant reduction opportunities have been split between 1) non-mobile sources, which consist of transportation infrastructure and stationary source reductions and 2) mobile sources, which consist of reductions from reduced vehicle emissions resulting from reducing vehicle miles traveled.

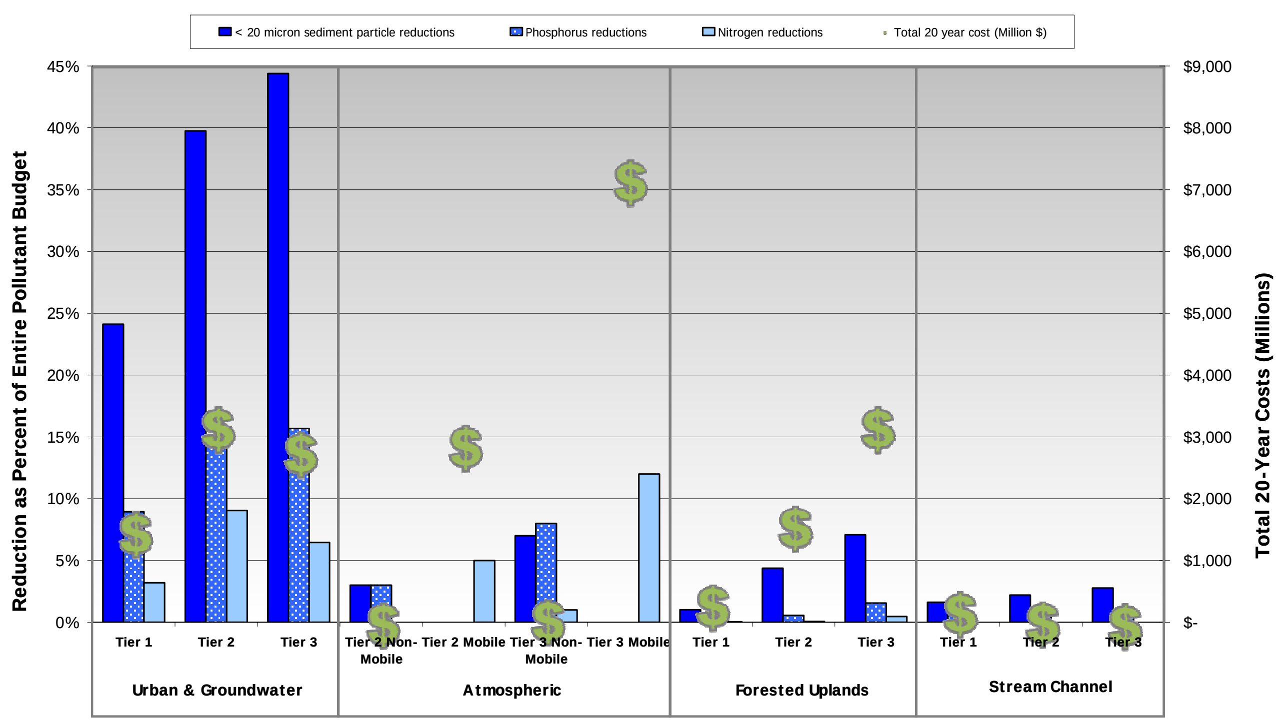


Figure 6-1. Chart of the data presented in Table 6-2. Load reduction percentages are shown on the left axis and total 20 year costs are shown on the right axis.

Load Results

1. Urban and groundwater sources show the largest opportunity to reduce pollutants of concern.
    a. In general, these controls show several times more load reduction potential than other controls for fine sediment particles (36 percent versus 3 percent on average).
    b. Nutrient loads from this source are also controllable to a lesser extent (2-13 percent for phosphorus and 4-6 percent for nitrogen).
2. Atmospheric controls provide the largest opportunity (13 percent) to reduce nitrogen loads and can reduce similar fractions of the fine sediment (8 percent) and phosphorus (8 percent) loads.
3. Forest and Stream Channel sources show some potential for load reductions in fine sediment (1-7 percent), but small potential for reduction of nutrients (0-2 percent).
4. Achieving clarity goals will require implementation of controls in all source categories.

Cost Results

5. Urban and groundwater pollutant controls show 20 year costs ranging from $1.5-3.2 billion. These costs are similar to forest upland costs and higher than costs for other source categories but higher load reduction potentials make urban and groundwater pollutant control relatively cost effective.
6. Forested uplands costs show a broad range ($320 million to $3.1 billion) that corresponds positively with increasing load reductions. The estimates show somewhat lower cost effectiveness than urban and groundwater sources and emphasize the need to focus restoration on high priority areas to make these controls cost competitive.
7. Atmospheric non-mobile pollutant control costs ($35-$88 million) are orders of magnitude less than mobile costs ($2.9 to $7.2 billion).
8. Stream channel costs are lower for higher numbered Treatment Tiers, unlike other source categories. This is because Tier 3 controls involve basic bank hardening that is inexpensive and effective for reducing channel loads. However, this analysis did not include the potential treatment of upland loads being transported by the stream. Tier 1 restorations are considered likely to provide water quality benefits by allowing sedimentation in flood plains, as well as other benefits such as flood control and enhanced riparian habitat. Thus, these results could be adjusted upward in the future as tools for estimating all benefits are fully developed.

6.3. Setting and Treatment Tier Review

Each SCG provided in-depth descriptions of its Tiers and Settings in its respective chapter. For easy reference, the Setting and Tier definitions are summarized here. These summaries will assist the reader when interpreting the results tables.

