Final Lake Tahoe Total Maximum Daily Load

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List of Acronyms and Abbreviations

These acronyms and abbreviations appear in the report. Most are spelled out initially in each chapter, but this list is provided for ease of reference.

AnnAGNPS	Agricultural Non-Point Source Pollutant Version 3.30
BAP	Biologically Available Phosphorus
BMP	Best Management Practice
C	Carbon
^oC	Degrees Celsius
CARB	California Air Resources Board
CDM	Camp Dresser and McKee
CDOM	Colored dissolved organic matter
CFR	Code of Federal Regulations
cfs	cubic feet per second
chl-a	Chlorophyll *a*
CONCEPTS	Conservational Channel Evolution and Pollutant Transport System
CWA	Clean Water Act
DCNR	Nevada Department of Conservation and Natural Resources
DIN	Dissolved Inorganic Nitrogen
DON	Dissolved Organic Nitrogen
DOQs	Digital Orthophotographic Quadrangles
DRI	Desert Research Institute
EMC	Event Mean Concentration
ET	Evapotranspiration
ft	Feet
GIS	Geographic Information System
IWQMS	Integrated Water Quality Management Strategy
km	Kilometer
L	Liter
LA	Load Allocation
LC	Loading Capacity
LSPC	Loading Simulation Program in C++ (Lake Tahoe Watershed Model)
LTADS	Lake Tahoe Atmospheric Deposition Study
LTBMU	US Forest Service - Lake Tahoe Basin Management Unit
LTIMP	Lake Tahoe Interagency Monitoring Program
m	Meter
µm	Micrometer
mg	Milligram
mL	Milliliter
MOS	Margin of Safety
MFR	Multi-family Residential
MT	Metric Ton
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection

NHD	National Hydrography Dataset
NH_4^+	Ammonium
NOx	Oxides of Nitrogen
NO_3^-	Nitrate
NTU	Nephelometric Turbidity Units
n/y	Number of Particles per Year
ONRW	Outstanding National Resource Water
PCO	Pollutant Control Opportunity
PM	Particulate Matter
PN	Particulate Organic Nitrogen
PP	Particulate Phosphorus
PPr	Primary Productivity
PRO	Pollutant Reduction Opportunity
Q-wtd	Flow weighted
RGAs	Rapid Geomorphic Assessments
RMHQs	Requirements to Maintain Higher Quality
SCG	Source Catagory Group
s.d.	Standard deviation
SFR	Single-family Residential
SNPLMA	Southern Nevada Public Lands Management Act
SRP	Soluble Reactive Phosphorus
SWQIC	Storm Water Quality Improvement Committee
SWRCB	State Water Resources Control Board
TDP	Total Dissolved Phosphorus
TERC	Tahoe Environmental Research Center
THP	Total Acid-Hydrolyzable-Phosphorus
TKN	Total Kjeldahl Nitrogen (all organic nitrogen plus NH_4^+)
TKN + nitrate	Total Dissolved Nitrogen
TMDL	Total Maximum Daily Load
TON	Total Organic Nitrogen
TP	Total Phosphorus
TRG	Tahoe Research Group
TRPA	Tahoe Regional Planning Agency
UC Davis	University of California Davis
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
VEC	Vertical Extinction Coefficient
WLA	Waste Load Allocation
WQS	Water Quality Standard

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Thank you!!!!

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Preface

The Lake Tahoe Total Maximum Daily Load (Lake Tahoe TMDL or TMDL) was developed through a collaborative effort between the Nevada Division of Environmental Protection (NDEP) and the California Regional Water Quality Control Board, Lahontan Region (Water Board). Each state must comply with, administer and enforce its own state laws, regulations and policies which govern Lake Tahoe aesthetic water quality issues. Consequently, this TMDL Report, submitted by Nevada to the United States Environmental Protection Agency (EPA) in August 2011, has been slightly modified from the document submitted by the Water Board dated November 2010. The revisions correct errors, clarify Nevada's regulatory structure and approach to implementation and emphasize that the proposed implementation timelines may need to be adjusted for a variety of reasons, but particularly the availability of future funding. This document does not include Chapter 16 of the Water Board's submittal as the Regulatory Analysis required under the California Environmental Quality Act does not pertain to Nevada.

TMDLs established under CWA Section 303(d) function primarily as planning devices and are not self-executing[1]. A TMDL does not, by itself, prohibit any conduct or require any actions. Instead, each TMDL represents a goal that *may* be implemented by adjusting pollutant discharge requirements in individual National Pollutant Discharge Elimination System (NPDES) permits or establishing nonpoint source controls[2]. Thus, the Lake Tahoe TMDL is a planning tool and not a regulatory document.

An implementation plan is included in this submittal. Although not subject to EPA approval, this component helps establish reasonable assurance that the TMDL will be implemented. NDEP intends to implement the urban uplands source category component of the TMDL through Memoranda of Agreement (MOA) with urban stormwater jurisdictions including Douglas and Washoe Counties and the Nevada Department of Transportation. NDEP will evaluate the need to establish such agreements with implementing agencies in the other source categories.

Through the TMDL Management System, NDEP and the Water Board will collaboratively conduct periodic assessments of progress toward the interim Clarity Challenge and TMDL numeric targets to inform decisions such as whether load allocations, milestones and/or implementation strategies and actions need to be adjusted. These decisions will be accomplished in a collaborative manner between the Lahontan Water Board and NDEP to the extent possible. However, NDEP reserves the right and authority to make independent decisions if it deems necessary.

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[1] Pronsolino v. Nastri, 291 F.3d 1123, 1129 (9th Cir. 2002)
[2] Sierra Club v. Meiburg, 296 (F.3d 1021, 1025 (11th Cir. 2002)

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Executive Summary

This document is the Staff Report that summarizes the Numeric Target, Pollutant Source Analysis, Load Allocations, Implementation Plan and Adaptive Management Process for the Lake Tahoe Total Maximum Daily Load (Lake Tahoe TMDL).

Lake Tahoe is an oligotrophic alpine lake situated on the California-Nevada border at approximately 6223 feet elevation. The lake surface area is 194 mi^2 with a contributing drainage area of 314 mi^2. Lake Tahoe is fed by 63 tributary streams and 52 intervening zones that drain directly to the lake. The largest tributary is the Upper Truckee River, which contributes approximately 25 percent of the lake's annual flow. The Truckee River, Lake Tahoe's one outlet, flows to its terminus in Nevada's Pyramid Lake. The natural rim of Lake Tahoe is at 6223 feet above sea level. A dam regulates water flow from the natural rim to the maximum legal lake level of 6229.1 feet.

Section 303(d) of the Clean Water Act requires states to compile a list of impaired water bodies that do not meet water quality standards and to establish total maximum daily loads (TMDLs) for such waters. California has adopted a deep water transparency water quality objective for Lake Tahoe, which is the average annual Secchi depth measured between 1967 and 1971, equivalent to an annual average Secchi depth of 29.7 meters (97.4 feet). The deep water transparency water quality objective for Lake Tahoe has not been met since its adoption. In 2009 the annual average Secchi depth was approximately 20.8 meters (68.1 feet), or 8.9 meters (29.3 feet) from the standard. Nevada and California have both adopted a clarity standard to protect Lake Tahoe's deep water aesthetics, which specifies the vertical extinction coefficient must be less than 0.08 per meter at any depth below one meter. This clarity standard is also not in attainment.

The ongoing decline in Lake Tahoe's deep water transparency and clarity is a result of light scatter from fine sediment particles (primarily particles less than 16 micrometers in diameter) and light absorption by phytoplankton. The addition of nitrogen and phosphorus to Lake Tahoe contributes to phytoplankton growth. Fine sediment particles are the most dominant pollutant contributing to the impairment of the lake's deep water transparency and clarity, accounting for roughly two thirds of the lake's impairment. Because these three pollutants are responsible for Lake Tahoe's deep water transparency loss, California has listed Lake Tahoe under Section 303(d) as impaired by input of nitrogen, phosphorus, and sediment. Nevada listed Lake Tahoe under Section 303(d) as impaired due to the failure to attain Nevada's clarity standard.

For multi-jurisdictional waterbodies, the U.S. Environmental Protection Agency (EPA) recommends that States develop TMDL targets to protect the most sensitive use or objective. To best satisfy the multi-jurisdictional water quality objectives, the deep water transparency water quality objective was selected as the most appropriate and protective numeric target. The goal of the Lake Tahoe TMDL is to set forth a recommended plan to restore Lake Tahoe's historic deep water transparency to 29.7

meters annual average Secchi depth. Achieving this goal is expected to result in attainment of the clarity standard as well.

A pollutant source analysis conducted by the Water Board and Nevada Division of Environmental Protection identified urban uplands runoff, atmospheric deposition, forested upland runoff, and stream channel erosion as the primary sources of fine sediment particle, nitrogen, and phosphorus loads discharging to Lake Tahoe. The largest source of fine sediment particles to Lake Tahoe is urban stormwater runoff, comprising 72 percent of the total fine sediment particle load. The urban uplands also provide the largest opportunity to reduce fine sediment particle and phosphorus contributions to the lake.

The Lake Clarity Model indicates that in order to achieve the TMDL numeric target, fine sediment particle, phosphorus, and nitrogen loads need to be reduced by 65 percent, 35 percent, and 10 percent, respectively. The load reduction analysis suggests achieving these load reductions could take 65 years. Achieving a 20-year interim transparency goal, known as the Clarity Challenge, would necessitate basin-wide pollutant load reductions to be achieved within 15 years, followed by five years of monitoring to confirm whether 24 meters of Secchi depth transparency has been reached. Implementation efforts need to reduce basin-wide fine sediment particle, phosphorus, and nitrogen loads on the order of 32 percent, 14 percent, and 4 percent, respectively to achieve this goal. These estimates assume that climate change, catastrophic events and/or reduced funding levels do not adversely affect progress toward attaining these targets.

The Lake Tahoe TMDL's Pollutant Reduction Opportunity Report identified options for reducing pollutant inputs to Lake Tahoe from the four largest pollutant sources: urban upland runoff, atmospheric deposition, forested upland runoff, and stream channel erosion. The Integrated Water Quality Management Strategy Report combined selected pollutant controls to develop several integrated implementation strategies. Stakeholder input helped guide the development of a single Recommended Strategy to meet the Clarity Challenge goal.

The Recommended Strategy focuses on reducing basin-wide fine sediment particle loading to Lake Tahoe and provides the basis for the Lake Tahoe TMDL pollutant load allocation distribution and for the TMDL implementation plan to achieve the Clarity Challenge. The Recommended Strategy demonstrates that load reductions needed to achieve the Clarity Challenge are possible but are estimated to cost $1.5 billion in aggregate capital expenditures with an additional $11 million annualized operations and maintenance over a 15 year implementation period. It must be emphasized that these costs are gross estimates, and more accurate cost information will be developed by implementing partners in the future.

Implementation actions are required to achieve needed load reductions from each of the four major pollutant source categories. The Lake Tahoe TMDL implementation plan emphasizes ongoing implementation of known technologies while encouraging more advanced and innovative operations, maintenance, and capital improvement efforts to address urban stormwater pollution. Ongoing land management practices and policies are expected to achieve necessary fine sediment particle, nitrogen, and phosphorus load reductions from forested areas. Stream restoration projects will address stream channel bank and bed erosion sources. Measures to reduce dust from paved and unpaved roadways, parking areas, construction sites, and other disturbed lands are expected to reduce fine sediment particle and phosphorus loading from the atmosphere.

The Water Board and Nevada Division of Environmental Protection have developed detailed performance measures, along with assessment and reporting protocols for the urban pollutant source category. These measures include a Lake Clarity Crediting Program to link actions to expected pollutant load reductions and an Accounting and Tracking Tool to track load reduction progress.

Adaptive management, or periodic evaluation and reassessment, is necessary for the long term success of the Lake Tahoe TMDL. The Lake Tahoe TMDL Management System provides a framework for adaptively managing the implementation of the Lake Tahoe TMDL. This framework guides a continual improvement cycle to track and evaluate project implementation and load reductions, and informs the milestone assessments the Water Board and Nevada Division of Environmental Protection will conduct during implementation of the Lake Tahoe TMDL. The Management System will provide an adaptive framework through which climate change, catastrophic wildfires, and other significant events may be accounted for and addressed. NDEP retains the authority to amend the implementation schedule based on economic conditions and available funding.

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1 Introduction

Lake Tahoe is a unique environmental treasure located in the Sierra Nevada mountain range on the California and Nevada border and is known worldwide for its outstanding clear blue waters. The lake was designated in 1980 as an Outstanding National Resource Water by the State of California and the USEPA, a designation reserved for exceptional waters with unique ecological or social significance. Nevada has designated Lake Tahoe as a water of extraordinary ecological or aesthetic value.

Lake Tahoe's famed transparency and clarity have shown a significant decline since regular monitoring began. Transparency and clarity decline has been attributed to the rapid human population growth that occurred within the basin during this time period. The Clean Water Act requires states to establish water quality objectives for all waterbodies, identify those that fail to meet water quality objectives and develop Total Maximum Daily Loads (TMDLs) to address their impairments. This TMDL has been developed to address Lake Tahoe's transparency and clarity impairments.

Transparency vs. Clarity

Transparency and clarity are similar expressions concerning the transmission of light through water. Transparency is the depth to which the human eye can see down into the water column, and clarity is the depth light can penetrate the water column. For Lake Tahoe, transparency measurements can only be done in deep water, not in shallow water less than about 70 feet deep.

1.1 Purpose and Scope

For an impaired water body, the TMDL process identifies one or more numeric targets based upon existing water quality objectives and specifies the maximum amount of pollutant or pollutants a water body can receive and remain in attainment of water quality objectives. The goal of the TMDL, when implemented, is for the waterbody to fully attain its designated beneficial uses. Within this context, a completed TMDL provides the framework for a comprehensive water quality restoration plan to address identified pollutant sources.

The Lake Tahoe TMDL identifies the pollutants responsible for the loss of transparency and their originating sources. Three pollutants — fine sediment particles, nitrogen, and phosphorus — are responsible for the transparency impairment of Lake Tahoe and these three pollutants enter the lake from diverse sources. This TMDL identifies the amount of each pollutant entering the lake from these sources, the reductions needed, the reduction opportunities that are available, and the implementation plan to achieve these reductions.

This TMDL addresses Lake Tahoe's deep water clarity and transparency impairment and does not address other real or potential problems, such as algae growth in the nearshore or aquatic invasive species.

1.2 Involved Entities

The California Regional Water Quality Control Board, Lahontan Region (Water Board), and the Nevada Division of Environmental Protection (NDEP) cooperatively developed the Lake Tahoe TMDL to address pollutant loading from all sources and to meet the planning and regulatory needs of both states. Additionally, the Lake Tahoe TMDL is developed to meet United States Environmental Protection Agency (USEPA) Clean Water Act requirements and to support the Tahoe Regional Planning Agency (TRPA) goals and objectives.

Other public agencies and stakeholders were involved during TMDL development through a comprehensive, collaborative effort to update resource management plans and environmental regulations in the Lake Tahoe basin for the next twenty years, known as the Pathway planning process. The Pathway planning process involved meetings and workshops where interested parties have contributed ideas, shared resources and expertise, recommended mutually beneficial options, and created consistency across agencies. Additional information on Pathway is available at www.pathwaytahoe.org.

1.3 New Research Undertaken for TMDL Development

Numerous state, federal, academic, and private entities conducted new research in the development of this TMDL to provide the most current information possible. The research effort began in 2001 and involved over 100 contributing scientists, with significant combined funding from state and federal agencies. The Lake Tahoe TMDL effort is the most comprehensive evaluation of Lake Tahoe's clarity and transparency decline ever completed in the Lake Tahoe basin.

1.4 Phased Approach

The Lake Tahoe TMDL program was divided into three phases that emphasize answering a number of key questions. Phase One initiated the research to determine Lake Tahoe's pollutants, pollutant capacity and existing inputs. Phase Two includes a cooperative process for pollutant reduction analysis and planning. Phase Three involves implementation of the pollutant reduction plan. The products of each phase and related key management questions are summarized in Table 1-1.

Table 1-1. TMDL Phased Development

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, algae growth, and meteorology
	How much of each pollutant is reaching Lake Tahoe?	Existing pollutant input 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 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 input reduction opportunities **Document:** Pollutant Reduction Opportunity Report
	What strategy should we implement to reduce pollutant inputs to Lake Tahoe?	Integrated strategies to control pollutants from all sources **Document:** Integrated Water Quality Management Strategy Project Report
		Pollutant 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 pollutant 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?	TMDL continual improvement and adaptive management system, targeted research
		Document: Periodic Milestone Reports

1.5 Notes

The Lake Tahoe TMDL report summarizes information from three distinct supplementary documents: 1) Lake Tahoe TMDL Technical Report, 2) Pollutant Reduction Opportunity Report, and 3) Integrated Water Quality Management Strategy Report. These three supplementary documents support the scientific and technical conclusions in the Lake Tahoe TMDL report and contain the detail often referenced in the TMDL report.

The Lake Tahoe TMDL Technical Report - June 2010 details the pollutant load source estimates and the lake clarity response modeling analysis. This report was first drafted in September 2007 and circulated to stakeholders and interested parties during 2007-2008. Based on received oral and written comments as well as internal review, scientific peer review and editing, parts of the TMDL Technical Report were updated in June 2010.

The Pollutant Reduction Opportunity Report, V2.0 identifies options for reducing pollutant loads to Lake Tahoe from the major fine sediment particle and nutrient sources. The analysis provides potential pollutant load reduction estimates and associated costs at a basin-wide scale associated with implementation at several levels of effort.

The Integrated Water Quality Management Strategy Report presents a Recommended Strategy for implementation and an evaluation of different options for allocating load reductions throughout the basin. The report summarizes the extensive stakeholder process undertaken to consolidate the load reduction opportunities into a package of preferred methods and approaches that reduce pollutant loads from each of the four source categories to meet the Clarity Challenge target at 20 years

The September 2007 draft Lake Tahoe TMDL Technical Report, Pollutant Reduction Opportunity Report, and Integrated Water Quality Management Strategy Report all describe fine sediment particles as those particles with diameters less than 20 micrometers (µm). That definition is not precise. The correct definition for the pollutant of concern is fine sediment particles less than 16 µm. Although incorrectly noted as < 20 µm in the reference documents, all calculations and data presented in the three supplementary documents were based on a fine sediment particle definition of < 16 µm. The error has been corrected in the June 2010 Lake Tahoe TMDL Technical Report.

Many figures and tables in this report and in the three supplementary documents are best viewed in color, particularly map layers generated from a geographic information system analysis.

Because most research and data collection efforts conducted during the TMDL analysis used the metric system, data and calculation information provided in this report are listed in metric units. Some conversions to standard units have been provided in select chapters.

2 Basin and Lake Characteristics

The Lake Tahoe basin and Lake Tahoe itself have unique, outstanding characteristics compared to other places in California and the country. This chapter describes the physical characteristics of the basin and lake.

2.1 Characteristics of the Lake Tahoe Basin

2.1.1 Location and Topography

The California – Nevada state line splits the Lake Tahoe basin, with about three-quarters of the basin's area and about two-thirds of the lake's area lying in California (Figure 2-1). The geologic basin that cradles the lake is characterized by mountains reaching over 4,600 feet (1,402 meters) above lake level, steep slopes, and erosive granitic soils. Volcanic rocks and soils are also present in some areas.

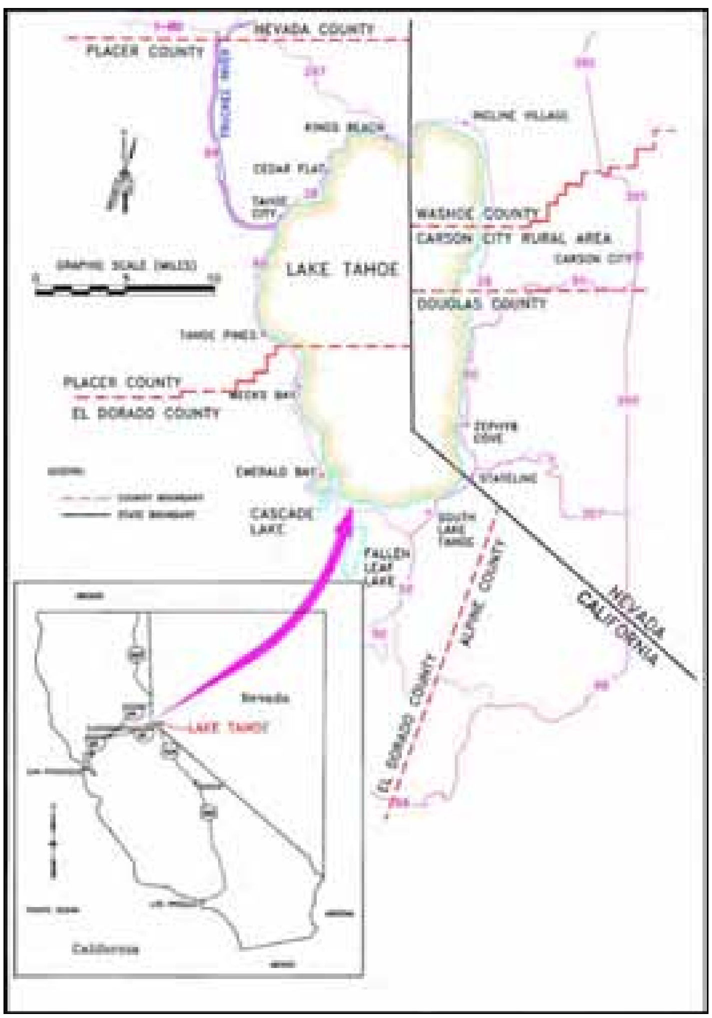

Figure 2-1. Location of the Lake Tahoe basin (USACE 2003).

2.1.2 Geology and Soils

The Lake Tahoe basin was formed approximately 2 to 3 million years ago by geologic faulting that caused large sections of land to move up and down. Uplifted blocks created the Carson Range on the east and the Sierra Nevada on the west while down-dropped blocks created the Lake Tahoe basin in between.

About 2 million years ago, lava from Mt. Pluto on the north side of the basin blocked and dammed the northeastern end of the valley and caused the basin to gradually fill with water. As the lake water level rose, the Truckee River eroded an outlet and a stream course through the andesitic lava flows down to the Great Basin hydrologic area to the east. Subsequent glacial action (between 2 million and 20,000 years ago) temporarily dammed the outlet, causing lake levels to rise as much as 600 feet above the current level. A detailed account of the basin's geology and its effect on groundwater flow and aquifer characteristics is given by USACE (2003).

Nearly all the streams in the basin lie on bedrock, with the exception of some south shore area tributaries and the lower reaches of some streams. Aquifers for the Ward Creek, Trout Creek, and Upper Truckee River watersheds slope toward the lake, which would imply a net flow into the lake (Loeb et al. 1987). However, some recent studies in the Pope Marsh area of the south shore indicate that under the influence of water pumping and seasonal effects, the net flow in some areas may be from the lake into the adjacent aquifer system (Green 1998, Green and Fogg 1998).

Lake Tahoe basin soils are mostly granitic derived soils, while volcanic soils occur in the north and northwestern parts of the basin. Soils near the lake consist of alluvial wash deposits (Crippen and Pavelka 1970). Soils in the basin have a wide range of erosion potential, and soil permeability ranges from moderate to very rapid, with the lowest permeabilities found in the northwest quadrant of the basin (Tetra Tech 2007).

2.1.3 Land Uses

Land uses in the Lake Tahoe basin have an influence on lake clarity and other environmental attributes. A detailed natural and human history of the basin is in the *Lake Tahoe Watershed Assessment* (USDA 2000).

The basin was discovered by European-American explorers in 1844. Since then, the basin has been altered by several significant, anthropogenic influences: clear-cut logging of an estimated 60 percent of the basin during the Comstock-era (1870s-10s), livestock grazing (1900s-1950s), urbanization of the lakeshore and lowest-lying parts of the basin beginning in the 1950s (USDA 2000), and public acquisition and protection of thousands of acres of sensitive lands since the mid-1960s. As of 1996, public ownership represented 85 percent of the total land area of the basin.

More than 80 percent of the watershed is vegetated (montane-subalpine type), covered predominantly by mixed coniferous forests, though bare granite outcrops and meadows are also common. About 2 percent of the watershed is impervious surface associated with urban development (Figure 2-2), which equates to over 5,000 acres (20 km^2) (Minor and Cablk 2004). Much of the impervious land cover is adjacent to the lake or its major tributaries. Additionally, 14 of the 63 individual watersheds have at least 10 percent impervious land area.

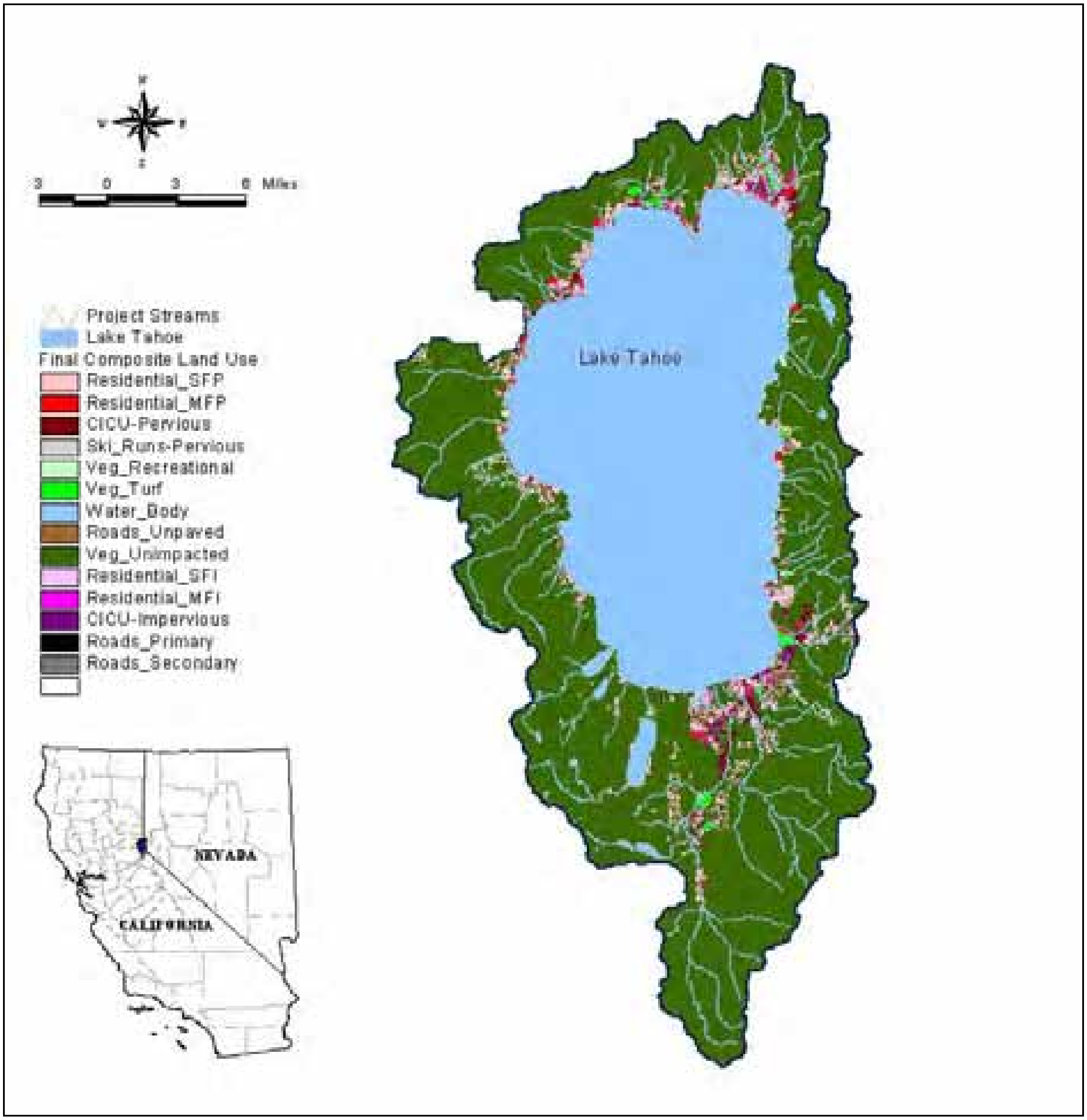

Figure 2-2. Land-uses in the Lake Tahoe basin (Tetra Tech unpublished).

Most urban development exists along the lake's shoreline, with the largest concentrations at South Lake Tahoe in the south, Tahoe City in the northwest, and Incline Village in the northeast. The north and west shores are less densely populated, and much of the east shore is undeveloped.

2.1.4 Climate and Hydrology

Climate (specifically, precipitation as rain and snow) is the single most important factor influencing pollutant delivery to Lake Tahoe. Precipitation drives the mobilization and transport of pollutants from the landscape into the tributaries or directly into the lake.

The lake's surface area, which is relatively large compared to its watershed area, is an important factor because a significant amount of precipitation (36 percent) enters the lake directly. Therefore significant amounts of airborne pollutants (fine sediment, nitrogen, and phosphorus) enter the lake directly.

The Lake Tahoe basin has a Mediterranean-type climate characterized by wet winters and dry summers. Most precipitation in the basin falls between October and May as snow at higher elevations and as snow/rain at lake level. Over 75 percent of the precipitation is delivered by frontal weather systems from the Pacific Ocean between November and March. However, precipitation timing can vary significantly from year to year (Coats and Goldman 2001, Rowe et al. 2002). Lower elevations receive about 20 inches (51 cm) of annual precipitation, but the upper elevations on the west side of the basin receive about 59 inches (150 cm) (USDA 2000).

The snow pack at higher elevations typically melts and runs off in May and June. However, at lower elevations near the lakeshore, the snow pack typically melts earlier in the spring and can even melt mid-winter if temperature and solar radiation conditions are right. Commonly, the lower elevation snow pack melts completely before the tributaries crest with snowmelt from the higher, colder elevations.

Thunderstorms, especially rain-on-snow events, can lead to high runoff in a short amount of time, contributing to pollutant transport into Lake Tahoe and its tributaries. Thunderstorms in summer or fall can be intense and can generate large loads for short periods of time, typically in isolated geographic locations. However, summer thunderstorms contribute little to annual precipitation and typically are not responsible for significant pollutant loads to tributaries (Hatch et al. 2001, S. Hackley unpublished).

A well-defined rain shadow exists across the lake from west to east (Crippen and Pavelka 1970, Sierra Hydrotech 1986, and Anderson et al. 2004). The west shore averages about 35 inches/year (90 cm/year) of precipitation, while the east shore averages about 20 inches/year (51 cm/year).

2.2 Characteristics of Lake Tahoe

2.2.1 Location and Topography

Lake Tahoe is near the crest of the Sierra Nevada mountain range at an elevation of 6,224 feet (1,897 meters) above sea level. Slopes rise quickly from the lake's shore, reaching 30 to 50 percent slope in many places.

2.2.2 Size

Lake Tahoe is approximately 22 miles (35.5 kilometers) at its maximum length from north to south and 12 miles (19.3 kilometers) at its maximum width from east to west. The surface area of the lake covers nearly two-fifths of the Lake Tahoe basin — at 123,800 acres (501 km^2), the surface area is significantly large for its drainage area of 200,650 acres (812 km^2). Consequently, a significant amount of the precipitation that falls within the basin falls directly on the lake.

Lake Tahoe is the eleventh-deepest lake in the world with a maximum depth of 1,657 feet (505 meters) and an average depth of 1,027 feet (313 meters). The lake holds nearly 39 trillion gallons of water.

2.2.3 Hydrology

Lake Tahoe is fed by 63 tributary streams. The largest tributary is the Upper Truckee River, which contributes approximately 25 percent of the lake's annual in-flow. There are also 52 areas that drain directly to the lake without first entering streams, known as intervening zones. The lake has one outlet on its northwest side, forming the start of the Truckee River, which ultimately drains to Pyramid Lake, a terminal lake in Nevada.

The lake's hydraulic residence time is 650 years, which means that on average it takes 650 years for water that enters the lake to leave the lake. Because of its volume, depth, and geographic location, Lake Tahoe remains ice-free year-round, though Emerald Bay has frozen over during some extreme cold spells.

A concrete dam was completed in 1913 to regulate water outflow at the Truckee River outlet in Tahoe City, California. In 1988, the dam was seismically retrofitted and enlarged to its current configuration. The upper six feet of the lake forms the largest storage reservoir in the Truckee River basin, with an effective capacity of 240 billion gallons (745,000 acre-feet) (Boughton et al. 1997). Since 1987, lake levels have fluctuated from 6,220 feet (about 3 feet below the natural rim) during a prolonged drought in 1992 to 6,229 feet (about 0.2 feet above the legal maximum) during the flood of January 1997 (Boughton et al. 1997). The dam is under federal control.

3 Optical Properties of Lake Tahoe

The clarity and transparency of Lake Tahoe have been the subject of extensive research for many years. The clarity and transparency of water are influenced by many factors, including natural lighting (affected by sun angle, cloud cover, and waves), properties of water molecules, lake mixing, colored dissolved organic matter, and especially, in the case of Lake Tahoe, particulate material in the water. Material in the water can include inorganic particles (soil sediment) and organic particles (such as live suspended algae, suspended detritus or dead organic material) and a combination of these types of particulate matter in the form of aggregations that typically form around a biochemically ‘sticky’ organic matrix mediated by bacterial excretions. Transparency is most commonly measured as Secchi depth. Secchi depth is measured using a circular plate, known as a Secchi disk, which is lowered into the water until it is no longer visible. High Secchi depths indicate clear water; whereas low Secchi depths indicate cloudy or turbid water. Clarity is recorded by using a submersible photometer to measure the vertical extinction of photosynthetically active light per meter of water.

3.1 Particles Absorb and Scatter Light

Light is absorbed and scattered as it travels through water. The optical properties of water can be divided into apparent and inherent properties. Apparent optical properties are a function of natural lighting and are influenced by sun angle, cloud cover and water surface conditions such as waves. Inherent optical properties depend on the water and the material contained in the water column. An important inherent optical property of water is light attenuation, which is a result of absorption and scattering of light.

Particles in water both absorb and scatter light. In Lake Tahoe, light scattering and absorption are caused by inorganic and organic particles. Absorption also occurs from colored dissolved organic material (CDOM), such as naturally occurring tannins, humics and anthropogenic compounds that enter the lake (Taylor et al. 2003, Swift 2004). While absorption of light by CDOM was measurable in Lake Tahoe, it was a small portion of lake transparency loss in comparison to the fine sediment particles (Swift et al. 2006). CDOM was included in the optical component of the Lake Clarity Model. Also, water molecules themselves absorb and scatter light. Since the contribution of CDOM to light attenuation is so minor at Lake Tahoe and attenuation due to water molecules is an inherent characteristic of all waters, scattering and absorption by particles is dominant in Lake Tahoe. This can be seen in recent Secchi depth data collected in Lake Tahoe (Figure 3-1). These data show the significant relationship between the measured number of particles in Lake Tahoe and the corresponding Secchi depth (Swift 2004).