Table 6-3. Summary of Treatment Tiers for each source category

Treatment Tier name	Summary definition
Atmospheric	
Tier 1	A baseline of existing loading from which to compare. This source category was different than others because this *Tier* does not result in load reductions.
Tier 2	A set of PCOs that is deemed effective and particularly cost effective. Numeric estimates are based on average literature values.
Tier 3	A set of PCOs deemed more effective and difficult to implement. Estimates based on literature values that were the most favorable for load reduction.
Urban & Groundwater	
Tier 1	An upper-end use of existing practices and technologies. Spatial application within the treatment area considers typical site and funding constraints. Assumes 50% completion of residential best management practices (BMPs).
Tier 2	A significantly higher-use, advanced, gravity-driven treatment technologies applied more aggressively within the treatment area. Traditional limitations on property acquisition and maintenance rates are relaxed in this Tier. Assumes 100% completion of residential BMPs.
Tier 3	A composite of pumping and centralized treatment systems for concentrated settings (both moderate and steep) and Tier 2 treatments for dispersed settings (both moderate and steep).
Forested Uplands	
Tier 1	Includes *standard* treatments used or required by management agencies in current practice.
Tier 2	A middle level of treatment that includes *state-of-the-art* practices designed to achieve *functional* rehabilitation of hydrologic properties.
Tier 3	Treatments designed to develop site conditions that will mimic undisturbed, *natural* conditions after a period of time. This Tier represents the maximum load reduction possible in the Setting.

Table 6-4. Summary of Treatment Settings for each source category

Setting name	Definition
Atmospheric Settings	
Setting 1	The entire band of land less than 0.2 kilometer from the Lake. Pollutant emissions from this Setting will reach the Lake most readily.
Setting 2	The entire band of land less than 1 kilometer from the Lake (includes Setting 1).
Setting 3	The entire band of land less than 3 kilometers from the Lake (includes Settings 1 & 2)
Setting 4	The entire Lake Tahoe Basin (includes Settings 1, 2, & 3)
Urban and Groundwater Settings	
Concentrated – Steep	Areas where impervious coverage is relatively concentrated and there is minimal space for PCOs to be constructed. Average slope of the area is *greater than* 10%.
Concentrated – Moderate	Areas where impervious coverage is relatively concentrated and there is minimal space for PCOs to be constructed. Average slope of the area is *less than* 10%.
Dispersed – Steep	Areas where impervious coverage is relatively dispersed and there is adequate area for PCOs to be constructed among the impervious coverage or downhill from it. Average slope of the area is *greater than* 10%
Dispersed – Moderate	Areas where impervious coverage is relatively dispersed, and there is adequate area for PCOs to be constructed among the impervious coverage or downhill from it. Average slope of the area is *less than* 10%.
Forested Uplands Settings	
Setting A	Highly disturbed areas with significant compaction such as unpaved roads.
Setting B	Areas subject to major soil disturbance such as ski runs, campgrounds, and steep bare slopes. These areas are characterized by moderate vegetative cover, little mulch or duff, and low-infiltration capacity.
Setting C	Typical Tahoe forested areas that are managed for forest health and defensible space. These areas are characterized by well-established plant communities, thick duff layers and high soil-hydrologic function. The large majority of the Basin land area falls into Setting C.
Stream Channel Settings	
Upper Truckee River	The entire restorable channel of the Upper Truckee River.
Blackwood Creek	The entire restorable channel of Blackwood Creek.
Ward Creek	The entire restorable channel of Ward Creek.

6.4. Load Reduction Tables

The SCGs estimated potential load reduction information for application of all Tiers to each Setting. These results can facilitate a more detailed understanding of the intricacies of estimating Basin-wide loads and inform the development of Integrated Strategies. Tables are presented for each pollutant of concern including:

- Fine Sediment
- Phosphorus
- Nitrogen

Fine Sediment

Findings presented in the Lake Tahoe TMDL Technical Report estimate that light scattering by fine sediment particles contributed greater than 55 to 60 percent of total light attenuation (Lahontan and NDEP 2007, see citation in Section 2.8). Fine sediment load reductions are presented by number of particles less than 20 microns per year because this variable is a better predictor of clarity effects than the mass of fine sediment. The particle counts are extremely large numbers and are presented as 10^{18} particles smaller than 20 microns in diameter. The pollutant budget estimate for total fine particles to Lake Tahoe is 481 x 10^{18} (Lahontan and NDEP 2007, see citation in Section 2.8).

Table 6-5. Estimated potential fine sediment particle load reductions

	< 20 micron sediment particle reductions by setting ($x10^{18}$ Particles/year)				
Atmospheric	**Setting 1**	**Setting 2**	**Setting 3**	**Setting 4**	**Basin-wide**
Tier 2 Non-Mobile	3.6	8.7	12	14	14
Tier 2 Mobile	0.12	0.29	0.39	0.46	0.46
Tier 2 Sub-total	3.7	9.0	12	15	15
Tier 3 Non-Mobile	8.00	22	31	36	36
Tier 3 Mobile	0.25	0.69	0.97	1.1	1.1
Tier 3 Sub-total	8.3	23	32	37	37
Urban & Groundwater	**Conc.-Steep**	**Conc.-Moderate**	**Disp.-Steep**	**Disp.-Moderate**	**Basin-wide**
Tier 1	27	57	15	17	116
Tier 2	38	93	26	34	191
Tier 3	58	95	26	34	213
Forested Uplands	**Setting A**	**Setting B**	**Setting C**		**Basin-wide**
Tier 1	1.0	3.9	0		4.9
Tier 2	1.1	4.2	16		21
Tier 3	1.1	4.3	29		34
Stream Channel	**Blackwood Ck.**	**Upper Truckee**	**Ward Ck.**		**Total**
Tier 1	1.6	5.3	0.89		7.8
Tier 2	2.5	6.5	1.5		11
Tier 3	3.2	8.3	1.8		13

Notes:

1. Atmospheric pollutant reduction opportunities have been split between 1) non-mobile sources, which consist of transportation infrastructure and stationary source reductions and 2) mobile sources, which consist of reductions from reduced vehicle emissions resulting from reducing vehicle miles traveled.

2. Totals are calculated using all available figures, however, rounding may result in some totals not summing to the exact amount shown.

Results

1. Urban and groundwater sources show the greatest potential for fine sediment load reduction. These initial results show that treatments to urban Settings with concentrated impervious coverage have significantly higher load reduction potential than moderate slopes with dispersed impervious coverage.
2. Restoration to undisturbed conditions of typical forested lands has the potential to achieve significant fine sediment pollutant load reductions. The estimates show more than an order of magnitude more potential for the undeveloped forested areas (Setting C) than for unpaved roads (Setting A), but this is because unpaved roads represent only 0.2 percent of the undeveloped forest areas.7

[7] The forested upland SCG developed scaling factors to optimize loading estimates for sediment to closely match the Watershed Model's sediment load estimates for each sub-watershed. From this, regression equations derived from extensive field research were used to estimate the percent silt and clay associated with a given sediment load. This method for estimating silt and clay as a percentage of Total Suspended Sediment differed from the approach that was employed to develop the current pollutant load budget from the Lake Tahoe TMDL Technical Report. This explains why Tier 3 load reduction estimated by the forested upland SCG is slightly higher (48 vs. 41 $x10^{18}$ particles) than the pollutant budget.

3. Atmospheric sediment load reductions opportunities are nearly completely attributable to non-mobile sources. Potential atmospheric sediment load reductions are less than 1/3 of those available through urban & groundwater sources, but still significant. The atmospheric load reduction potential for the entire Basin is approximately four times greater than the areas < 200 meters from the Lake (Setting 1).
4. Stream channel load reduction potential is approximately five times larger for the Upper Truckee River than Ward Creek.

Phosphorus

Efforts from Phase One of the Lake Tahoe TMDL showed that primary productivity is predominantly phosphorus limited (Lahontan and NDEP 2007, see citation in Section 2.8). The pollutant budget estimate for phosphorus loading to Lake Tahoe is 46 metric tons per year (Lahontan and NDEP 2007, see citation in Section 2.8). **Error! Reference source not found.**6 presents the estimated potential for load reductions in metric tons per year. A Basin-wide total is displayed on the right side of the table.

Table 6-6. Estimated potential phosphorus load reductions for all source categories and Settings

	Phosphorus Load Reductions by Setting (Metric Tons/Year)				
Atmospheric	**Setting 1**	**Setting 2**	**Setting 3**	**Setting 4**	**Basin-wide**
Tier 2 Non-Mobile	0.35	0.87	1.2	1.5	1.5
Tier 2 Mobile	0.00	0.00	0.00	0.00	0.00
Tier 2 Sub-total	0.35	0.87	1.2	1.5	1.5
Tier 3 Non-Mobile	0.78	2.2	3.1	3.7	3.7
Tier 3 Mobile	0.00	0.00	0.00	0.00	0.00
Tier 3 Sub-total	0.78	2.2	3.1	3.7	3.7
Urban & Groundwater	**Conc.-Steep**	**Conc.-Moderate**	**Disp.-Steep**	**Disp.-Moderate**	**Basin-wide**
Tier 1	1.2	1.7	0.66	0.55	4.1
Tier 2	1.1	2.9	1.6	1.3	6.9
Tier 3	1.6	2.7	1.6	1.3	7.2
Forested Uplands	**Setting A**	**Setting B**	**Setting C**		**Basin-wide**
Tier 1	0.16	0.02	0.00		0.18
Tier 2	0.19	0.04	0.03		0.26
Tier 3	0.27	0.13	0.34		0.74
Stream Channel	**Blackwood Ck.**	**Upper Truckee**	**Ward Ck.**		**Total**
Tier 1	0.06	0.18	0.03		0.27
Tier 2	0.09	0.22	0.05		0.36
Tier 3	0.11	0.28	0.06		0.45

Note: Totals are calculated using all available figures, however, rounding may result in some totals not summing to the exact amount shown.

Results

1. Urban and groundwater sources show the greatest potential for load reductions. Concentrated coverage moderate sloped Settings show twice the potential reductions of other Settings.
2. Atmospheric sources provide some potential for controlling phosphorus loads, but only approximately half of the potential shown by urban and groundwater sources. All atmospheric reductions are attributable to non-mobile controls.
3. Forested and stream channel sources show limited potential for phosphorus control. Even with the most aggressive forested uplands and stream channel Treatment Tiers, reductions are approximately an order of magnitude lower than urban and groundwater, and atmospheric sources.
4. Urban surface water pollutant controls are estimated to reduce dissolved phosphorus loads to groundwater by up to 0.87 metric tons per year in the Tier 2 analysis. These potential load reductions are not included in the table above because loads to groundwater do not directly

translate into load reductions to the lake, and inputs to groundwater can take many years to affect pollutant inputs to Lake Tahoe.

Nitrogen

Although Nitrogen is not the primary limiting nutrient, there are annual periods where this nutrient co-limits the phytoplankton growth in Lake Tahoe. Most importantly, when nitrogen and phosphorus are added in combination, algal growth was significantly higher in all the individual experiments. Consequently, the control of both nitrogen and phosphorus is important (Lahontan and NDEP 2007, see citation in Section 2.8). The pollutant budget estimate for nitrogen loading to Lake Tahoe is 397 metric tons per year (Lahontan and NDEP 2007, see citation in Section 2.8). **Error! Reference source not found.**7 displays estimates of potential load reductions by Setting and Treatment Tier. Basin-wide totals are shown on the right-most column.

Table 6-7. Estimated potential nitrogen load reductions for all source categories and Settings

	Nitrogen Load Reductions by Setting (Metric Tons/Year)				
Atmospheric	**Setting 1**	**Setting 2**	**Setting 3**	**Setting 4**	**Basin-wide**
Tier 2 Non-Mobile	0.5	0.8	1.1	1.4	1.4
Tier 2 Mobile	7.4	12	15	19	19
Tier 2 Sub-total	8.0	13	17	20	20
Tier 3 Non-Mobile	1.3	2.1	2.7	3.3	3.3
Tier 3 Mobile	18	29	38	47	47
Tier 3 Sub-total	20	32	41	50	50
Urban & Groundwater	**Conc.-Steep**	**Conc.-Moderate**	**Disp.-Steep**	**Disp.-Moderate**	**Basin-wide**
Tier 1	2.8	6.5	1.5	1.9	13
Tier 2	8.0	16	6.2	6.1	36
Tier 3	4.6	8.6	6.2	6.1	25.5
Forested Uplands	**Setting A**	**Setting B**	**Setting C**		**Basin-wide**
Tier 1	0.13	0.03	0		0.16
Tier 2	0.15	0.04	0.05		0.24
Tier 3	0.23	0.17	1.6		2.0
Stream Channel	**Blackwood Ck.**	**Upper Truckee**	**Ward Ck.**		**Total**
Tier 1	N/A	N/A	N/A		N/A
Tier 2	N/A	N/A	N/A		N/A
Tier 3	N/A	N/A	N/A		N/A

Note: Totals are calculated using all available figures, however, rounding may result in some totals not summing to the exact amount shown.