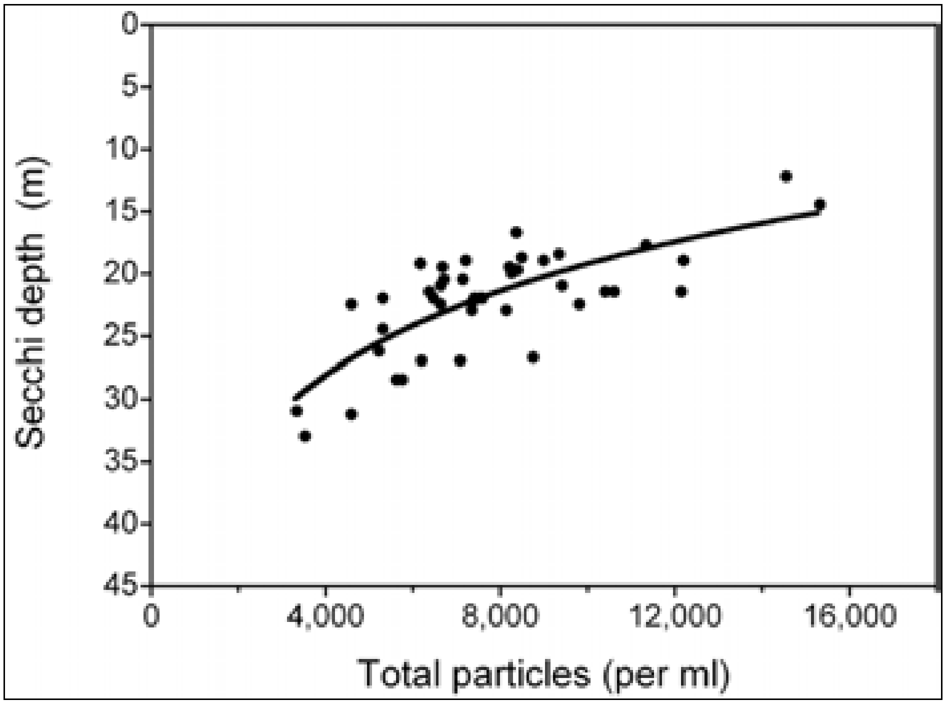

Figure 3-1. Relationship between in-lake particle number (< 16 µm) and Secchi depth with P-value = 0.001 and R^2 = 0.057 (modified from Swift 2004).

3.2 Effect of Particle Size on Lake Transparency

The hypothesis that fine inorganic particles from soil and dust, less than 16 micrometers (µm) in diameter, contribute to measurements of lake clarity loss was first published by Jassby et al. (1999). This was immediately followed by the first comprehensive study of particle number, size, and composition in Lake Tahoe during 1999-2000 (Coker 2000), which determined that the particles from 1 – 10 µm dominate and that in the 10 – 16 µm range, particle numbers are almost negligible. The original 1999-2000 investigation of particle size distribution was followed up by a series of studies including an examination of the spatial and temporal distribution of particle concentration and composition in Lake Tahoe (Sunman 2001), characterization of biotic particles and limnetic aggregates in Lake Tahoe (Terpstra 2005), lake particles and optical modeling (Swift 2004, Swift et al. 2006), and distribution of fine sediment particles in Lake Tahoe streams (Rabidoux 2005). Figure 3-2 is taken from the work of Swift et al. (2006) and shows the percent of the light attenuation due to inorganic particle scattering as a function of the particle size classes used in the Lake Clarity Model. The plot shows little to no impact of inorganic particles > 16 µm on light scattering (the dominant factor influencing attenuation in Lake Tahoe; Swift et al. (2006)). These results come directly from an analysis of Lake Tahoe waters throughout the year. Swift (2004) reported measured concentrations for particulate matter to range from 0.05 - 0.35 mg/L in Lake Tahoe's water column, depending on depth and time of year.

Data from Sunman (2001) suggest that fine sediment particles (less than 16 µm) take approximately 3 months to settle through the upper 100 meters of the water column.

This long retention time, in addition to its dominant role in scattering light, indicates the importance of the fine sediment particle contribution to clarity loss.

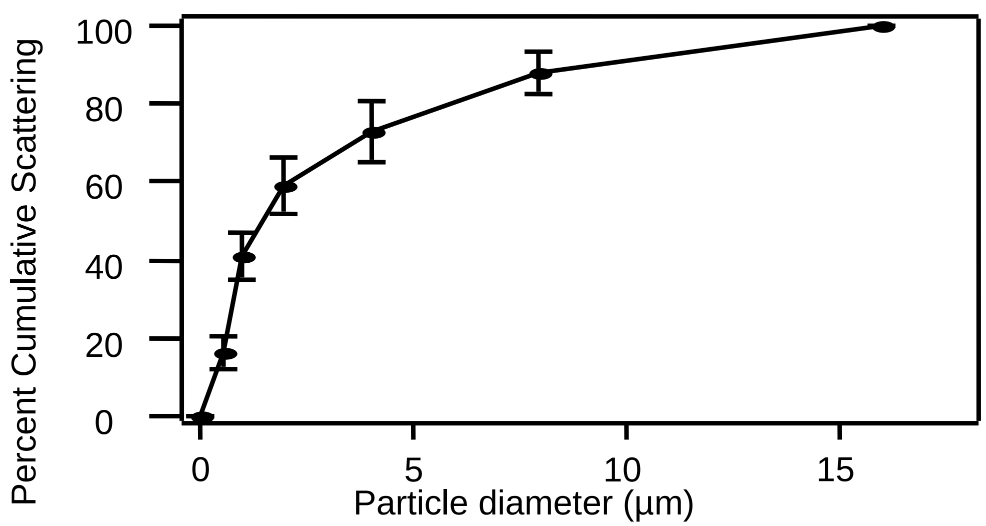

Figure 3-2. Influence of particle size on light scattering (modified from Swift et al. 2006).

3.3 Inorganic Sediment Particles Dominate Clarity Condition

Both inorganic and organic particles contribute to clarity loss in Lake Tahoe (Swift et al. 2006). Earlier investigations (Goldman 1974, 1994) focused primarily on increased phytoplankton productivity and the onset of cultural eutrophication as the dominant cause of clarity loss. However, recent studies at Lake Tahoe now show that inorganic particles have a more significant effect on clarity loss than do organic particles. These studies show that inorganic particles, with their high ability to scatter light, are actually the dominant cause of clarity loss (Swift et al. 2006).

Swift et al. (2006) determined that light scattering by inorganic particles for the period between 1999 and 2002 contributed greater than 55 to 60 percent of light attenuation, while organic particles contributed about 25 percent (Figure 3-3). The remaining 15 to 20 percent of light attenuation was due to absorption by water molecules and, to a much lesser extent, dissolved organic matter. Specifically for Lake Tahoe, these findings lend support to the earlier hypothesis (Jassby et al. 1999) that inorganic particles dominate clarity loss for most of the year.

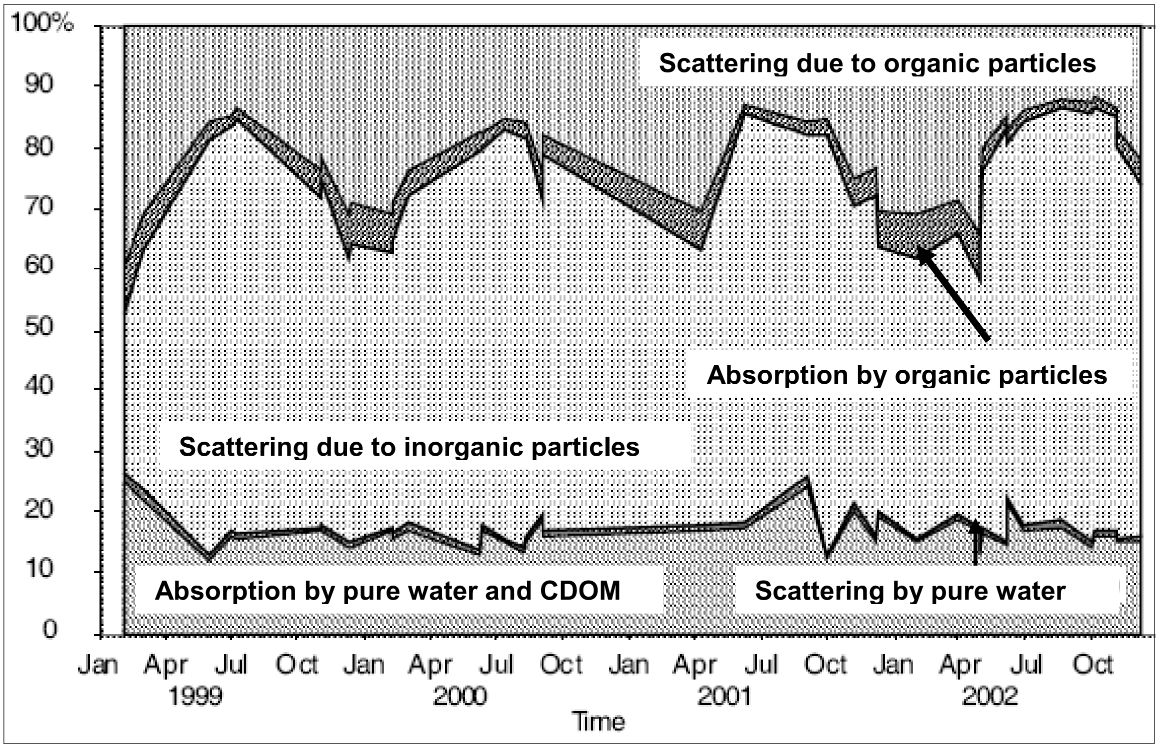

Figure 3-3. Results of an optical model showing the percentage of light absorption and scattering caused by water, CDOM (colored dissolved organic matter), and different types of particles, at different times of the year (modified from Swift et al. 2006). Inorganic particles refer to mineral or soil-based particles while organic particles include both living and dead matter.

3.4 Organic Particles - Algae and Phytoplankton

Algae and phytoplankton are the dominant source of suspended organic particles. Though organic particles are not the main cause of reduced transparency, these particles still contribute to transparency loss by attenuating light.

3.4.1 Increased Primary Productivity of Phytoplankton

The first measurements of phytoplankton (suspended, microscopic algae) growth in Lake Tahoe were made in 1959 (Goldman 1974). At that time, the annual phytoplankton growth rate was slightly less than 40 g C $m^{-2}y^{-1}$ and typical of an ultra-oligotrophic lake. For the years prior to 1959, average annual primary productivity was reconstructed from an analysis of sediment cores. Heyvaert (1998) determined that the baseline, pre-disturbance (prior to 1861 and the Comstock logging period) primary productivity was 28 g C $m^{-2}y^{-1}$. Interestingly, the calculated value from the sediment core analysis for 1900-1970, the period between the effects of the Comstock logging era in the late 1800s and the onset of urbanization of the Tahoe basin, was almost identical at 29 g C

> **Primary productivity** is the rate at which organisms (like phytoplankton) convert inorganic materials and sunlight into organic matter, through the process of photosynthesis. In most aquatic ecosystems, the phytoplankton biomass produced from primary productivity forms the base of the food web.

$m^{-2}y^{-1}$. This shows the ability of Lake Tahoe to return to historic levels following watershed recovery.

The rates of primary productivity recorded in 1959 were only about 30 percent more than the estimated baseline rates. By 2005, measured primary productivity had increased approximately 500 percent over 1959 conditions, to 203 g C $m^{-2}y^{-1}$ (UC Davis – TERC 2008). Although conditions vary year-to-year, the methodology used to measure algal growth has remained consistent over the period of record, and primary productivity data show a highly significant upward trend that continues at a rate of approximately 5 percent per year (Figure 3-4). Goldman (1988) discusses the onset of early cultural eutrophication in Lake Tahoe highlighting the role of nutrients in relation to the measured trend in primary productivity.

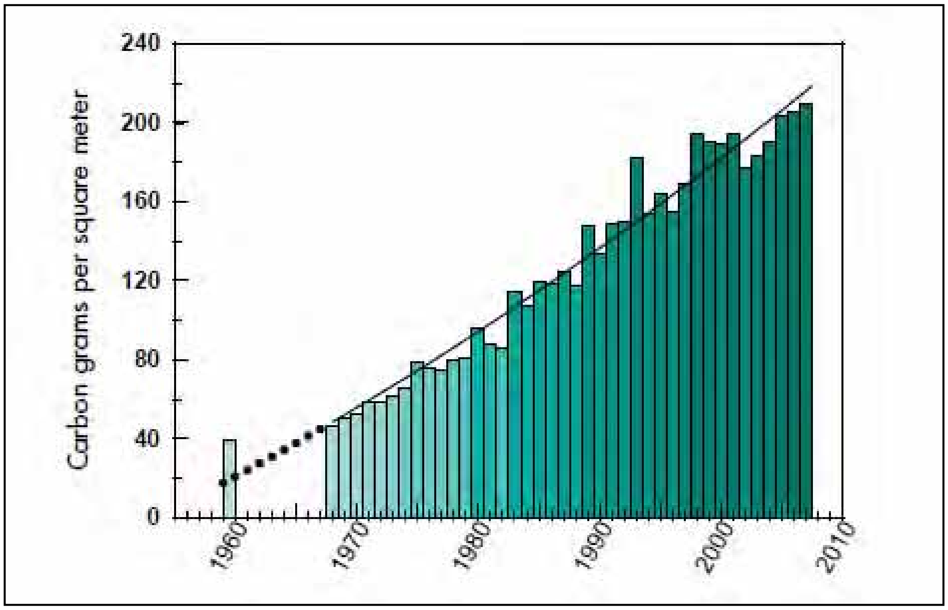

Figure 3-4. Annual average primary productivity in Lake Tahoe from approximately 25-30 measurements per year (UC Davis – TERC 2008).

Chlorophyll Concentrations and Composition of the Phytoplankton Community

The amount of free-floating algae (phytoplankton) in the water is determined by measuring the concentration of chlorophyll *a*. Though algae abundance varies annually, it does not show a long-term increase (Figure 3-5).The average annual chlorophyll *a* level in Lake Tahoe has remained relatively uniform at 0.6-0.7 µg/L since 1996.

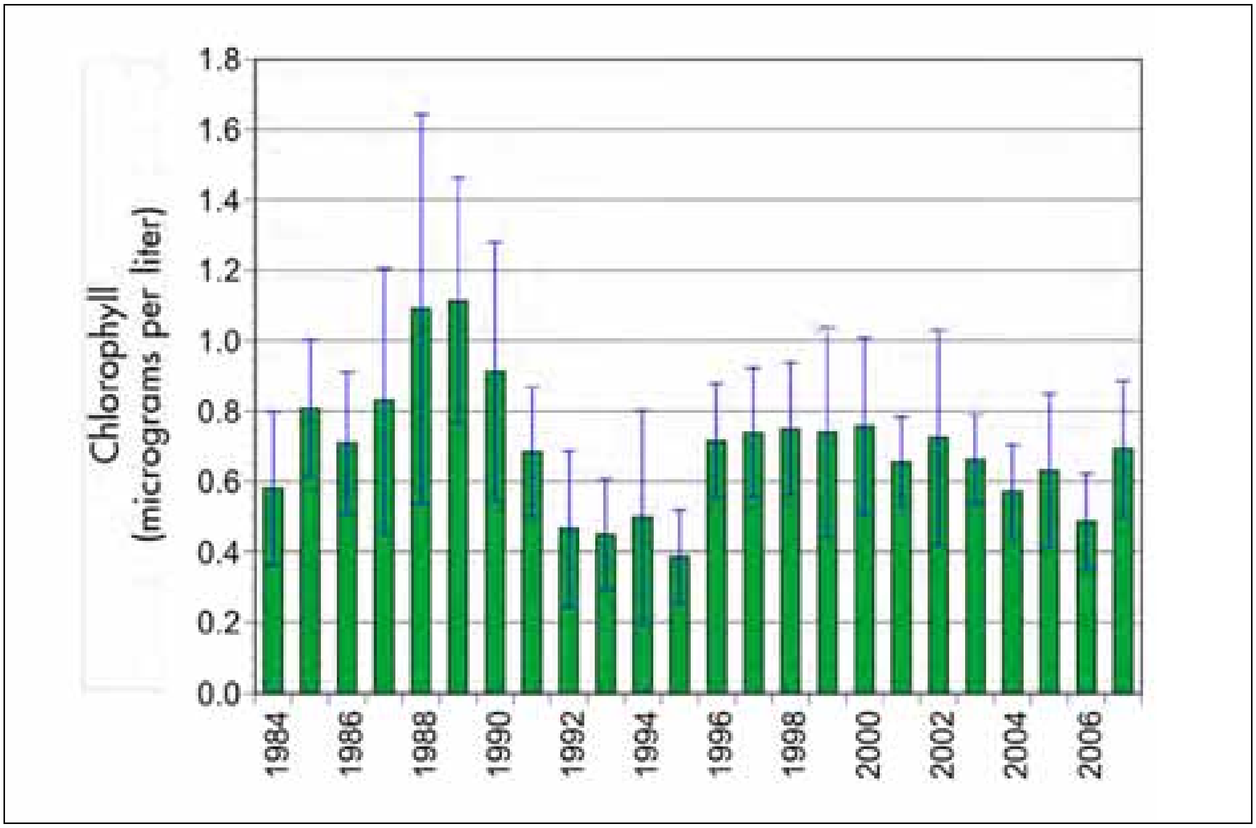

Figure 3-5. Annual chlorophyll *a* concentration in Lake Tahoe. Values represent annual means from approximately 25-30 measurements per year taken in the photic zone and volume averaged (UC Davis - TERC 2008).

Lake Tahoe has a deep-chlorophyll maximum, a common feature in the summer and early autumn, at a depth of 197-328 feet (60-100 meters) below the surface (Coon et al. 1987). While this biomass does not directly influence Secchi depth (20-30 meters deep), it was discussed above that these particles can affect clarity during the initial periods of lake mixing when they are swept up into the surface waters. Over the years the deep-chlorophyll maximum has risen in the water column to a shallower depth (Goldman 1988, Swift 2004).

Over the last four decades, changes have occurred in the standing crop, species composition and richness, and patterns of dominance (Hunter et al. 1990, Hunter 2004). The overall decline in relative abundance of diatoms is indicative of Lake Tahoe's eutrophication, as is an observed increase in araphid pennate diatoms at the expense of centric diatoms. In addition, the disappearance of *Fragilaria crotonensis* after 1980 is attributed to its inability to compete well in phosphorus-limited waters.

3.4.2 Nutrients in Lake Tahoe

Nutrients (nitrogen and phosphorus) stimulate growth of algae and other phytoplankton in Lake Tahoe. Nitrogen and phosphorus come in many different forms, with certain forms being more bioavailable to algae (i.e. more readily usable by algae for growth).