Results

1. Atmospheric mobile sources and urban and groundwater sources show the greatest potential for nitrogen load reduction.
2. Tier 3 atmospheric controls are more than twice as effective as the Tier 2 controls. More than one-third of the potential load reductions for atmospheric sources are available within 200 meters of the Lake.
3. Within urban and groundwater sources, concentrated impervious coverage areas show greater potential for load reductions than dispersed impervious coverage areas.
4. Forested Settings show nitrogen reductions one to three orders of magnitude lower than other source categories. These results are considered by the SCIC and forested uplands SCG to be especially conservative. Future efforts are expected to reveal larger potential load reductions of nitrogen from the forested uplands.
5. Urban surface water pollutant controls are estimated to reduce dissolved nitrogen loads to groundwater by up to two metric tons per year in the Tier 2 analysis. These potential load reductions are not included in the table above because loads to groundwater do not directly

translate into load reductions to the lake, and inputs to groundwater can take many years affect pollutant inputs to Lake Tahoe.

6.5. Cost Tables

Cost information provides key feedback to determine the potential resource limitations that could constrain implementation of pollutant controls. Cost can also be a significant determiner of public acceptability for pollutant controls. SCGs estimated the associated costs of applying appropriate Treatment Tiers to each Setting. Basin-wide totals are also provided for each Treatment Tier. For the atmospheric controls, the Basin-wide column repeats the information presented for Setting 4 because this setting represents the entire Basin. Tables are presented and interpreted for:

- Total 20 Year Cost
- Capital Costs
- O&M Costs
- Cost Effectiveness

Total 20 Year Costs

Overall costs for a typical 20 planning horizon are a common way to evaluate capital improvement project costs. Table 6-8 presents estimated total costs to install, operate and maintain pollutant controls for a 20-year time frame. Specific consideration of the capital and O&M costs is provided in the two following sections.

Table 6-8. Estimated total 20-year costs of pollutant controls including capital investment and O&M cost

		Total 20 Year Cost (Millions $)			
Atmospheric	**Setting 1**	**Setting 2**	**Setting 3**	**Setting 4**	**Basin-wide**
Tier 2 Non-Mobile	$8.6	$19	$27	$35	$35
Tier 2 Mobile	$710	$1,500	$2,200	$2,900	$2,900
Tier 2 Sub-total	$720	$1,600	$2,200	$2,900	$2,900
Tier 3 Non-Mobile	$22	$48	$68	$88	$88
Tier 3 Mobile	$1,800	$3,900	$5,600	$7,200	$7,200
Tier 3 Sub-total	$1,800	$3,900	$5,600	$7,300	$7,300
Urban & Groundwater	**Conc.-Steep**	**Conc.-Moderate**	**Disp.-Steep**	**Disp.-Moderate**	**Basin-wide**
Tier 1	$520	$630	$240	$120	$1,500
Tier 2	$950	$1,300	$560	$360	$3,200
Tier 3	$850	$1,100	$560	$360	$2,870
Forested Uplands	**Setting A**	**Setting B**	**Setting C**		**Basin-wide**
Tier 1	$27	$130	$160		$320
Tier 2	$35	$140	$1,400		$1,600
Tier 3	$37	$200	$2,900		$3,100
Stream Channel	**Blackwood Ck.**	**Upper Truckee**	**Ward Ck.**		**Total**
Tier 1	$52	$140	$22		$210
Tier 2	$14	$30	$6.5		$51
Tier 3	$4.9	$8.0	$2.2		$15

Notes:

1. Atmospheric pollutant reduction opportunities have been split between 1) non-mobile sources, which consist of transportation infrastructure and stationary source reductions and 2) mobile sources, which consist of reductions from reduced vehicle emissions resulting from reducing vehicle miles traveled.
2. Totals are calculated using all available figures, however, rounding may result in some totals not summing to the exact amount shown.

Results

1. Annualized costs of Tier 1 and 2 controls in dispersed coverage urban Settings are less than half of the costs for concentrated coverage urban Settings.

2. Forested upland controls are more than an order of magnitude more expensive in low-disturbance, forested areas than for compacted, high-disturbance areas such as ski runs, campgrounds, and bare slopes. This is because of the great aerial extent of the forested areas.
3. Atmospheric PCOs analyzed by the SCG included revenue generating transit programs. Atmospheric cost results presented do not include the potential revenue that could be generated through VMT reduction incentives. This makes these results more comparable to other source categories.. Treatments for atmospheric mobile sources are significantly more expensive than controls for non-mobile sources.
4. Pollutant controls for ski runs, campgrounds and bare slopes (forested uplands Setting B) are roughly five times more expensive than unpaved road controls (forested uplands Setting A). However, these costs are only about 20% higher on a per acre basis.
5. Pollutant controls on stream channel source are related to the size of the watershed. Pollutant controls on Ward Creek are about half of the cost of controls on Blackwood Creek. Pollutant controls on Blackwood Creek are about half of the cost of controls on the Upper Truckee River.
6. Stream channel costs are lower for higher numbered Treatment Tiers, unlike other source categories. This situation arises because Tier 3 controls involve basic bank hardening that is inexpensive and effective for reducing channel loads. However, this analysis did not analyze the potential treatment of upland loads being transported by the stream. Tier 1 restorations are considered likely to provide these benefits. These restorations also provide other important benefits such as flood control and enhanced riparian habitat. Thus, these results may be adjusted significantly in the future as tools for estimating all benefits are developed.
7. In some instances, atmospheric PCOs overlap with Urban and Forest PCOs. As a result, Integrated Strategies that employ both atmospheric and urban or forest controls will include some double counting of costs. Integrated strategies that do not employ both atmospheric controls, but do employ urban or forest controls will not account for the associated atmospheric pollutant reductions. Examples of such overlap include:
    - Paved roads where the atmospheric group estimated the total costs of street sweeping and the urban and groundwater group estimated the cost of PSC-1 which includes street sweeping/vacuuming.
    - Unpaved roads where atmospheric dust control strategies could potentially overlap forested uplands particulate runoff controls.