Nitrogen in Lake Tahoe

The average total nitrogen concentration for Lake Tahoe was calculated to be 65 micrograms per liter (µg/L) (Jassby et al. 1995). There are many forms of nitrogen that are measured in lake water. The majority (85 percent) of nitrogen in Lake Tahoe is in the dissolved form as either dissolved organic nitrogen (approximately 60 percent of total nitrogen) or dissolved inorganic nitrogen (approximately 25 percent of total nitrogen). The dissolved inorganic nitrogen consists of both nitrate (NO_3^-) and ammonium (NH_4^+), forms that are typically directly available for algae uptake and growth. Particulate nitrogen comprises approximately 15 percent of the total nitrogen concentration (based on a summary of monitoring and research data by Marjanovic (1989) and is not readily bioavailable.

Phosphorus in Lake Tahoe

Jassby et al. (1995) calculated the average total phosphorus concentration for Lake Tahoe to be 6.3 µg/L. Phosphorus in lake water is typically defined by the analysis method. Particulate phosphorus is approximately 10 percent of the whole-lake total phosphorus. As was observed for nitrogen, most of the lake's phosphorus is in the dissolved form. The total dissolved phosphorus fraction can be further divided into soluble reactive phosphorus and dissolved organic phosphorus. The total acid hydrolyzable-phosphorus (THP) represents the portion of total phosphorus that is converted to ortho-phosphate during chemical analysis. The THP is intended to represent the potentially bioavailable phosphorus.

Long-term Nitrogen and Phosphorus Trends

In the mid-1980s Lake Tahoe began to experience an increase in nitrogen from atmospheric deposition directly onto the lake surface (Jassby et al. 1994). Atmospheric deposition provides most of the dissolved inorganic nitrogen and total nitrogen in the annual nutrient load. Increased amounts of atmospheric nitrogen have caused an observed shift from co-limitation by nitrogen and phosphorus to persistent phosphorus limitation in the phytoplankton community (Jassby et al. 1994, 1995, and 2001).

Algal growth studies also support the finding of increased nitrogen in Lake Tahoe; these long-term bioassay experiments show a shift from co-limitation by both nitrogen and phosphorus, to predominant phosphorus limitation (Goldman et al. 1993).

3.5 Lake Dynamics

Thermal Stratification and Deep Lake Mixing

Thermal stratification and deep lake mixing are common and natural processes in lakes, including Lake Tahoe. In Lake Tahoe between February and April, distinct temperature layers develop at different depths of the lake due to heating by the sun. The layers have different densities that impede top-to-bottom movement of water and pollutants. The thermocline is the zone between the warm, lower density surface layer and the cool, dense lower layer. In Lake Tahoe the thermocline is strongest between late July and early September, at a depth of approximately 21 meters (Coats et al. 2006).

As summer progresses into fall, surface temperature is reduced and the thermocline weakens and deepens slowly until winter when vertical mixing, or turnover, occurs. Mixing, or de-stratification, generally occurs during autumn and winter due to cooling air temperatures and wind (Pamlarsson and Schladow 2000). Lake depth, size, shape, and meteorological conditions also influence mixing and the stratification processes. Deep mixing occurs when the water column is isothermal. The depth of vertical mixing in Lake Tahoe varies from about 100 meters to the bottom of the lake at about 500 meters, depending on the intensity of winter storms. On average, Lake Tahoe mixes to the bottom once every four years, which is a statistical average because mixing does not happen on a regular schedule.

Lake mixing is an important part of nutrient cycling and fine sediment particle dynamics in Lake Tahoe. Mixing brings nutrient-rich waters from deeper portions of the lake up to the surface, where together with pollutants introduced by surface runoff, sub-surface flow, and atmospheric deposition, the nutrients can be utilized by algae and contribute to reduced lake clarity. There is a positive correlation showing that increased depth of mixing during the winter results in increased algal growth the following summer (Goldman and Jassby 1990a, b).

During sustained summer wind events, surface water can be forced downward and, in response, colder, deeper water rises to the surface by a process called upwelling. During summer upwelling events, the Secchi depth often exceeds 30 meters because the water brought to the surface has a low number of fine sediment particles, resulting in an increased transparency (Pamlarsson and Schladow 2000). Lake mixing that occurs following destratification and formation of isothermal conditions affects the entire lake; whereas during upwelling, thermal stratification remains intact with the transport of deep waters. Upwelling is a transient condition that is location-dependent and not a whole-lake phenomenon.

Another important hydrodynamic process in Lake Tahoe occurs as streams discharge to the lake. Water temperature, associated water density, and stream flow have a profound impact on the depth at which stream water is inserted into the lake (Perez-Losada and Schladow 2004). Stream water carries significant sediment loads to Lake Tahoe; therefore, the depth at which stream water mixes in the lake has the potential to significantly affect lake transparency. Cold, dense stream flow and associated sediment loads will insert deeper in the lake while warmer flows will insert at shallower depths and have a more immediate impact on transparency.

Since 1970, Lake Tahoe has warmed at an average rate of 0.015 degrees Celsius per year (Coats et al. 2006). This has increased the thermal stability, increased the resistance to mixing, reduced the depth of the October thermocline, and shifted the onset of stratification toward earlier dates. The continuing impact of warming on biological communities and water quality is a concern. Chapter 12, Adaptive Management, includes additional information regarding climate change and its potential impact on Lake Tahoe's transparency.

A Higher Deep-Chlorophyll Maximum

Over the years, the deep-chlorophyll maximum in Lake Tahoe has risen in the water column to a shallower depth (Goldman 1988, Swift 2004). The deep-chlorophyll maximum (a common feature in summer and early autumn) does not directly influence the Secchi depth of 20 – 30 meters because the deep-chlorophyll maximum is deeper at 60 – 100 meters (Coon et al. 1987). However, the particles of the deep-chlorophyll maximum can affect clarity during the initial periods of lake mixing when they are swept up to the surface waters.

The deep-chlorophyll maximum is the depth where the highest concentrations of chlorophyll *a* are found.

3.6 Nearshore Water Quality

Like the deeper, open waters (mid-lake) of Lake Tahoe, the nearshore area also has water quality problems. The nearshore is the primary point of contact that the residential and tourist populations have with Lake Tahoe. Since nearshore areas are obvious to even the casual observer, and impairment can interfere with aesthetic and recreational enjoyment, scientific data has been collected from the nearshore. However, this TMDL addresses the deep water clarity and transparency of the lake and does not focus on the nearshore conditions. Consequently, this section provides a cursory view of the nearshore characteristics.

The definition of nearshore, for the purpose of the Lake Tahoe TMDL, is the area that extends from the lake shoreline to about 20 meters of water depth. This definition differs from the TRPA Code of Ordinances definition, which is "the zone extending from the low water elevation of Lake Tahoe (6,223.0 feet Lake Tahoe Datum) to a lake bottom elevation of 6,193.0 feet Lake Tahoe Datum, but in any case, a minimum lateral distance of 350 feet measured from the shoreline."

The nearshore area is affected by surface loading either as direct discharge, tributary inflow, and groundwater loading. Watershed runoff must first pass through the nearshore area on route to the deeper waters. Nearshore water quality is historically indicated by turbidity which is a measurement of cloudiness in the water caused by suspended particles. Turbidity is expressed as nephelometric turbidity units (NTU) with higher values indicating less clarity, or greater cloudiness (Taylor et al. 2003). A Secchi disk is not used to measure nearshore transparency because the water is not deep enough and the disk can be readily seen on the bottom. Another indicator of nearshore water quality is the abundance and distribution of periphyton, or attached algae. These attached algae are typically seen as a filamentous form which often grows at nuisance levels. These filamentous algae also support epiphytic algae which are either single-celled or cell clusters that grow attached to the larger filaments. The growth of both forms of attached algae is stimulated when nitrogen and phosphorus are present in the water column.

Since 1995, Eurasian watermilfoil (*Myriophyllum spicatum*), the rooted aquatic plant, has experienced a dramatic spread in the nearshore region relative to historic conditions (Anderson et al. 2004). Ecosystem impacts related to milfoil in Lake Tahoe have been investigated with respect to water quality and the facilitation of other invasive aquatic species (e.g. Walter 2000, Kamerath et al. 2008).

3.6.1 Turbidity

Stormwater runoff, including spring time snow melt and summer thunderstorms, carries turbid water from the upland into the tributaries or directly into the nearshore. Studies by Taylor, et. al. (2003) showed that turbidity in the nearshore is typically less than 0.15 NTU, but was as high as 20 NTU in certain places. High turbidities, those defined by Taylor et al. (2003) as levels above 0.25 NTU, were directly influenced by runoff from developed areas. Less than five percent of the entire Lake Tahoe shoreline had turbidities above 0.25 NTU during a runoff event. The highest turbidities, which were found along the south shore areas, were influenced by runoff from a developed area. Most of south shore's developed areas drain into either the Upper Truckee River, Trout Creek, or Bijou Creek, and the mouths of these three tributaries were directly associated with the highest turbidities in the nearshore.

The interaction of stream inflows, resuspension of bottom sediments, nearshore processes, and deep water (mid-lake) conditions, is poorly understood. Nearshore turbidity measurements cannot be used to determine the flux of fine sediment particles into the lake and are not substitutes for directly monitoring the streams and culverts that discharge into the lake. Currently, scientists do not know how nearshore turbidity affects deep water transparency (Taylor et al 2003).

3.6.2 Attached Algae

In studying Lake Tahoe's deep water transparency, Goldman (1974) measured initial nearshore conditions and concluded that the first visible evidence of Lake Tahoe's trend towards eutrophication was the increased growth of attached algae along the shoreline in the 1960s. The accumulation of attached algae on rocks, piers, boats, and other hard-bottomed substrates is a striking indicator of Lake Tahoe's declining water quality. Thick, green or white expanses of periphyton biomass often coat the shoreline in portions of the lake during the spring. When this material dies and breaks free, beaches can be littered with mats of algae.

The urbanized northwest area of Lake Tahoe has significantly more growth of attached algae than does the undeveloped east shore area, both recently (2000 – 2003) and historically (1982 – 1985) (Hackley et al. 2004, 2005). Additionally, growth of attached algae exhibits a distinct seasonal pattern:

- In spring and early summer, high biomass accrual occurs because growth is stimulated by elevated nitrogen and phosphorus loads from spring surface runoff and groundwater flow (Loeb 1986, Reuter and Miller 2000).
- In mid-summer, biomass dies-off and sloughs away. By July, biomass returns to near its annual baseline level.

For the past 40 years, attached algae have not received much study while deep water transparency has been the focus of scientific attention. Since it is not known what relationships, effects, or influences attached algae have on the deep water transparency, this TMDL does not address the attached algae issue. Water Board and NDEP staff believe that actions to improve the transparency may have positive effects on the nearshore conditions by indirectly reducing turbidity and attached algal mass. However, additional research is needed to better understand the nearshore conditions and how management actions in the upland areas may influence those conditions.

4 Problem Statement

Assessment of monitoring data collected since 1968 has revealed the degradation of pelagic (deep water) water quality conditions as measured by two distinct indicators. The status and trend of distinct indicators for both transparency and clarity indicate that pelagic lake water quality conditions remain degraded relative to historic levels.

4.1 Transparency Decline

Transparency is expressed as Secchi depth, which is the depth to which an observer can see a 25-cm diameter white disk lowered into the water from the surface.

Continuous long-term evaluation of water quality in Lake Tahoe between 1968 and 2009 has documented a decline of water transparency from an annual average of 31.2 meters to 20.8 meters, respectively (Jassby et al. 1999, 2003, UC Davis - TERC 2010). Transparency is expressed as Secchi depth and is the depth to which an observer can see a 25 cm (10 inch) diameter white disk lowered into the water from the surface. This long-term loss of transparency (Figure 4-1) is both statistically significant ($p < 0.001$) and visually apparent to some users of the lake. Measurements have been taken at the same location since monitoring began with only two observers collecting this data, thereby reducing human variability in the field. Secchi depth is recorded throughout the entire year and each annual average is composed of between 25 to 35 individual readings. Jassby et al. (1999) provides estimates of precision.

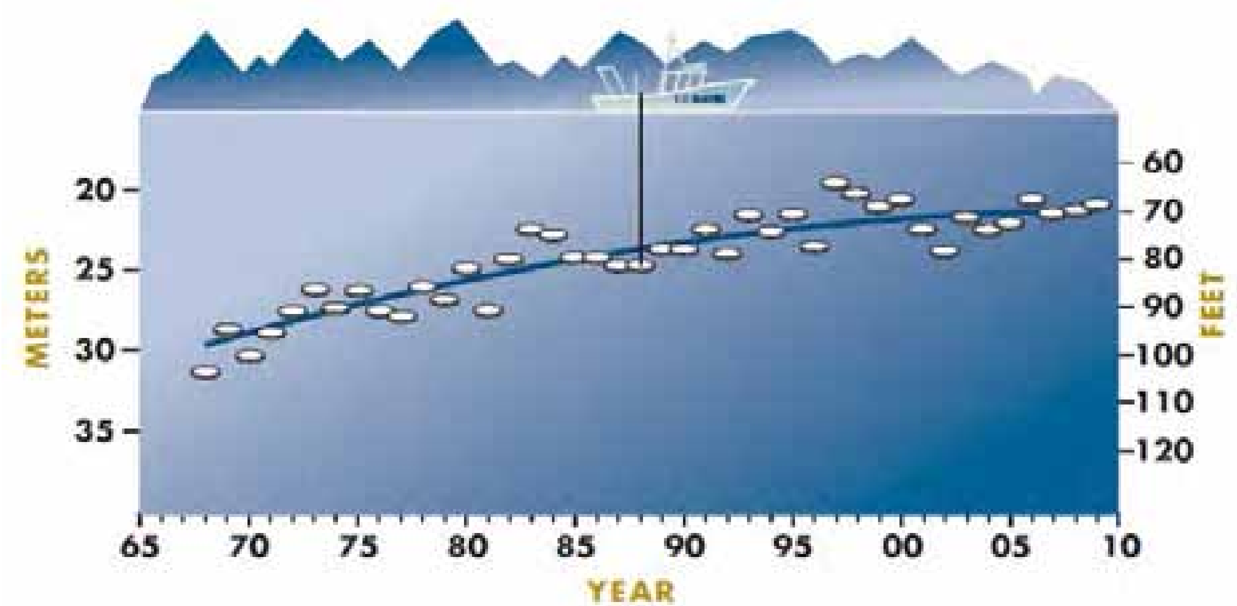

Figure 4-1. Average Annual Secchi Depth measurements (UC Davis – TERC 2010).

Based on the most recent Secchi depth data for 2009 and applying a more sophisticated statistical approach known as a *generalized additive model*, it was recently reported that between 2001 and 2009 there was an apparent slowing in the rate of transparency loss (UC Davis - TERC 2010). Researchers caution that the rate of transparency loss could change. The nine years of most recent data is insufficient to declare with certainty that the apparent slowing will be sustained into the future. Since even the most recent annual Secchi depth value of 20.8 meters (68.1 feet) measured in 2009 is about 8.9 meters (29.3 feet) less than the water quality standard and TMDL target of 29.7 meters (97.4 feet), the impairment to water quality is significant. The steady decline of Secchi depth can be seen with the average annual Secchi depth values from 1968 through 2009 (Table 4-1).

Table 4-1. Annual Average Secchi Depth values for the period of record (UC Davis – TERC unpublished). Measurements are made year-round at a rate of between 25 to 35 times per year.

Year	Secchi Depth (meters)	Year	Secchi Depth (meters)
1968	31.2	1989	23.6
1969	28.6	1990	23.6
1970	30.2	1991	22.4
1971	28.7	1992	23.9
1972	27.4	1993	21.5
1973	26.1	1994	22.6
1974	27.2	1995	21.5
1975	26.1	1996	23.5
1976	27.4	1997	19.5
1977	27.8	1998	20.1
1978	26.0	1999	21.0
1979	26.7	2000	20.5
1980	24.8	2001	22.4
1981	27.4	2002	23.8
1982	24.3	2003	21.6
1983	22.4	2004	22.4
1984	22.8	2005	22.1
1985	24.2	2006	20.6
1986	24.1	2007	21.4
1987	24.7	2008	21.2
1988	24.7	2009	20.8

UC Davis scientists calculate the annual average Secchi depth by using a method commonly referred to as trapezoidal integration. First, linear interpolation is used between sampling points (Secchi depth measurements) to compute daily values. Then the daily values are summed for the year and divided by the number of days in the year to derive the annual average Secchi depth (Arneson 2010 personal communication).

The long-term transparency decline is addressed in several ways. California has a nondegradation policy. Additionally, Lake Tahoe is federally designated as an

Outstanding National Resource Water (ONRW). In 1998 Lake Tahoe was listed in California as water quality-limited, as mandated by the Federal Clean Water Act Section 305(b). That same year, Lake Tahoe was included on California's Section 303(d) list of impaired waterbodies requiring development of TMDLs (SWRCB 2003).

4.2 Clarity Decline

In addition to a shallower Secchi depth (transparency), Lake Tahoe also now has a shallower depth for the vertical extinction of light (clarity; Figure 4-2). This means that light cannot penetrate as deep into the water. The light penetration zone (or euphotic zone as defined as the approximate depth where algal photosynthesis and respiration are equal and primary productivity goes to zero), has been as deep as about 100-110 meters at Lake Tahoe (Coon et al. 1987), but over the past decade has largely ranged from 70-80 meters. In 2002 and 2006, Lake Tahoe was placed on Nevada's Section 303(d) list of impaired waterbodies (NDEP 2002, 2006) for nonattainment of the clarity standard.

Clarity is expressed as the vertical extinction of light, as measured by a vertical extinction coefficient (VEC), which is the fraction of light held back (or extinguished) per meter of water depth by absorption and scattering.