Capital Costs

Capital costs are often covered by different funding sources than O&M costs because State and Federal funding is frequently available for capital improvements. Table 6-9 presents estimated capital costs for a 20-year time frame in 2007/2008 equivalent dollars.

Table 6-9. Estimated capital costs over 20-years

	20 Year Capital Cost (Millions $)				
Atmospheric	**Setting 1**	**Setting 2**	**Setting 3**	**Setting 4**	**Basin-wide**
Tier 2 Non-Mobile	$6.9	$15	$22	$28	$28
Tier 2 Mobile	$68	$150	$210	$280	$280
Tier 2 Sub-total	$75	$160	$230	$300	$300
Tier 3 Non-Mobile	$18	$40	$57	$74	$74
Tier 3 Mobile	$170	$370	$530	$690	$690
Tier 3 Sub-total	$190	$410	$590	$760	$760
Urban & Groundwater	**Conc.-Steep**	**Conc.-Moderate**	**Disp.-Steep**	**Disp.-Moderate**	**Basin-wide**
Tier 1	$500	$600	$230	$110	$1,400
Tier 2	$830	$1,200	$490	$310	$2,800
Tier 3	$770	$950	$490	$310	$2,500
Forested Uplands	**Setting A**	**Setting B**	**Setting C**		**Basin-wide**
Tier 1	$5.4	$28.0	$160		$193
Tier 2	$8.1	$30	$1,400		$1,400
Tier 3	$37	$200	$2,900		$3,100
Stream Channel	**Blackwood Ck.**	**Upper Truckee**	**Ward Ck.**		**Total**
Tier 1	$52	$140	$22		$210
Tier 2	$14	$30	$6.5		$51
Tier 3	$4.9	$8.0	$2.2		$15

Totals are calculated using all available figures, however, rounding may result in some totals not summing to the exact amount shown.

Results

1. Stream channel pollutant controls show the lowest capital costs. They are up to two orders of magnitude lower than urban and groundwater capital costs.
2. Urban and groundwater and forest controls show the highest capital costs. Urban and groundwater controls in concentrated impervious coverage Settings show 2-6 times higher costs than dispersed impervious coverage Settings.
3. The high ratio of undisturbed forest area (Setting C) to other forested Settings is evident in the high capital costs for this Setting.
4. Tier 1 capital costs for forested uplands are an order of magnitude less expensive than Tier 2 and 3 costs.
5. Like the 20 year total costs presented in Table 6-8, stream channel capital costs follow a trend opposite to other source categories and the same discussion applies.
6. Atmospheric capital costs for controls on mobile sources are roughly ten times the capital costs for non-mobile sources.

O & M Costs

O&M costs are of great interest to project implementers and local governments because these costs are usually funded locally. This cost category can determine both acceptability of the control and design of a project. Table 6-10 presents average annual O&M costs that include all requirements to maintain effectiveness of the PCOs at the efficiency used in load-reduction estimates for the expected life of the project.

Table 6-10. Estimated average annual O&M costs

	Average Annual O&M Cost (Millions $)				
Atmospheric	**Setting 1**	**Setting 2**	**Setting 3**	**Setting 4**	**Basin-wide**
Tier 2 Non-Mobile	$0.08	$0.18	$0.26	$0.34	$0.34
Tier 2 Mobile	$32	$70	$100	$130	$130
Tier 2 Sub-total	$32	$70	$100	$130	$130
Tier 3 Non-Mobile	$0.17	$0.38	$0.54	$0.70	$0.70
Tier 3 Mobile	$80	$180	$250.0	$330.0	$330
Tier 3 Sub-total	$81	$180	$250.0	$330.0	$330
Urban & Groundwater	**Conc.-Steep**	**Conc.-Moderate**	**Disp.-Steep**	**Disp.-Moderate**	**Basin-wide**
Tier 1	$1.0	$1.2	$0.47	$0.23	$2.9
Tier 2	$6.3	$8.9	$3.7	$2.4	$21
Tier 3	$4.1	$5.0	$3.7	$2.4	$15
Forested Uplands	**Setting A**	**Setting B**	**Setting C**		**Basin-wide**
Tier 1	$1.1	$5.3	$0.00		$6.4
Tier 2	$1.4	$5.6	$0.00		$7.0
Tier 3	$0.00	$0.00	$0.00		$0.00
Stream Channel	**Blackwood Ck.**	**Upper Truckee**	**Ward Ck.**		**Total**
Tier 1	$0.00	$0.00	$0.00		$0.00
Tier 2	$0.00	$0.00	$0.00		$0.00
Tier 3	$0.00	$0.00	$0.00		$0.00

Totals are calculated using all available figures, however, rounding may result in some totals not summing to the exact amount shown.

Results

1. Annual O&M costs for urban & groundwater dispersed impervious coverage Settings are 2-10 times lower than concentrated impervious coverage Settings.
2. Stream channel treatments and Tier 3 forested uplands treatments do not require O&M because these Treatment Tiers seek to restore natural, self-sustaining processes.
3. Atmospheric cost results do not include the potential revenue that could be generated through VMT reduction incentives. Non-mobile source O&M control costs are orders of magnitude lower than mobile source O&M control costs.

Cost Effectiveness

Cost-effectiveness information can provide guidance as to the least expensive approach to reduce a particular pollutant load. The information presented in Table 6-11 is a simple division of the annual 20 year cost for Basin-wide implementation of the Treatment Tier by each load reduction estimate. No attempt has been made to separate the cost to control a particular pollutant because most controls contribute to reductions in more than one pollutant. This analysis makes it possible to compare results between differing source categories or Treatment Tiers (columns) but not between the differing pollutants (rows).

Table 6-11. Cost effectiveness by pollutant and Treatment Tier

	< 20 micron sediment reductions (Million $/10^18 Particles)	Phosphorus reductions (Million $/MT)	Nitrogen reductions (Million $/MT)	Fine sediment reductions (Million $/MT)
Atmospheric				
Tier 2 Non-Mobile	$0.12	$1.2	$1.2	$0.01
Tier 2 Mobile	$310	N/A	$7.6	$21
Tier 2 Sub-total	$9.7	$97	$7.3	$0.66
Tier 3 Non-Mobile	$0.12	$1.2	$1.3	$0.01
Tier 3 Mobile	$330	N/A	$7.7	$21
Tier 3 Sub-total	$9.8	$98	$7.3	$0.65
Urban & Groundwater				
Tier 1	$0.65	$18	$6.0	$0.08
Tier 2	$0.84	$23	$4.5	$0.10
Tier 3	$0.66	$20	$5.5	$0.05
Forested Uplands				
Tier 1	$3.3	$91	$110	$0.03
Tier 2	$3.7	$300	$340	$0.03
Tier 3	$4.6	$220	$84	$0.04
Stream Channel				
Tier 1	$1.3	$39	N/A	$0.01
Tier 2	$0.24	$6.9	N/A	$0.00
Tier 3	$0.06	$1.7	N/A	$0.00

Notes:

1. Values generated by dividing the annual average of the total 20 year cost for the tier by each pollutant's annual load reduction.
2. Cost figures provide relative cost comparisons and are not suitable for long term budgeting purposes.
3. N/A used when no load reduction is estimated.
4. Totals are calculated using all available figures, however, rounding may result in some totals not summing to the exact amount shown.

Results

1. Atmospheric cost results do not include the potential revenue that could be generated through VMT reduction incentives.
2. Stream channel controls show the greatest cost effectiveness for removal of fine sediment, but these controls do not provide a large amount of potential load reduction.
3. Urban and groundwater sources show good cost effectiveness for reducing fine sediment and provide a large potential to remove this pollutant.
4. Nitrogen reductions from atmospheric controls are the most cost effective. These controls can also provide a large amount of nitrogen reduction.

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7. Next Step and Schedule

The results of this report will form the basis for discussion during the Lake Tahoe TMDL 2007 Public Participation Series. The input provided during this series of workshops and meetings will help to craft the most acceptable approach to pollutant load reductions. This input will guide decision makers from the Lake Tahoe TMDL agencies as they select an integrated package of pollutant controls; effectively answering the question, "**What strategy should we implement to reduce pollutant inputs to Lake Tahoe?"** The selected Integrated Water Quality Management Strategy (Integrated Strategy) will be the basis for load allocations that will be incorporated into the planning documents used by Tahoe Basin agencies.

In a similar time frame, implementation and monitoring plans will be developed. The implementation plan will provide additional detail about the process that will achieve necessary load reductions. The monitoring plan will describe how to measure the load-reduction effects of projects and programs. It will also lay out the continual improvement and adaptive management plan for the Lake Tahoe TMDL. All these elements will be incorporated into the Final TMDL.

Table 7-1. Lake Tahoe Lake Tahoe TMDL synopsis with next steps highlighted

TMDL phase	Questions	Products
Phase One— Pollutant Capacity and Existing Inputs	**What pollutants are causing Lake Tahoe's clarity loss?**	Research and analysis of fine sediment, nutrients and meteorology
	How much of each pollutant is reaching Lake Tahoe?	Existing pollutant load to Lake Tahoe from major sources
	How much of each pollutant can Lake Tahoe accept and still achieve the clarity goal?	Linkage analysis and determination of needed pollutant load reduction
		Document: TMDL Technical Report
Phase Two— Pollutant Reduction Analysis and Planning	**What are the options for reducing pollutant inputs to Lake Tahoe?**	Estimates of potential pollutant load reduction opportunities **Document:** Lake Tahoe TMDL Pollutant Reduction Opportunity Report
	What strategy should we implement to reduce pollutant inputs to Lake Tahoe?	Integrated Strategies to control pollutants from all sources
		Load reduction allocations and implementation milestones
		Implementation and Monitoring Plans
		Document: Final TMDL
Phase Three— Implementation and Operation	**Are the expected reductions of each pollutant to Lake Tahoe being achieved?**	Implemented projects & tracked load reductions
	Is the clarity of Lake Tahoe improving in response to actions to reduce pollutants?	Project effectiveness and environmental status monitoring
	Can innovation and new information improve our strategy to reduce pollutants?	Lake Tahoe TMDL continual improvement and adaptive management system, targeted research
		Document: Periodic Milestone Reports

Additional overview information about other steps in Phases Two and Three are available in an overview document entitled *Charting a Course to Clarity: The Lake Tahoe TMDL*, available on the Lahontan Web site (http://www.waterboards.ca.gov/lahontan/TMDL/Tahoe/Tahoe_Index.htm).

7.1. Lake Tahoe TMDL Schedule

Phase One was completed in August of 2007 with the release of the Technical report. Phase Two has been active since June of 2006 and completes its first major step with the release of this report. Information in this report will be used in a public process to provide input to form Integrated Strategies for load reductions through December 2007. This input will inform selection of load allocations and establishment of milestones in the spring of 2008. The spring of 2008 will also see parallel development of the implementation and monitoring plans. All the elements of the Lake Tahoe TMDL will be combined into a Final TMDL in the fall of 2008, ending Phase Two.

Phase Three will begin following the release of the Final TMDL and will continue until load-reduction targets are achieved. Although regular, periodic milestones are expected, the implementation and operation phase is expected to occur over long time frames within the range of 20–100 years.