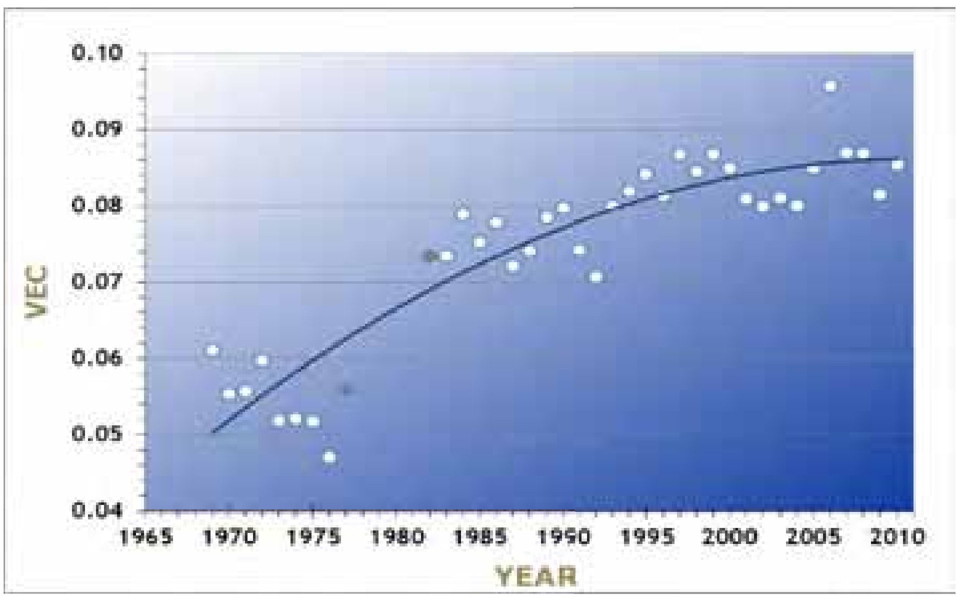

Figure 4-2. Annual average VEC measurements taken for the period of record, 1969-2010 (UC Davis TERC 2011). White data points represent annual averages where data was available for the entire year (approximately 25-35 measurements spaced over the calendar year). Gray data points are averages of partial data collection years (1977 and 1982). Data was not reported for 1967, 1968 and between 4/21/77 and 7/6/82 due to instrument malfunction (UC Davis TERC – 2011).

5 Water Quality Standards

As required by the federal Clean Water Act, the states of California and Nevada have established beneficial uses, water quality objectives, and non-degradation objectives for Lake Tahoe. Additionally, the Tahoe Regional Planning Agency (TRPA) has developed and implemented goals, threshold standards, and indicators for the Lake Tahoe basin. This chapter summarizes the regulatory framework of the federal Clean Water Act, as well as state and regional regulatory agencies' water quality standards.

5.1 The Federal Clean Water Act

The federal Clean Water Act establishes a regulatory framework to restore degraded surface waterbodies. The act directs the states to adopt water quality standards for waterbodies, subject to USEPA approval. These water quality standards are to protect public health or welfare, to enhance the quality of water, and to serve the purposes of the Clean Water Act by helping to "restore and maintain the chemical, physical and biological integrity" of state waters (Clean Water Act section 101(a)). Accordingly, states must designate beneficial uses of the water, set objectives (numeric or narrative) to protect the uses, and maintain high quality waters by means of non-degradation provisions.

5.2 States of California and Nevada

The state of California protects beneficial uses of waters and water quality through the California Water Code implemented by the State Water Resources Control Board (State Board) and nine California Regional Water Quality Control Boards (Regional Water Boards). The California Regional Water Quality Control Board, Lahontan Region (Water Board) is responsible for the Lake Tahoe basin, as well as areas from the Oregon border to the northern Mojave Desert, east of the Sierra Nevada crest. The State Board sets statewide policy in implementing state and federal laws and regulations, and the nine Regional Water Boards adopt and implement Water Quality Control Plans (Basin Plans).

Basin Plans set forth water quality standards for the surface and groundwater of the region, by establishing designated beneficial uses and the objectives (narrative and/or numerical) that must be attained and maintained to protect beneficial uses. Basin Plans implement a number of state laws and federal programs, the most important of which are the federal National Pollutant Discharge Elimination System Permit program and the state Porter–Cologne Water Quality Control Act (California Water Code § 1300 et seq).

The state of Nevada protects water quality through the Nevada Water Pollution Control Law as implemented by the Department of Conservation and Natural Resources, Division of Environmental Protection (NDEP). NDEP is responsible for developing and implementing comprehensive plans to reduce or eliminate water pollution including those that affect the Lake Tahoe basin.

5.2.1 Beneficial Uses and Water Quality Objectives

In addition to a number of other designated uses, the states of California and Nevada have identified the visual aesthetics of Lake Tahoe's water as a quality to be protected through designation of the following beneficial uses: "non-contact water recreation" (in California) and both "water of extraordinary ecologic or aesthetic value" and "recreation not involving contact with water" (in Nevada). Accordingly, the two states also established numeric water quality objectives/standards to protect these beneficial uses which include indicators of water column optical properties, nutrient concentrations, and various biological indicators (Table 5-1).

Table 5-1. California and Nevada numeric objectives related to the aesthetic beneficial uses of Lake Tahoe.

Parameter	California[a]	Nevada[b]
Clarity	The vertical extinction coefficient must be less than 0.08 per meter when measured at any depth below the first meter. Turbidity must not exceed 3 NTU at any point of the lake too shallow to determine a reliable extinction coefficient. In addition, turbidity shall not exceed 1 NTU in shallow waters not directly influenced by stream discharges. The Regional Board will determine when water is too shallow to determine a reliable vertical extinction coefficient based upon its review of standard limnological methods and on advice from the UC Davis Tahoe Research Group.	The vertical extinction coefficient must be less than 0.08 per meter when measured at any depth below the first meter. Turbidity must not exceed 3 NTU at any point of the lake too shallow to determine a reliable extinction coefficient.
Transparency	The Secchi disk transparency shall not be decreased below the levels recorded in 1967-1971, based on a statistical comparison of seasonal and annual mean values. The 1967-1971 levels are reported in the annual summary reports of the "California – Nevada – Federal Joint Water Quality Investigation of Lake Tahoe" published by the California Department of Water Resources. [Note: the 1967-1971 annual mean Secchi depth was 29.7 meters.]	NA[C]
Soluble Phosphorus (mg/L)	NA[C]	Annual Average $\leq$ 0.007
Total Phosphorus (mg/L)	Annual Average $\leq$ 0.008	NA[C]
Total Nitrogen (as N) (mg/L)	Annual Average $\leq$ 0.15	Annual Average $\leq$ 0.25 Single Value $\leq$ 0.32
Total Soluble Inorganic Nitrogen (mg/L)	NA[C]	Annual Average $\leq$ 0.025
Algal Growth	The mean annual algal growth potential at any point in the lake	The mean annual algal growth

Parameter	California[a]	Nevada[b]
Potential	must not be greater than twice the mean annual algal potential at a limnetic reference station. The limnetic reference station is located in the north central portion of Lake Tahoe. It is shown on maps in annual reports of the Lake Tahoe Interagency Monitoring Program. Exact coordinates can be obtained from the UC Davis Tahoe Research Group.	potential at any point in the lake must not be greater than twice the mean annual algal potential at a limnetic reference station and using analytical methods determined jointly with the EPA, Region IX.
Plankton Count (No./mL)	Mean seasonal $\leq$ 100	Jun – Sep Average $\leq$ 100
	Maximum $\leq$ 500	Single Value $\leq$ 500
Biological Indicators	Algal productivity and the biomass of phytoplankton, zooplankton, and periphyton shall not be increased beyond the levels recorded in 1967-1971 based on statistical comparison of seasonal and annual means. The 1967-1971 levels are reported in the annual summary reports of the "California – Nevada – Federal Joint Water Quality Investigation of Lake Tahoe" published by the California Department of Water Resources. [Note: The numeric criterion for algal productivity (or Primary Productivity, PPr) is 52 g C m^{-2} y^{-1} as an annual mean.]	NA[C]

[a] Provision in State Regulation: Water Quality Control Plan for the Lahontan Region (LRWQCB 1995)
[b] Provision in State Regulation: Nevada Administrative Code 445A.191
[c] No applicable numeric water quality objectives or standards

Water Column Optical Properties

Secchi depth (transparency) is a measure of how far the human eye can see down through the water column and is a measure for deep water. Specifically, Secchi depth is the depth to which an observer can see a 25-cm diameter white disk lowered into the water from the surface. The Water Board has adopted a Secchi depth transparency objective. Nevada has not adopted a transparency water quality objective but NDEP is evaluating the need for a similar standard.

The vertical extinction of light (clarity), which California and Nevada have both adopted as a water quality objective for Lake Tahoe, is a measure of how far light can penetrate the water column, and thus is also a measure for deep water clarity. The vertical extinction of light is described as a vertical extinction coefficient (VEC), which is the fraction of light held back (or extinguished) per meter of water depth by absorption and scattering. Therefore, higher VEC values indicate less clarity. Light can penetrate the water column farther than the eye can see; thus, the vertical extinction of light extends beyond the Secchi depth. The vertical extinction coefficient was measured using a sensor that captured light in the 400-700 nm range, otherwise known as photosynthetically active radiation.

Turbidity is a measure of water cloudiness primarily caused by suspended sediment. Turbidity standards in the lake have generally been applied in the shallow, nearshore water as turbidity measurements in deep waters are at or below the method detection limits. Neither Secchi depth nor VEC is appropriate for shallow, nearshore water due to the lack of sufficient depth for accurate measurements.

5.2.2 Nondegradation Objectives

All California water bodies are subject to a nondegradation objective that requires continued maintenance of high quality waters. Additionally, in 1980 the Water Board and USEPA designated Lake Tahoe an Outstanding National Resource Water (ONRW) which requires the highest level of protection under the nondegradation objective.

The Regional Board, in its Basin Plan, also emphasizes Lake Tahoe's outstanding qualities (LRWQCB 1995):

> *Lake Tahoe's exceptional recreational value depends on enjoyment of the scenic beauty imparted by its clear, blue waters.*

The State of Nevada's antidegredation policy is contained in Nevada Revised Statutes (NRS) 445A.565; it states:

> *Any surface waters of the state whose quality is higher than the applicable standards of water quality as of the date when those standards became effective must be maintained in their higher quality. No discharges of waste may be made which will result in lowering the quality of these waters unless it has been demonstrated to the commission that the lower quality is justifiable because of economic or social considerations*.

While Nevada has not officially designated Lake Tahoe an ONRW as California has, its special significance is indicated by it being the only waterbody in the state with the beneficial use designation of "water of extraordinary ecological or aesthetic value"

5.3 Tahoe Regional Planning Agency

To protect Lake Tahoe, the California and Nevada legislatures agreed to create the Tahoe Regional Planning Agency (TRPA) in 1969 by adopting the Tahoe Regional Planning Compact. The Compact, as adopted by the 96th Congress of the United States, defines the purpose of the TRPA (TRPA 1980):

> *To enhance governmental efficiency and effectiveness of the Region, it is imperative there be established a Tahoe Regional Planning Agency with the powers conferred by this compact including the power to establish environmental threshold carrying capacities and to adopt and enforce a regional plan and implementing ordinances which will achieve and maintain such capacities while providing opportunities for orderly growth and development consistent with such capacities.*

The Compact also emphasizes minimizing development-related disturbances in the Lake Tahoe basin by calling for a "land use plan for the…standards for the uses of land, water, air space and other natural resources within the Region…" (Article V(c)(1)). The

Land Use Element includes the Water Quality sub-element, which is introduced with the following language (TRPA 1980):

The purity of Lake Tahoe and its tributary streams helps make the Tahoe basin unique. Lake Tahoe is one of the three clearest lakes of its size in the world. Its unusual water quality contributes to the scenic beauty of the Region, yet it depends today upon a fragile balance among soils, vegetation, and man. The focus of water quality enhancement and protection in the basin is to minimize man-made disturbance to the watershed and to reduce or eliminate the addition of pollutants that result from development.

5.3.1 Goals

The TRPA Compact established several policies related to water quality planning and implementation programs. Relative to standards, the Compact states that the Regional Plan shall provide for attaining and maintaining federal, state or local water quality standards, whichever are the most stringent.

In addition to the establishment of Numerical, Management and Policy standards for water quality, the TRPA's Regional Plan focuses on two water quality goals:

GOAL #1: Reduce loads of sediment and algal nutrients to Lake Tahoe; Meet sediment and nutrient objectives for tributary streams, surface runoff, and subsurface runoff, and restore 80 percent of the disturbed lands.

GOAL #2: Reduce or eliminate the addition of other pollutants that affect, or potentially affect, water quality in the Tahoe basin.

5.3.2 Threshold Standards and Indicators

To achieve its goals, the TRPA established a number of threshold standards and indicators that include numeric objectives for protection of lake clarity. The relevant threshold standards and indicators are listed below.

WQ-1 Littoral (Nearshore) Lake Tahoe

Threshold Standard: Decrease sediment load as required to attain turbidity values not to exceed 3 NTU in littoral Lake Tahoe. In addition, turbidity shall not exceed 1 NTU in shallow waters of Lake Tahoe not directly influenced by stream discharge.

Indicator: Turbidity offshore at the 25-meter depth contour at 8 locations, both near the mouths of tributaries and away from the tributaries.

WQ-2 Pelagic Lake Tahoe, Deep Water

Threshold Standard: Average Secchi depth, December–March, shall not be less than 33.4 meters[3].

Indicator: Secchi depth, winter average; Tahoe Research Group (now Tahoe Environmental Research Center) index stations (meters).

The TRPA and California objectives for deep water transparency are different regarding Secchi measurement. The TRPA uses a winter (December – March) average while California uses an annual average.

5.3.3 Regional Plan Update

The TRPA is updating its Regional Plan, Code of Ordinances, and Environmental Threshold Carrying Capacities (thresholds). In its 2006 Threshold Evaluation report, TRPA stated that it will use the recommended threshold updates as the platform to construct the new Regional Plan. The incorporation of recommended threshold updates into the Regional Plan will occur using a phased approach because additional research is required to update standards. Initial updates to thresholds in the first phase will be small, with broader changes anticipated in the second phase. Basic to this strategy is that TRPA and its partners will develop and implement the new Regional Plan Package including the needed institutional relationships, the adaptive management system, and the financing package for the EIP update.

The TRPA 2006 Threshold Evaluation report recommended targeting projects/best management practices for removal of phosphorus and fine sediment, intensifying sweeping and maintenance of road rights-of-way to remove fine sediment, and to shift the management of stormwater discharge limits to TMDL-based pollutant load reductions, including tracking and modeling these pollutant loads with the models developed under the TMDL process. TRPA also recommended changing its WQ-2 threshold to be consistent with the transparency water quality objective as stated in Lahontan Water Board's Basin Plan. Specifically, TRPA proposes to use the annual average Secchi depth of 29.7 meters as its updated threshold standard for deep water transparency.

TRPA based this proposed threshold change on the recommendations of the Water Quality Technical Working Group. This technical group, convened in late 2004 through 2007 as part of a larger Tahoe basin Pathway process, consisted of a committee of scientists and Lake Tahoe agency representatives who reviewed certain TRPA thresholds and recommended changes to improve consistency among the TRPA thresholds, Basin Plan, NDEP regulations, and the USFS Forest Plan. In addition to reviewing the water quality standards and thresholds, the Water Quality Technical

[3] 109.6 feet

Working Group developed a desired condition statement for Lake Tahoe clarity, so all stakeholders, including regulators, project implementers, and the public at large, could align individual plans to the same goal:

> ***Lake Tahoe Clarity Desired Condition****: Restore, then maintain the waters of Lake Tahoe for the purposes of human enjoyment and preservation of its ecological status as one of the few large, deepwater, ultraoligotrophic lakes in the world with unique transparency, color and clarity.*

Regional Board and NDEP staff will continue working with TRPA to ensure that updates to TRPA's Regional Plan do not conflict with the requirements under this TMDL.

6 Numeric Target

The purpose of the Lake Tahoe TMDL is to develop a plan for restoring Lake Tahoe's historic transparency and clarity. The Water Board, Nevada Division of Environmental Protection (NDEP), and the Tahoe Regional Planning Agency (TRPA) identified the visual aesthetics of Lake Tahoe's clarity as a beneficial use affording Lake Tahoe a high level of protection. As discussed in Chapter 5, each of the three entities adopted its own water quality objectives to protect Lake Tahoe's aesthetic beneficial use, but not all of the objectives are the same.

Nevada's antidegredation policy requires any surface waters whose quality is higher than the applicable standards of water quality as of the date when those standards became effective to be maintained in their higher quality. However, California antidegredation policy requires surface waters to be maintained in higher quality. Similarly, federal antidegredation policy prohibits the long-term degradation of ONRWs like Lake Tahoe. The TRPA Compact specifies that their regional plan shall provide for attaining and maintaining Federal, State or local water quality standards, whichever are strictest in the respective portions of the region for which the standards are applicable. For multi-jurisdictional waterbodies, the U.S. Environmental Protection Agency recommends that States develop a TMDL target to protect the most sensitive use or objective. The deep water transparency water quality objective was identified as the most sensitive objective and thus the most appropriate to satisfy the multi-jurisdictional policies and objectives. The TMDL numeric target is therefore defined as 29.7 meters average annual Secchi depth.

It is also important to emphasize that attainment of the transparency water quality objective is also expected to result in achievement of the clarity standard. As stated previously, the Lake Tahoe TMDL focuses solely on the deep water transparency and clarity, and does not address shallow, nearshore conditions of the lake.

6.1 Transparency and Clarity Objectives

The Water Board has both transparency and clarity water quality objectives, while Nevada has only adopted a clarity standard. In consideration of the multi-jurisdictional aspects of Lake Tahoe, the relationship between the transparency and clarity objectives was evaluated to determine the most appropriate TMDL numeric target.

6.1.1 Transparency (Secchi Depth) vs. Clarity (VEC) Objectives

Transparency of Lake Tahoe's deep water is measured by lowering a 25 centimeter diameter Secchi disk into the water until the disk cannot be seen from directly above. The Water Board transparency water quality objective states:

For Lake Tahoe, the Secchi disk transparency shall not be decreased below the levels recorded in 1967-1971, based on a statistical comparison of seasonal and annual mean values. The "1967-71 levels" are reported in the annual summary reports of the "California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe" published by the California Department of Water Resources.

The State Water Resources Control Board adopted a Statement of Policy with respect to Maintaining High Quality of Waters in California in 1968 (Resolution No. 68-16). The 1967-1971 period of record was selected to set a baseline average Secchi depth condition and a restoration target that corresponded to this resolution adoption date. The annual average Secchi depth value established by the Water Board for this time period is 29.7 meters.

Deep water *clarity* is measured as the vertical extinction coefficient (VEC) of light in the water column. California and Nevada both have the same clarity objective for deep water in Lake Tahoe:

The vertical extinction coefficient must be less than 0.08 per meter when measured at any depth below the first meter.

The VEC is a measurement of the fraction of light held back per meter of water from particle absorption and scattering (Goldman and Horne 1983). VEC, which measures light penetration deeper in the water column than the Secchi depth, is calculated as the slope of the log-transformed vertical light data. University of California Davis Tahoe Environmental Research Center (UC Davis TERC) researchers have determined the most appropriate depth range over which to measure and calculate VEC is 2-75 meters. This band encompasses the entire photic zone (as defined by the 1% light level) where nearly all the light-based biology occurs (UC Davis TERC 2011).

The relationship between mean VEC and mean Secchi depth readings in Lake Tahoe was examined for the period of record[4] (Figure 6-1; UC Davis TERC 2011). Between the years 1969-1971, annual average VEC measurements ranged from 0.055/m – 0.061/m, which correspond to annual average Secchi depths between 28.5-30.2 meters. According to the best fit equation, a VEC value of 0.08/m is comparable to a Secchi depth of approximately 22 meters, nearly 8 meters different from actual conditions measured between 1967-1971. These observations show that the California water quality objective for average annual transparency (i.e. Secchi depth) is the only TMDL numeric target capable of satisfying water quality objectives/standards of both states.

[4] The period of record for VEC is 1969 thru 2010; data collected from 1967 thru 1968 and between 4/21/77 and 7/6/82 were determined to be unreliable due to instrument malfunction. The period of record for Secchi depth is 1968 thru 2009; 1967 was a partial data collection year that did not allow for an anual average to be determined.

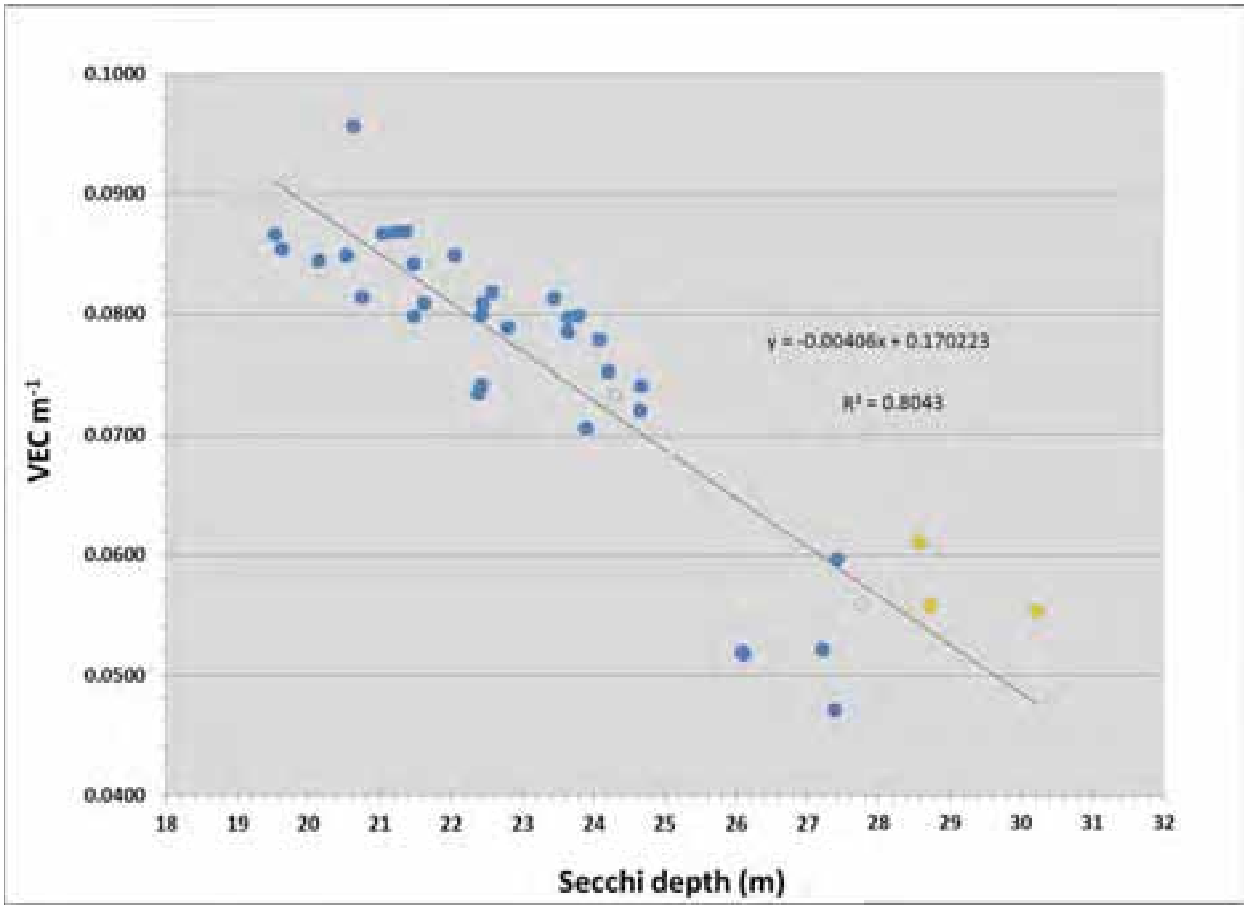

Figure 6-1. Annual average VEC plotted against annual mean Secchi depths for period of record - 1969-2010 (UC Davis TERC 2011). Orange circles represent 1969-1971 data; blue circles represent all other years; hollow circles represent partial data collection years (1977 and 1982).

6.1.2 TRPA Transparency Objective

The Tahoe Regional Planning Agency (TRPA) objective for deep water transparency is a winter Secchi depth of 33.4 meters. Based on the same 1968-1971 data set as the annual average Secchi depth, the TRPA objective specifies a winter average Secchi depth objective because measured light transmission is at its maximum during this season (Jassby et al. 1999). However, this objective does not account for seasonal variability. It overlooks the spring months when snowmelt results in the greatest pollutant loads being delivered to the lake as well as the summer which is typically when most people experience the visual quality of Lake Tahoe's deep water transparency. Furthermore, because the winter months coincide with upwelling events that bring clear water to the lakes surface, the winter seasonal average is more likely to be biased toward greater Secchi measurements. Consequently, the annual average Secchi depth of 29.7 meters (97.4 feet) is a more valid water quality objective.

6.2 Historic Transparency Data

The Water Board's transparency water quality objective references a Secchi depth dataset reported in the *California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe* (Department of Water Resources 1973). The University of California, Davis Tahoe Research Group (TRG) also measured Secchi depth during the same time period. These two datasets were collected during the reference period from 1967-1971 using different sample sites and different sized Secchi disks.

The California Department of Water Resources (DWR) used a 20 centimeter diameter, black and white quadrant, Secchi disk and measured deep water transparency at two stations generally along the California-Nevada state line for a total of 55 measurements. The DWR data show an average annual Secchi depth of approximately 25.5 meters. The DWR stopped collecting Secchi depth measurements at Lake Tahoe in 1974.

The TRG used a 25 centimeter diameter, all white Secchi disk and measured deep water transparency at a standardized index station for a total of 119 measurements between 1967 and 1971. The TRG data (UC Davis - TERC unpublished data) shows an average annual Secchi depth of 29.7 meters. UC Davis researchers continue to collect Secchi measurements at established monitoring points, providing more than 40 years of continuous transparency monitoring data.

The Lake Clarity Model and Lake Tahoe Watershed model analyses in this TMDL relied on the long term TRG Secchi depth data set. Because the UC Davis transparency data have been collected over a longer period and at a greater frequency than the DWR effort, the transparency objective and numeric target is based on the TRG data (UC Davis – TERC unpublished data). The Secchi depth measurements that were used to calculate the value of 29.7 meters were collected during each month with 29 ± 3 (mean ± standard deviation) individual measurements per year. Over the entire period of record Secchi depth continues to be measured within each month (year-round) at a frequency of 32 ± 4 (mean ± standard deviation) times per year.

6.3 Clarity Challenge

The Lake Tahoe TMDL program has developed an interim transparency goal called the Clarity Challenge. The Clarity Challenge proposes basin-wide fine sediment particle and nutrient load reductions adequate to achieve 24 meters annual average Secchi depth. Meeting the Clarity Challenge would mark a clear turning point from the decline in transparency and would represent a significant achievement in environmental restoration.

7 Source Analysis

This chapter summarizes the research and modeling work that generated the pollutant load estimates. Subsections describe research, monitoring, and modeling efforts for each source followed by discussions of relative confidence and methods used to convert sediment mass load estimates to number of fine sediment particles. This chapter highlights the complete information documented in the Lake Tahoe TMDL Technical Report (Lahontan and NDEP 2010).

7.1 Introduction

Data collected over the past 40 years within the Lake Tahoe Basin was used to estimate nitrogen, phosphorus, and fine sediment particle loading to the lake from five primary pollutant loading sources: upland runoff, atmospheric deposition, stream channel erosion, and shoreline erosion. As of 1968, all of Lake Tahoe's treated sewage effluent was pumped out of the basin; a management practice that continues to this day. Consequently, this source is not relevant with respect to this TMDL. Fine inorganic particles have a significant impact on Lake Tahoe's clarity (e.g. Jassby et al. 1999, Perez-Losada 2001, Swift 2004) Swift et al. (2006) concluded that inorganic particles contribute from 55 to 60 percent of the clarity loss while organic particles contribute up to 25 percent of the clarity loss. The Lake Clarity Model was developed with this understanding. For the source analysis, fine sediment is defined as material with a diameter of less than 63 micrometers (µm) in size. The Lake Clarity Model requires that these particles be divided into the seven size categories of 0.5 – 1µm, 1 – 2 µm, 2 – 4 µm, 4 – 8 µm, 8 – 16 µm, 16 – 32 µm, and 32 – 64 µm for input to the model (Perez-Losada 2001, Sahoo et al. 2007).

Existing knowledge, ongoing monitoring efforts by the Lake Tahoe Interagency Monitoring Program, and studies conducted specifically for the Lake Tahoe TMDL Program all helped increase the confidence in the pollutant loading estimates for the five pollutant sources and were used to convert fine sediment load estimates to fine sediment particle numbers. Pollutant loading estimates from the major source categories are summarized in Table 7-1 and Figure 7-1, Figure 7-2, and Figure 7-3. Of the particles less than 63 micrometers in diameter, it is the particles smaller than 16 micrometers in diameter that have the most impact on lake clarity. The number of particles less than 16 micrometers in diameter are reported in Table 7-1 and Figure 7-3.

Table 7-1. Pollutant Loading Estimates.

Source Category		Total Nitrogen (metric tons/year)	Total Phosphorus (metric tons/year)	Number of Fine Sediment Particles ($x10^{18}$)
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	0
Shoreline Erosion		2	2	1
TOTAL		397	46	481

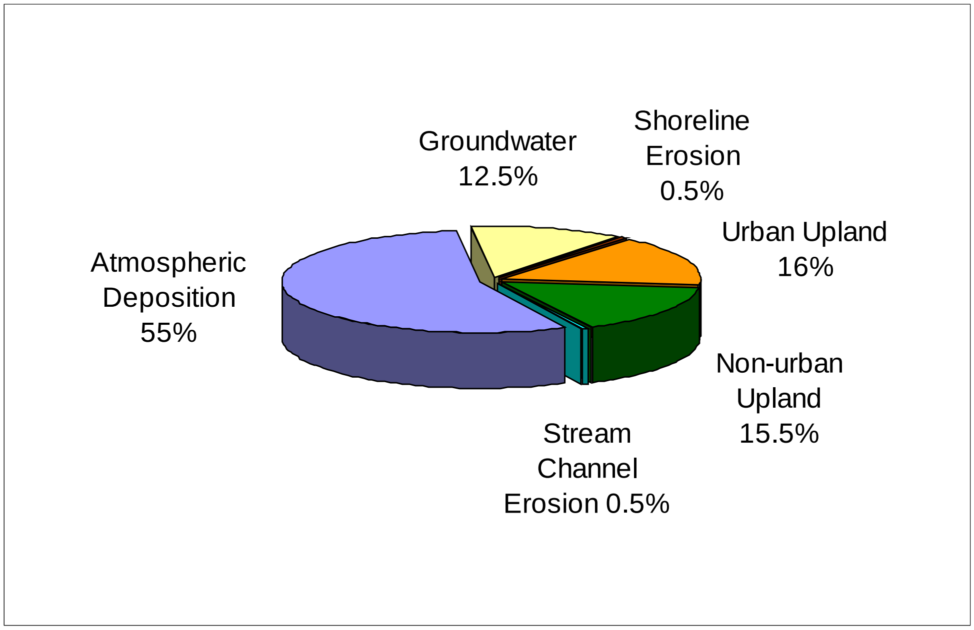

Figure 7-1. Percent Total Nitrogen Contribution per Source Category.

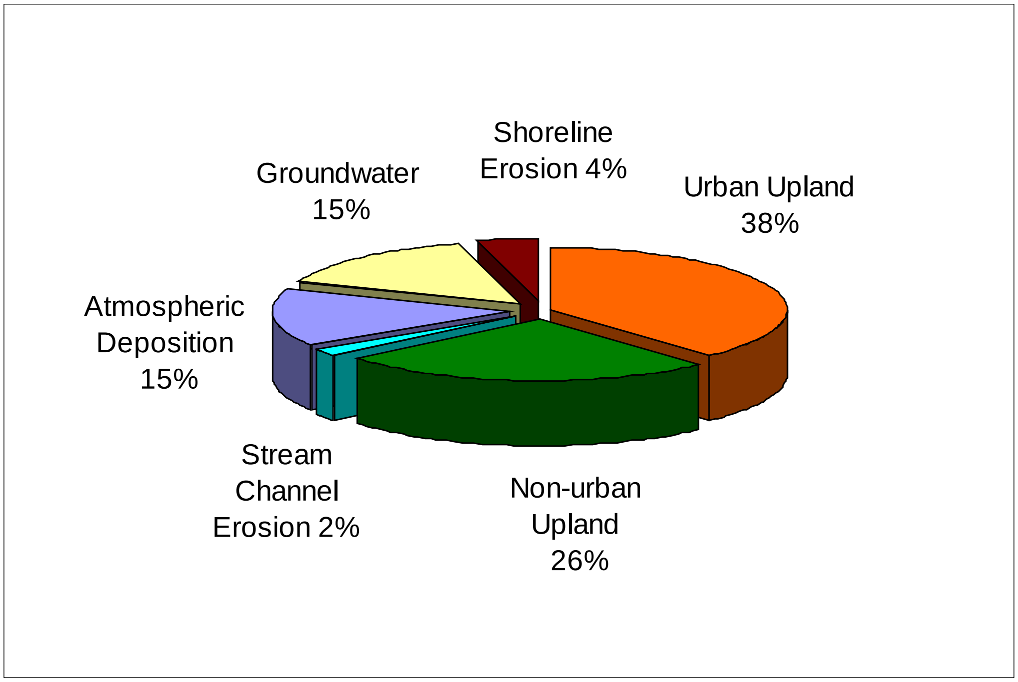

Figure 7-2. Percent Total Phosphorus Contribution per Source Category.

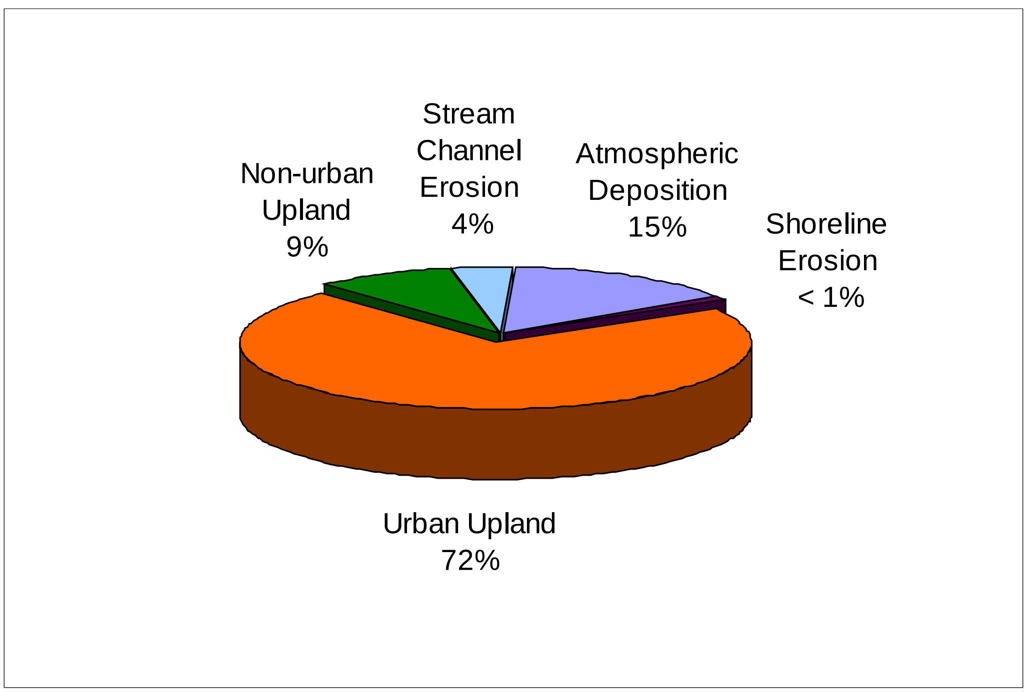

Figure 7-3. Percent Fine Sediment Particle (< 16 micrometer) Contribution per Source Category.

7.2 Groundwater

Groundwater flow contributes phosphorus and nitrogen to the lake at the aquifer-lake interface. To incorporate nutrient loading from groundwater into the Lake Clarity Model, existing data were re-evaluated. Note that fine sediment is not believed to be transported via groundwater and will not be discussed further in this section (S. Tyler 2003 personal communication, G. Fogg 2003 personal communication).

Thodal (1997) published the first basin-wide evaluation of groundwater quality and quantity from 1990-1992. His study provides a detailed evaluation of hydraulic gradient, hydraulic conductivity, and recharge-precipitation relationships. Thodal estimated total annual groundwater contributions based on these assessments. According to Thodal's study, the estimated annual groundwater contribution of nitrogen and phosphorus to the lake is 54 and 3.6 metric tons, respectively.