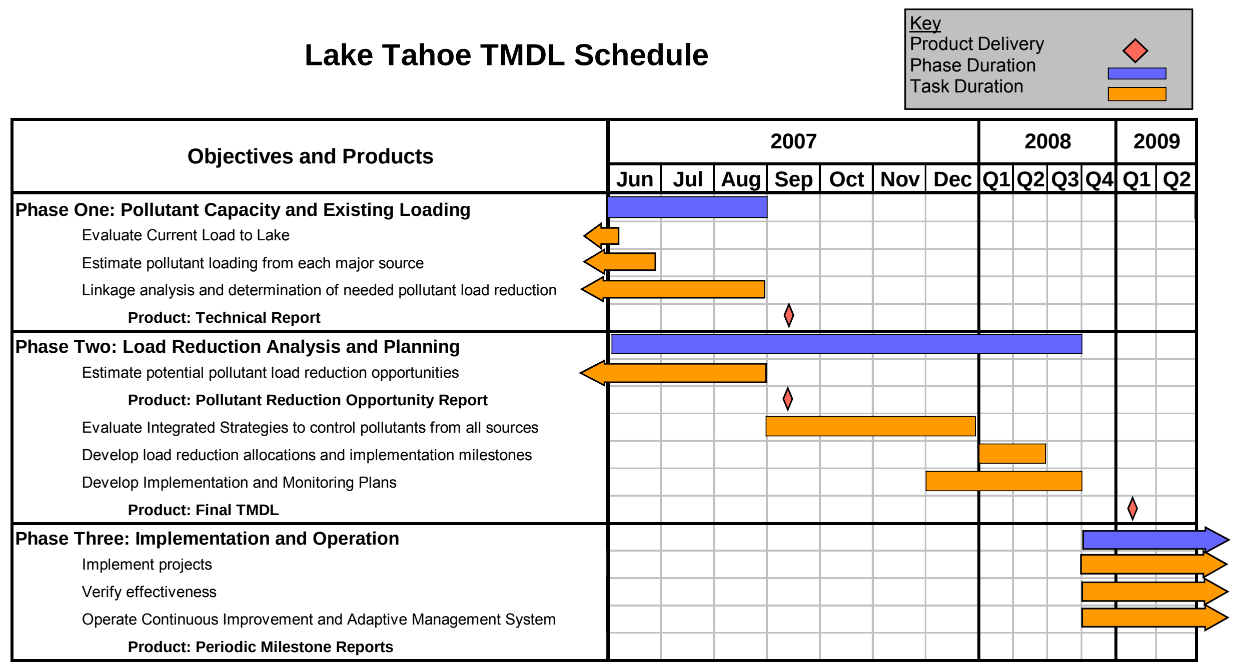

Figure 7-1. Gantt chart of the Lake Tahoe TMDL development process.

8. Glossary

Aerodynamic particle size. The diameter of a sphere of unit density, which behaves aerodynamically as a particle with different sizes, shapes, and densities.

Annualized cost of control. The average yearly costs of a control system including annual operating costs such as labor, materials, utilities and maintenance items, and annualized costs of the capital costs of control equipment purchase and installation.

Areal extent. The fraction (or percentage) of the source area that is affected by the control measure.

Bank Toe. The lower portion of a streambank, which is typically at the break in slope between the bank and the channel bed.

Basin. Refers to the Lake Tahoe Basin including its watershed and airshed.

Bio-Technical. Treatment measures that emphasize the use of biologic materials (either living or nonliving) to stabilize geologic surfaces (e.g., streambanks, hillslopes).

Capital Recovery Factor (CRF). The amount of money per dollar of investment in control equipment required to pay annual interest costs on unrecovered investment and to recover the costs of the investment in a specified number of years at the given interest rate.

Capture Fraction (CF). The fraction of a source's mass emissions captured by vegetation (or other surface obstruction).

Channel Incision. Process of streambed lowering that increases bank heights and reduces floodplain connectivity; which can result from several driving forces.

Cohesive Materials. Geologic/soil materials that resist erosion through electrochemical bonds between the particle (fine silts and clays).

Control efficiency. The degree (e.g., percentage) to which a control measure is effective in limiting the release of a pollutant.

Control extent. The fraction of emissions from a source category that would be affected by a control method.

Cost-effectiveness. Control cost divided by the mass of emissions reduced (most typically expressed in terms of *dollars per ton*).

Current Practice. A set of techniques or pollutant controls that have been commonly applied to areas of Lake Tahoe.

Deposition. Accumulation of airborne particles on ground-level surfaces through gravitational settling and other physical phenomena.

Deterministic Model. Mathematical model of natural physical (or biological) processes that uses parameters governed by defined conditions, relationships, and transformations (that can be validated with field or laboratory data) to predict outcomes.

Disturbance. Destabilization of a land surface from its undisturbed, natural condition thereby increasing the potential for fugitive dust emissions.

Drastic disturbance. Described areas where the native vegetation and animal communities have been removed and most of the topsoil is lost, altered, or buried (Schaller and Sutton 1978).

Dust. Fine, dry particles of matter able to be suspended in the air.

Economic Life. The length of time during which a product can be put to profitable use.

Emission activity level. A numerical measure of the intensity of a process that emits pollutants (e.g., miles traveled by a vehicle). Also referred to as source extent or process rate.

Emission factor. A representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant.

Emission parameters. Values that affect pollutant emissions, such as moisture level and silt content of the emitting material.

Floodplain Connectivity. Geomorphic condition where the channel dimensions, slope and streambank heights are such that the floodplain surface adjoining the channel experiences overbanking on a regular frequency (e.g., every year or two in most regions).

Floodplain. Relatively level or gently sloping land adjoining a stream that is subject to overbank flow during relatively large hydrologic (storm) events; if it is an *active* floodplain, it can have shallow water inundation for several days every couple of years; but floodplains can also be areas that only rarely have inundation—perhaps only a few days every several years.

F-Tables. Volume-discharge relationships used in the Watershed Model

Fugitive dust. Airborne particles where the emissions cannot reasonably be passed through a stack, chimney, vent, or other functionally equivalent opening; one component of fine sediment from atmospheric sources (the other component being elemental carbon).

Geo-Technical. Treatment measures that emphasize geologic and manufactured materials to stabilize geologic surfaces (streambanks, streambeds, hillslopes, and the like)

Grade Control. Treatment measures that stabilize a streambed, to protect against changes in channel slope (or grade).

Hot Spot. Location with severe erosion of stream banks or adjoining side slope.

Hydraulic Erosion. Bank erosion process driven by the force of flowing water against the bank materials.

Hydrograph. Variation of water flow or elevation over time; can be expressed over a range of time units (hourly, daily, event, or annual).