The United States Army Corps of Engineers (USACE) completed the *Lake Tahoe Basin Framework Study Groundwater Evaluation* (USACE 2003) as an independent assessment of Thodal's (1997) analysis. There were two notable differences between the Groundwater Evaluation approach (USACE 2003) and Thodal's work: (1) the USACE divided the Basin into six regions and six sub-regions based on jurisdictional boundaries and major aquifer limits; and (2) the USACE provided estimates of background nutrient contributions to Lake Tahoe.

The USACE (2003) study assumed no water was added to or taken from the system and the aquifers are homogenous. Nutrient concentrations were selected by one of three approaches. The first was an average concentration method that uses average measured phosphorus or nitrogen in each region. The second method evaluated downgradient nutrient concentrations to calculate the amount of phosphorus and nitrogen expected to reach the lake by proximity. The last approach was a land-use weighted concentration method that considered different development patterns within the identified groundwater regions.

Using these methods, the USACE developed regional/sub-regional groundwater discharge and nutrient loading estimates throughout the basin for the six delineated sub-regions. By combining the annual loads for the regions, the USACE generated an overall annual loading estimate for nitrogen and phosphorus for the entire Lake Tahoe basin that is very similar to Thodal's (1997) load estimate. USACE (2003) estimates are 50 metric tons of nitrogen annually and 6.8 metric tons of phosphorus annually.

7.3 Shoreline Erosion

Wave action and lake level fluctuation cause erosion of the Lake Tahoe shoreline as evidenced by the changing shape of the lake's shore over time. The Desert Research Institute (DRI) performed research to determine sediment and nutrient loading from shoreline erosion. *Historic Shoreline Change at Lake Tahoe from 1938 to 1994:*

Implications Sediment and Nutrient Delivery (Adams and Minor 2001) used aerial photographs to estimate the volume of material eroded by wave action from 1938-1994 to be 429,350 metric tons, or 7,150 metric tons per year. These maps and photographs were acquired from the Tahoe Regional Planning Agency (TRPA), United States Forest Service Lake Tahoe Basin Management Unit (LTBMU), and the United States Geological Survey (USGS). Sediment grab samples were collected from multiple shoreline locations to analyze the nutrient content of the eroded shorezone material.

The supplementary report *Shorezone Erosion at Lake Tahoe: Historical Aspects, Processes, and Stochastic Modeling* (Adams 2004) assessed the particle size distribution of collected shoreline sediment samples. The report estimates that of the total material annually eroded at the shoreline, an average annual load of 550 metric tons per year is silt and clay sized sediment (< 63 µm). The Water Board and NDEP staff used the information from Adams (2004) and converted the 550 metric tons of silt and clay to a total load of 1.08×10^{18} particles per year distributed into the seven size classes required for input to the Lake Clarity Model.

Based on the nutrient sampling data in Adams (2004), approximately 117 metric tons of phosphorus and 110 metric tons of nitrogen have been introduced into the lake because of shoreline erosion over the last 60 years. These volumes equate to approximately two metric tons of phosphorus per year and 1.8 metric tons of nitrogen per year. Shoreline erosion is therefore the smallest source of pollutants impacting Lake Tahoe's clarity and transparency.

7.4 Stream Channel Erosion

The first estimates of stream channel erosion were conducted by the USDA-National Sedimentation Laboratory for the *Lake Tahoe Basin Framework Study: Sediment Loadings and Channel Erosion* (Simon et al. 2003). This research combined detailed geomorphic and numerical modeling investigations of several representative watersheds with field measurements from approximately 300 sites in the Tahoe basin. To better quantify the contributions of fine sediment from stream channel erosion in all 63 tributary stream systems, the USDA-National Sedimentation Laboratory completed additional work contained in *Estimates of Fine Sediment Loading to Lake Tahoe from Channel and Watershed Sources* (Simon 2006). This study provides valuable information on the average annual fine sediment loadings in metric tons per year from streambank erosion and the relative contribution of each of the Basin's 63 streams. Fine sediment in this study is defined as sediment less than 63 µm in diameter. The USDS-National Sedimentation Laboratory work also provides the average annual fine sediment particle (< 16 µm) loading estimates in number of particles per year.

In support of the TMDL development, the magnitude and extent of channel erosion was determined using five methods (Simon et al. 2003, Simon 2006): (1) comparison of historical cross-section surveys; (2) reconnaissance surveys of stream channel stability; (3) rapid geomorphic assessments; (4) numerical modeling; and (5) basin-wide evaluations. For streams with no historical monitoring information, the USDA-National

Sedimentation Laboratory researchers used empirical relationships to extrapolate how much fine sediment was contributed from channel erosion.

Using past data with new information and the above-described methodologies, stream channel erosion was numerically simulated or extrapolated to determine sediment, nitrogen, and phosphorus loadings into Lake Tahoe. Based on this work, the fine sediment (< 63 µm) load was estimated at 3,800 metric tons (per year from stream channels. Phosphorous loading was estimated to be 0.6 metric tons per year and nitrogen loading at 2 metric tons per year.

Rabidoux (2005) developed regression equations to establish a relationship between fine sediment particle numbers and streamflow based on the data collected during 2002-2003. Rabidoux used a linear model, the Rating Curve Method, for estimating particle flux based on streamflow for each of the seven particle size classes used in the Lake Tahoe Clarity Model. Rabidoux applied the Bradu-Mundlak Estimator to the linear regression models to correct for statistical bias and to determine the final load flux estimations (Cohn et al. 1989).

Tetra Tech (2007) calibrated the Lake Tahoe Watershed Model parameters using measured data from the 10 LTIMP streams. The calibrated Lake Tahoe Watershed Model established flow estimates for the remaining streams that are not monitored as part of LTIMP. These streams were grouped to the LTIMP stream with the most similar geography and land use. Rating curves from the LTIMP streams were assigned to the modeled stream flows in their group to determine sediment flux for each tributary. Rabidoux's initial sediment load calculations included fine sediment particles (< 16 µm) from a mixture of sources, including stream channel erosion and upland runoff. When divided from the upland contributions to in-stream particle loads, the loading values for particles < 63 µm from stream channel erosion was estimated to be 27 percent of total stream particle load as calculated by the Rabidoux (2005) regression equations and modeled flow. The number of fine sediment particles less than 16 micrometers that is from stream channel erosion is 1.67×10^{19} particles per year.

7.5 Upland Source

Uplands, both urban and non-urban (forested) uplands, account for sediment and nutrient inputs from various land uses within the 63 watersheds and intervening zones (where surface water enters the lake directly). Upland sources include products of anthropogenic influences within the urbanized environment and products of natural surface erosion from undeveloped areas.

The Lake Tahoe TMDL Program contracted Tetra Tech, Inc. to develop the Lake Tahoe Watershed Model to estimate sediment and nutrient loads from the upland sources. Once calibrated, the model provided a tool to predict flows and quantify loads from the upland tributaries and to simulate changes in load expected from land use changes resulting from simulated basin-wide pollutant reduction strategies. The Loading Simulation Program C++ (LSPC) (http://www.epa.gov/athens/wwqtsc/html/lspc.html) was selected to develop the Lake Tahoe Watershed Model. LSPC is a USEPA approved model developed to facilitate large scale, data intensive watershed modeling applications. The model was calibrated using 11 years (1994-2004) of hydrology and water quality data. The calibrations compared simulated and observed values of interest in a hierarchical process that began with hydrology and proceeded to water quality. The hydrology and water quality data were collected as part of the Lake Tahoe Interagency Monitoring Program (LTIMP), which regularly gathers field data from 10 select streams that together account for half of all stream flow to the lake.

The Lake Tahoe Watershed Model requires a physical basis for representing the variability in hydrology and pollutant loading throughout the Basin, which are both related to land-use and geology. The model relies on six land-use categories: water body, single-family residence (SFR), multi-family residence (MFR), commercial/institutional/communications/utilities (CICU), transportation, and vegetation. Vegetation is further sub-divided into unimpacted, turf, recreational, ski areas, burned, and harvested. Unimpacted areas are further divided into 5 categories based on erosion potential to the lake. For further details of land-use descriptions and categories, refer to Section 4.3.4 of the Lake Tahoe TMDL Technical Report.

A two-year study by UC Davis measured particles and size distribution at the most downstream stations in the 10 LTIMP streams (Rabidoux 2005). The Lake Tahoe TMDL stormwater monitoring study, jointly conducted by UC Davis and the Desert Research Institute gathered data from stormwater runoff in the Tahoe basin (Heyvaert et al. 2007). Loads (number of fine sediment particles) from upland sources are expressed on the basis of urban and non-urban sources. The initial approach to distinguish fine sediment loading originating in urban land-uses from loading originating in non-urban land-uses included Rabidoux's streamflow-particle regression equations used with percent flow estimates from the urban landscape. These results were compared to data from the Lake Tahoe TMDL Stormwater Monitoring Study. The Lake Tahoe TMDL Stormwater Monitoring Study provided data for particle concentration for monitored storm events from 9 sites around Lake Tahoe, concurrently with Rabidoux's regression models.

Particle concentration in urban runoff is up to two orders of magnitude greater than in streams (Lahontan and NDEP 2010). Because of this inequity, the specific streamflow-particle relationships developed for the LTIMP streamflow were not considered to be appropriate for describing urban runoff without an adjustment factor. Additionally, intervening zones typically have a high percentage of urban land-use, preventing accurate predictions of intervening zone particle concentration based solely on Rabidoux's streamflow particle regression models. A multiplication factor was applied to the regression models to correct for the differences between streamflow and urban runoff particle characteristics. Loading from intervening zones was calculated using the urban loading correction factor. Refer to Section 5.1.2 of the Technical Report for detail of the equation application.

Based on the continuous simulations provided by the Lake Tahoe Watershed Model, Tetra Tech, Inc. estimated average annual fine sediment particle loads for urban and non-urban upland sources are 4,430 and 4,670 metric tons, respectively. Annually, total nitrogen and total phosphorus loads for the urban uplands were estimated to be 63 and 18 metric tons, while the non-urban upland contributes 62 metric tons of total nitrogen and 12 metric tons of total phosphorus. Total urban uplands fine sediment particle contribution to the lake is 3.48×10^{20} particles per year. Total contribution from non-urban uplands sources is 4.11×10^{19} particles per year.

A detailed description of the watershed model development process and its results can be found in *Hydrologic Modeling and Sediment and Nutrient Loading Estimation for the Lake Tahoe Total Maximum Daily Load Project* (Tetra Tech 2007) and is documented in the Lake Tahoe TMDL Technical Report (Lahontan and NDEP 2010).

7.6 Atmospheric Deposition

Atmospheric deposition refers to the deposition of pollutants that land directly on the lake surface. This can occur as dry deposition or as part of a precipitation event (wet deposition). Because the surface area of the lake is 501 km^2 in comparison to its drainage area of 812 km^2, airborne input of nutrients and fine sediment particles to Lake Tahoe's surface is significant.

The California Air Resources Board (CARB) conducted the *Lake Tahoe Atmospheric Deposition Study* (LTADS) to estimate the contribution of dry atmospheric deposition to Lake Tahoe. These estimates were paired with long term monitoring data collected by UC Davis - TERC to provide detailed pollutant loading numbers to use for lake clarity modeling purposes.

Gertler et al. (2006) and CARB (2006) found that airborne pollutants are generated mostly from within the Lake Tahoe basin and come from motor vehicles, wood burning, and road dust. Motor vehicles, including cars, buses, trucks, boats, and airplanes are primary sources of atmospheric nitrogen.

CARB (2006) and UC Davis - TERC used two different methods to measure dry atmospheric deposition to Lake Tahoe. The LTADS (CARB 2006) monitored nutrient and sediment concentrations in ambient air and used a pollutant deposition model to estimate atmospheric deposition to the surface of Lake Tahoe. UC Davis - TERC deployed wet, dry, and bulk (wet and dry) collectors on the lake surface to empirically estimate atmospheric deposition.

Wet deposition data used in the CARB analysis comes largely from the Ward Valley Lake Level (WVLL) station where approximately 30 - 40 precipitation events are measured during a typical year. A data record of nearly 25 years is available for nitrate, ammonium, and soluble reactive phosphorus (SRP) at the WVLL station. Historic data from Incline Village, Glenbrook, Meyers, Tahoe Vista, and Bijou were used for comparison with findings at WVLL. Comparisons show that phosphorus, nitrogen, and particulate matter concentrations associated with precipitation were similar at all sites. It was concluded that that the WVLL wet deposition concentration data were representative of near-shore locations and that this data could be used for basin-wide deposition estimates.

Wet and dry, whole-lake pollutant loading estimates for atmospheric deposition directly to the surface of Lake Tahoe were derived from both the UC Davis and LTADS studies. Dry deposition of particulate matter is estimated at 586 metric tons per year and wet at 163 metric tons per year for a total of approximately 749 metric tons per year. Atmospheric deposition of total nitrogen was approximately 218 metric tons per year and estimates for total phosphorus range between 6 - 8 metric tons. Because the Lake Clarity Model uses particle count rather than particle mass to estimate clarity changes, the CARB data was converted into number of fine sediment particles. CARB collected particle mass data in three size classes; $PM_{2.5}$, PM_8, and PM_{20}. The smallest of the size classes was further divided in two to account for composition differences associated with particle size in the $PM_{2.5}$ size class. The full set of seven-size classes required for input to the Lake Clarity Model was interpolated and extrapolated from these four-size measured classes. Refer to Section 5.1.4 of the Technical Report for equations used and assumptions made for this conversion. The total fine sediment particle contribution from atmospheric deposition is 7.4×10^{19} particles (< 16 µm) per year.

8 Linkage of Pollutant Loading to In-Lake Effects and Load Capacity Analysis

8.1 Background

The Lake Tahoe TMDL program developed the Lake Clarity Model to link pollutant loading from all sources (watershed and atmospheric deposition) to in-lake effects and specifically Secchi depth. The Lake Tahoe TMDL Technical Report (2010) contains detailed information on the linkage and load capacity analysis. This chapter summarizes much of the information found in the Technical Report. The reader is referred to the Technical Report for more in-depth analysis of pollutant sources and associated load capacity.

Three main objectives guided the Lake Clarity Model effort:

1. Develop a calibrated and validated model to simulate Secchi depth using the available input data.
2. Determine the levels of load reduction needed to meet the TMDL target(s).
3. Examine the effects of pollutant load reduction on Secchi depth using the Lake Clarity Model to guide the development of a science-based recommended pollutant load reduction strategy.

The Lake Clarity Model is a complex system that includes interacting sub-models for hydrodynamics, plankton ecology, water quality, particle dynamics, and lake optical properties with data input values for fine sediment particle and nutrient loads from atmospheric deposition, tributaries and intervening zones, shoreline erosion, and groundwater (nutrients only) (Figure 8-1).

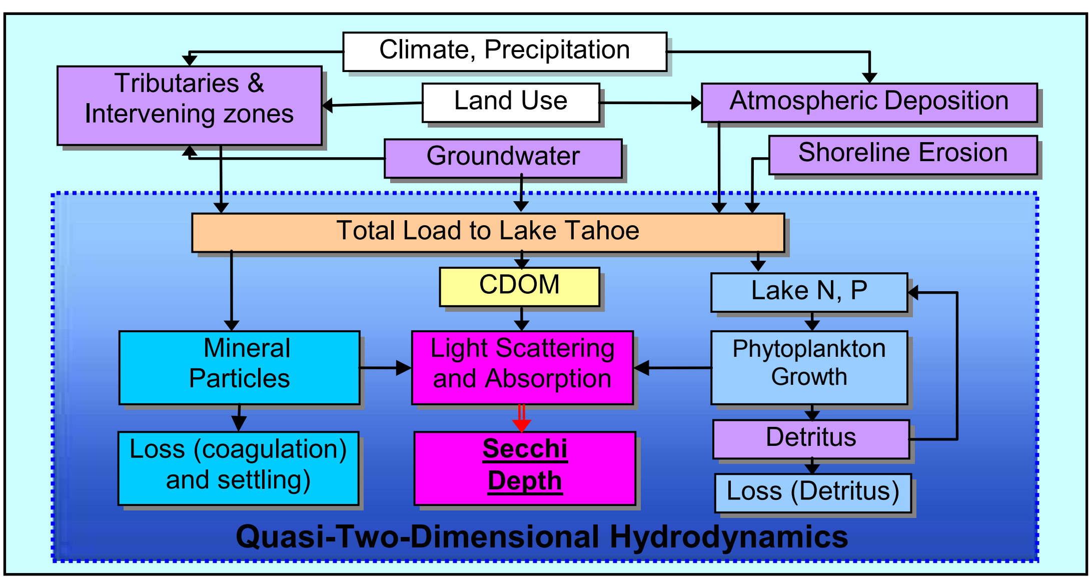

Figure 8-1. Conceptual Lake Clarity Model.

8.2 Lake Clarity Model Development & Operation

The Lake Clarity Model is the first lake water quality model designed and used for estimating Secchi depth in Lake Tahoe. Model development began in 1997 with a National Science Foundation Water and Watersheds program grant to UC Davis. The model was further refined as part of the Lake Tahoe TMDL program. The model accounts for a number of variables, including algal concentration, suspended inorganic sediment concentration, particle size distribution, and colored dissolved organic matter (CDOM) in predicting Secchi depth.

The hydrodynamic component of the model is based on the original Dynamic Reservoir Model (DYRESM) of Imberger and Patterson (1981). Lindenschmidt and Hamblin (1997) reported that DYRESM has already tested its widespread applicability to a range of lake sizes and types. Hamilton and Schladow (1997) combined the ecological sub-model and water quality sub-model that described the numerical description of phytoplankton production, nutrient cycling, the oxygen budget, and particle dynamics with the DYRESM model and demonstrated its wider applicability. The model has further been modified by Fleenor (2001) and completely adapted for use at Lake Tahoe (Perez-Losada 2001). An optical sub-model (Swift 2004, Swift et al. 2006) was developed based on fine sediment particle research at Lake Tahoe, and incorporated to estimate Secchi depth. The model was further refined during 2005-2007 as part of the Lake Tahoe TMDL science effort (Sahoo et al. 2007, 2009).