Hydrologic source controls (HSC). These reduce runoff by retaining or providing for the processes of interception, infiltration, and evapotranspiration.

Inert species. Fugitive dust plus elemental carbon.

Input Table. The table of information that is used as input to the Tahoe Watershed Model for any Setting. The information in these tables estimates the effects of PCOs on pollutant loading.

Integrated Water Quality Management Strategy (Integrated Strategy). A plan to help stakeholders to understand ways in which the necessary TMDL load reductions could be achieved using PCOs from all five of the major pollutant source categories.

Land use groups. A collection of similar urban upland land uses that are routed to a specific PCO(s) within the major load reduction elements (i.e., PSC, HSC, and SWT).

Legacy areas. *Legacy* is a term that is often used to refer to past impacts or disturbances. In the Tahoe Basin, the legacy areas of greatest concern to water quality are old, often abandoned roads, trails, and landings, many of which are associated with logging during the Comstock era.

Major load reduction elements. Hydrologic source control (HSC), pollutant source control PSC), and storm water treatment (SWT).

Mitigation. Eliminating, minimizing, or compensating for the net impact of a disturbance.

Mitigative control. A control measure that periodically removes the pollutant-causing materials.

Moisture content. A measurement, usually expressed as a percent, of the mass of water in a material sample.

Non-Cohesive Materials. Geologic/soil materials that resit erosionby their size, weight, and friction (sands and gravels).

Obliteration. The FUSCG defines *obliteration* as *functional restoration* of roads. See the definition of *functional restoration*.

Operating/Maintenance Costs (O&M). Expenses associated with personnel, materials, consumables, equipment repair, and other types of continuing expenses that would allow a PCO to maintain load reductions as estimated.

Overbanking. Process that occurs when water level within a stream channel rises above the top of one or both streambanks, allowing water to pass from the channel onto the adjoining land surface (typically a floodplain).

Planform. The map-view alignment or position of a stream channel.

Pollutant Control Option (PCO). A general term to describe the physical and nonphysical methods that can reduce pollutant loads to Lake Tahoe. Examples could include residential BMPs, a commuter shuttle system, or a fertilizer education program.

Pollutant source controls (PSC). These reduce the supply of pollutants by reducing the potential for pollutants of concern to be mobilized and transported.

Preventive control. A control measure that inhibits or minimizes source extent or incorporates process modifications or adjusts work practices to reduce the amount of pollutants.

Recapitalization. Refers to a one-time treatment (or investment) that will, in time, restore the key ecosystem functions necessary to create a functionally restored, sustainable site (See the definition of *functional restoration*). This is in contrast to traditional surface treatments that require ongoing inputs and maintenance and are not designed to be self-sustaining. .

Reference Table. Any one of several tables referenced within the Input Tables (defined above). These tables provide specific data about the functional effects of PSC, HSC and SWT for each Setting–Tier combination.

Setting. Representative areas of the Lake Tahoe Basin that could include similar physical characteristics, PCO applicability, or loading effects.

Silt content. Percentage of particles less than 75 µm in physical diameter.

Sinuosity. A measure of the curvature of a stream's planform, which is the ratio of channel length/valley length.

Slope. The gradient of a surface (hillslope, channel bed, bank, or water surface): the elevation change (rise)/horizontal distance (run); it can also be referred to as the gradient or grade.

Soil tilth. The physical and biological functional condition of the soil.

Source Category Group (SCG). One of the groups of technical experts evaluating load reduction options for Lake Tahoe.

Source Category. A set of sources that provide a significant proportion of the pollutant loads to Lake Tahoe. The Lake Tahoe TMDL has established five important source categories.

Source Extent. See *Emission activity level.*

Storm water treatment (SWT). This removes pollutants after they have entered concentrated storm water runoff flow paths

Stream Reach. Area along a stream that ranges from several hundred meters to a few kilometers long.

Stream Site. Area along a stream the ranges from a few meters to several hundred meters long.

Stream. As used in this study, it refers to the mainstem channel of tributary watersheds to Lake Tahoe.

Surcharge. Load (weight) on a streambank resulting from vegetation.

Surface loading. Mass of loose material per paved road surface area. Silt surface loading refers only to particles with physical diameters of smaller than 75 μm in physical diameter.

Terrace. Area of relatively level or gently sloping land adjacent to a stream, but whose surface is too high above the active channel bed to experience overbanking and inundation (except, perhaps under extreme flood conditions).

Total Suspended Particulate (TSP). Particles with aerodynamic diameter less than 30 μm; also includes particles less than 10 μm in diameter (PM10), and elemental carbon which is typically less than 1 μm in diameter.

Trackout. Accumulation of mud/dirt on paved roads, as deposited by vehicles that exit unpaved sites.

Traffic volume. Measure of the number of vehicles traveling over a road segment. Vehicle miles traveled (VMT) on a road equals the average daily traffic (ADT) times the roadway length.

Transportable Fraction (TF). Fraction of a source's mass emissions that remain airborne and available for transport away from the source after localized removal has occurred.

Treatment Tier. Groups of PCOs that can be applied to each Setting and demonstrate the broad spectrum of potential load reduction effectiveness and effort possible.

Urban Upland Setting. A generalized description of the key physiographic characteristics of a subwatershed (impervious area configuration and average urban slope), which directly influence the planning, design, and construction of urban storm water quality improvement projects in the Basin

Watershed. Areas defined by surface topography that drain to a common outlet.

9. Appendices

Urban & Groundwater – A: PSC Performance Review

Urban & Groundwater – B: Groundwater Loading Assessment

Urban & Groundwater – C: Setting Development

Urban & Groundwater – D: Input Tables and Reference Tables

Urban & Groundwater – E: Capital Cost Estimates

Forested Uplands – A: Additional Tables

Forested Uplands – B: Fire Literature Review

Stream Channel – A: Nutrient Analysis

Stream Channel – B: Pollutant Control Options Screening

Stream Channel – C: Bank Stability and Toe Erosion Modeling Methods

Stream Channel – D: Load Reduction Analysis Worksheets

Stream Channel – E: Pollutant Control Options Cost Estimates

Particle Mass to Particle Number Conversion