8.2.1 Data Inputs

Input data to the Lake Clarity Model includes daily weather information, daily stream inflow, lake outflow, pollutant loading estimates from each major source, lake physical data, initial water column conditions, physical model parameters, water quality boundary conditions, and water quality parameters. The Lake Clarity Model also required the in-lake profile data for the simulation starting date. Additional information for selected input parameters is highlighted below.

Meteorology – Meteorological activity drives the lake's internal heating, cooling, mixing, and circulation processes which in turn affect nutrient cycling, food-web characteristics, and other important features of Lake Tahoe's limnology. Required daily meteorological values for the Lake Clarity Model include solar short wave radiation, incoming long wave radiation (or a surrogate such as fraction of cloud cover), air temperature, vapor pressure (or relative humidity), wind speed and precipitation. Hourly recorded data from 1994 and 2004, collected at the meteorological station near Tahoe City, were either averaged or integrated as necessary to obtain daily values.

In-Lake Water Quality – As part of the ongoing Lake Tahoe Interagency Monitoring Program, UC Davis - TERC regularly collects numerous lake water samples at different depths. UC Davis - TERC researchers take samples at two lake stations: 1) the mid-lake (deep water) station at the 460-meter water depth and 2) the index station near the west shore at the 150-meter water depth. Parameters measured for the Lake Clarity Model include temperature, Secchi depth, photosynthetically active radiation, fine particles (seven different size classes), nitrate, ammonia, total Kjeldahl-N, total dissolved-P, total hydrolyzable-P, total-P, chlorophyll, and phytoplankton and zooplankton primary productivity.

8.2.2 Calibration and Validation

Model calibration and validation is necessary to adjust the model parameters to align predicted values with measured values. The calibration and validation also reduces uncertainty associated with input data measurement error and mathematical representation of the complex physical, chemical, and biological processes. Using the calibrated input values, the model is validated using an independent data set.

The Lake Clarity Model has approximately 50 unique model parameters among all the sub-models, but not all values or parameters were taken through a single, calibration and validation process. The hydrodynamic sub-model has been shown to not require calibration and has been successfully applied to a large number of lakes and reservoirs (e.g. Schladow and Hamilton 1997; Lindenschmidt and Hamblin 1997). Therefore, default values were used for the hydrodynamic inputs. Because there are not sufficient local zooplankton data to completely calibrate the zooplankton model parameters, values were taken from the literature. Only the water quality and ecological sub-models were needed to be calibrated as part of the Lake Tahoe TMDL development.

The optical sub-model parameters were developed by Swift et al. (2006) using measured lake profile data, laboratory results, and established literature values. UC Davis researchers validated these optical model parameters by comparing the actual measured Secchi depths with model predictions. In total, 157 field measurements were made in the five-year period (2000 to 2004). Annual average values summarized in Table 8-1 shows simulated and measured annual Secchi depths.

Table 8-1. Comparison of annual average Secchi depths (Sahoo et al. 2009).

Year	Measured Secchi Depth (m)	Simulated Secchi Depth (m)	Difference (m)	Difference (%)
2000	20.5	23.8	-3.3	-16.1
2001	22.6	23.1	-0.5	-2.2
2002	23.8	23.9	-0.1	-0.4
2003	21.6	23.3	-1.7	-7.8
2004	22.4	23.9	-1.5	-6.7

There is a three-year measured data set (2000-2002) from Lake Tahoe for water temperature, chlorophyll, nitrate, ammonia, biologically available phosphorus and particle size distribution and concentration. Lake Clarity Model results show that simulated temperatures closely match measured temperature records including the onset and degradation of thermal stratification and mixing. The modeled chlorophyll *a* concentrations also match well with the field measurements. The Lake Clarity Model was able to reproduce the characteristic deep chlorophyll maximum during the summer at 30-60 meters. The Lake Clarity Model was also able to simulate the documented decline of nitrate in the surface waters in the summer caused by algal uptake along with the build up of nitrate in deeper waters driven by mineralization of dead organic matter and nitrification. The measured biologically available phosphorus in the water column was found within the narrow range of < 1 to 3 micrograms per liter (µg/L) and the Lake Clarity Model simulated range was nearly identical at < 1 to < 2 µg/L.

8.3 Load Capacity Determination

The load capacity is defined as the maximum pollutant loading allowable to achieve a defined standard. In addition to the TMDL numeric target (29.7 meters annual average Secchi depth), the Lake Tahoe TMDL program has established an interim target of reaching approximately 24 meters of Secchi depth within the first twenty year implementation period.

Following model development, parameterization, calibration/validation and an initial sensitivity analysis, the Lake Tahoe TMDL program used the Lake Clarity Model to establish the relationship between annual average pollutant load reduction and the resulting average annual Secchi depth. This section briefly reviews Lake Clarity Modeling efforts to estimate how the Secchi depth may respond to a variety of loading scenarios. This information provides the framework for establishing Lake Tahoe's pollutant load capacity.

8.3.1 Transparency Response to Baseline Loading

The baseline simulation in the analysis below (Figure 8-2) represents the predicted future Secchi depths assuming the lake continues to receive similar fine sediment particle and nutrient loads as it has in the past 10 years (i.e. period of the source analysis). Because measured loading estimates included the effect of Best Management Practices in place as of water year 2004, those measures are included in the baseline condition. Figure 8-2 shows the projected trend for Secchi depth if no changes are made in current pollutant control efforts. Although the modeled trend flattens slightly, Lake Clarity Model predictions suggest that Lake Tahoe will continue to lose transparency if additional load reduction measures are not taken.

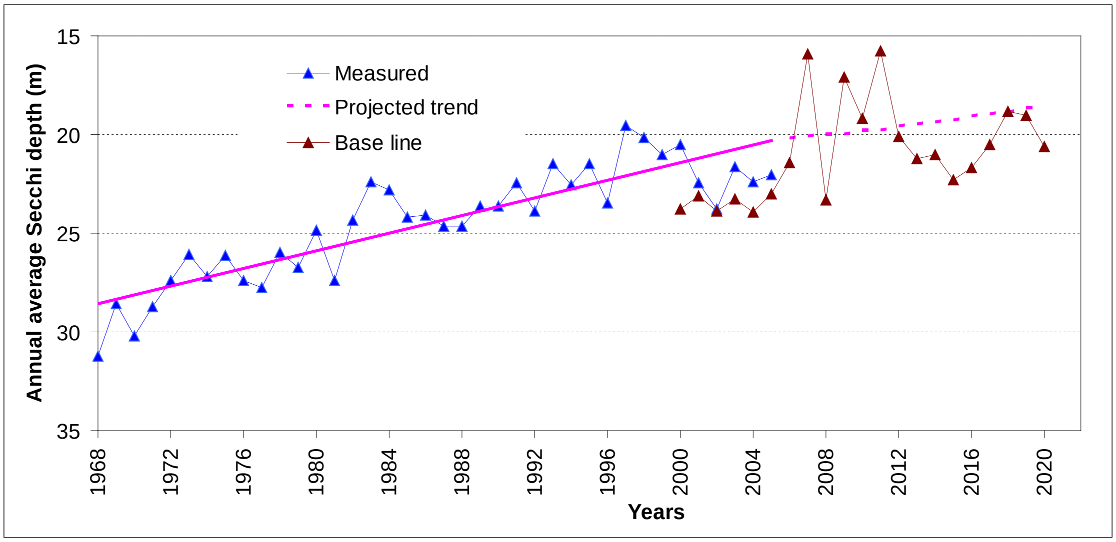

Figure 8-2. Measured and modeled Secchi depths for 2000-2020. The close agreement during the period between 2000-2005 between field data and modeled output highlight utility of the Lake Clarity Model (Sahoo et al. 2009).

8.3.2 Transparency Response to Pollutant Load Reduction

Lake Clarity Model simulations suggest that is it possible to achieve Secchi depths to meet both the interim Clarity Challenge target and the TMDL numeric target, provided necessary load reductions are achieved.

In this section, example model runs are presented to demonstrate the utility of the Lake Clarity Model to evaluate transparency response to reduction of nutrient and fine sediment particle loads. These model runs generated an initial range for the magnitude of pollutant reduction required to achieve the Secchi depth targets. The presented results are a few examples of all Lake Clarity Model runs performed as part of the TMDL analysis from conceptual pollutant reduction scenarios.

To begin the process, the Lake Clarity Model simulated transparency response to an initial set of load reduction options. Four load reduction scenarios (zero percent reduction, 25 percent reduction, 50 percent reduction, and 75 percent reduction) were applied to nutrients and fine sediment particles individually and in combination. The percent reductions were converted to absolute loads (metric tons or number of fine sediment particles) based on the basin-wide nutrient and fine sediment particle budgets. The Lake Clarity Model was run for a 10-year simulated period to account for a sufficient range of precipitation levels.

These results suggested that reaching the TMDL numeric target requires a significant level of pollutant reduction (greater than 50 percent). Consistent with the in-lake field studies reported by Swift (2004) and Swift et al. (2006), the Lake Clarity Model demonstrates the greater importance of reducing fine sediment loading as compared to nutrient loading. This insight was a key consideration used to formulate the recommended implementation strategy. At the higher levels of load reduction the model results show a synergistic effect from removing nutrient and fine sediment.

The Lake Clarity Model results also suggest there is little difference between nitrogen and phosphorus reduction when considering Secchi depth improvement. While algal growth bioassay experiments show that phosphorus alone is more likely to stimulate phytoplankton growth, versus solely nitrogen, the combination of nitrogen and phosphorus additions results in significant increases in algal biomass at virtually all times of the year (Hackley et al. 2007).

Table 8-2. Modeled average Secchi depth for the years 2011–2020 for different load reduction scenarios. The 0 percent reduction assumes no additional water quality BMP/restoration efforts beyond the level accomplished during the period 1994-2004. The number within the parentheses represents the standard deviation over the estimated annual average Secchi depths (Sahoo et al. 2009).

Reduction (%)	Average Secchi Depth (meters) for the Years 2011–2020				
	Nutrient (N) Reduction	Nutrient (P) Reduction	Nutrient (N+P) Reduction (m)	Fine Sediment Reduction	Nutrient (N+P) and Fine Sediment Reduction
0	20.1 (2.1)	20.1 (2.1)	20.1 (2.1)	20.1 (2.1)	20.1 (2.1)
25	20.4 (2.1)	20.5 (1.8)	21.3 (2.2)	23.2 (2.5)	23.2 (2.2)
50	21.0 (2.3)	21.6 (2.1)	21.4 (2.4)	26.2 (2.3)	27.0 (2.2)
75	22.0 (2.5)	21.8 (2.4)	21.7 (2.3)	28.6 (2.6)	35.3 (2.8)

8.3.3 Lake Clarity Model Helps Quantify Specific Load Reduction Approach

The Lake Clarity Model was used to evaluate needed load reductions to achieve both interim and ultimate transparency goals. To achieve the load reductions needed to meet the Clarity Challenge, the TMDL Pollutant Reduction Opportunity analysis evaluated on-the-ground options for reducing pollutant loads from the various sources. Source-specific load reduction opportunities were evaluated in collaboration with stakeholders to determine achievability and feasibility of the various pollutant load reduction opportunities. These source-specific load reductions from the primary pollutant sources were input to the Lake Clarity Model to show transparency response.

Table 8-3 lists the fine sediment particle and nutrient load reductions needed to achieve both the Clarity Challenge and TMDL numeric target based on the load reduction opportunity analysis. The Pollutant Reduction Opportunity Report (Lahontan and NDEP 2008a) contains detailed information from the evaluation process.

Table 8-3. Basin-wide pollutant reductions needed to meet interim Clarity Challenge target and TMDL numeric target.

Pollutant	Interim Secchi Depth 24.0 meters "Clarity Challenge"	Target Secchi Depth 29.7 meters TMDL Numeric Target
Fine Sediment Particles (< 16 μm)	32 %	65 %
Phosphorus	17 %	35 %
Nitrogen	4 %	10 %

9 Load Reduction Analysis and Recommended Implementation Strategy

After estimating annual loads from the major pollutant sources, the Water Board and the Nevada Division of Environmental Protection (NDEP) identified and quantified pollutant load reduction opportunities, evaluated the relative costs and water quality benefits from implementing various load reduction actions, and used the resulting findings to develop a comprehensive implementation approach for meeting required pollutant load reductions.

The Water Board and NDEP conducted the Pollutant Reduction Opportunity project (Lahontan and NDEP 2008a) to assess the cost and expected fine sediment, nitrogen, and phosphorus load reductions from implementing known, quantifiable pollutant control measures for the major pollutant sources. Through the Integrated Water Quality Management Strategy effort (Lahontan and NDEP 2008b), the Water Board and NDEP crafted three different integrated implementation strategies based on feasible options identified by the Pollutant Reduction Opportunity project. The Water Board and NDEP then refined the integrated strategies into a single implementation approach through an iterative process involving stakeholder feedback regarding the political, social, and economic implications of the proposed strategies. The resulting Recommended Water Quality Management Strategy ("Recommended Strategy") provides the basis for the load reduction allocation schedule of fine sediment particles and nutrients to Lake Tahoe for the first fifteen year TMDL implementation phase (Lahontan and NDEP 2008b).

The Recommended Strategy provides the basis for both the Lake Tahoe TMDL pollutant load allocation and implementation plans. The allocation plan specifies the load reduction schedule for each of the four major source categories so the numeric target is achieved. The Implementation Plan is a package of representative actions to achieve the load reductions necessary to meet the required load reductions.

9.1 Source Category Load Reductions

To meet the Clarity Challenge target, fine sediment particle loads to Lake Tahoe need to be reduced by an estimated 32 percent relative to the basin-wide Lake Tahoe TMDL baseline pollutant budget. Total nitrogen and total phosphorus load reductions over the same period are expected to be four percent and 17 percent, respectively. Table 9-1 shows how the basin-wide fine sediment particle, total nitrogen, and total phosphorus load reductions are distributed among the four primary pollutant source categories.

Table 9-1. Source load reductions expected from implementing the Recommended Strategy. Reductions are expressed as an estimated percent of the basin-wide fine sediment particle load from these four sources (not including groundwater and shoreline erosion).

Pollutant Source	To Meet the Clarity Challenge		
	Fine Sediment Particle Load Reduction	Total Nitrogen Load Reduction	Total Phosphorus Load Reduction
Forest upland	1%	0%	0%
Stream channel erosion	2%	0%	0%
Atmospheric deposition	5%	0.5%	7%
Urban uplands	24%	3.5%	10%
Basin-wide Total	**32%**	**4%**	**17%**

Ongoing implementation measures and additional load reduction actions will be needed to further reduce fine sediment particle and nutrient loads to meet the TMDL numeric target.

9.1.1 Urban Runoff

Urban runoff produces the majority of fine sediment and phosphorus loading and provides the greatest estimated potential for pollutant control. Therefore, responsible parties (local municipalities and state highway departments) are expected to prioritize advanced operations and maintenance practices and innovative technologies that will reduce fine sediment particle and associated nutrient loads from the urban runoff source category. As noted in Table 9-1, implementing the Recommended Strategy is expected to reduce the basin wide fine sediment particle load by approximately 24 percent. To achieve the TMDL numeric target, a 70 percent reduction in the fine sediment particle load carried by urban stormwater runoff is necessary.

The Recommended Strategy assumes that pollutant controls will be applied differently based on configuration of impervious coverage and slope. Areas of concentrated impervious coverage, such as commercial land uses with extensive streets, parking areas, and rooftops, may require intensive application of advanced pollutant control measures, while land uses with dispersed impervious coverage will likely need less advanced treatments. Enhanced operations and maintenance of roadways and associated pollutant controls are important elements in the Recommended Strategy to reduce pollutants from urban runoff discharges. Additional information about the mix of pollutant controls included in each treatment tier and the process for deriving load estimates is in the

Integrated Water Quality Management Strategy Final Report (Lahontan and NDEP 2008b).

9.1.2 Atmospheric Deposition

Although atmospheric deposition is a smaller source of fine sediment particles (roughly fifteen percent of the basin-wide load), atmospheric deposition contributes approximately 55 percent of basin-wide nitrogen and 15 percent of basin-wide phosphorus directly to the lake. The TMDL Implementation Plan includes cost-effective treatments to control dust from sources such as unpaved parking areas, construction sites, dirt roads, traction abrasives on paved surfaces, and organic soot from residential wood burning. Water Board and NDEP staff expect these control measures will reduce the basin-wide sediment particle load by approximately five percent and the phosphorus load by about seven percent.

Nitrogen emissions from mobile sources (i.e., vehicles) will be controlled through continuation of the air quality control programs enforced by the Tahoe Regional Planning Agency, including implementation of the updated Lake Tahoe Regional Transportation Plan (TRPA 2008).

9.1.3 Stream Channel Erosion and Stream Restoration

Stream channel erosion contributes roughly 3.5 percent of the basin-wide fine sediment particle load to Lake Tahoe. As shown in Table 9-1, implementing the Recommended Strategy is projected to significantly reduce this contribution (by more than half) in the first 15 years.

The TMDL Implementation Plan emphasizes restoration activities on the three tributaries that input the most fine sediment particles to Lake Tahoe. Together, these three streams are responsible for 96 percent of the stream channel erosion fine sediment particle load reaching the lake:

- Upper Truckee River (60%)
- Blackwood Creek (23%)
- Ward Creek (13%)

Several resource management agencies in the Lake Tahoe basin, including the United States Forest Service Lake Tahoe Basin Management Unit, the California Tahoe Conservancy, and the California Department of Parks and Recreation, have planned stream restoration projects on these three major tributaries.

Restoration activities on the Upper Truckee River, Blackwood Creek, and Ward Creek are estimated to reduce the basin-wide fine sediment particle loads by roughly two percent within the first 15 years. From a source category perspective, this translates to reducing the stream channel erosion contribution by more than half. To achieve the TMDL numeric target, a 90 percent reduction in the fine sediment particle loads coming from stream channel erosion is needed.

The broader ecosystem and habitat benefits of stream restoration are expected to be significant. A combination of full channel restoration and bank stabilization measures will provide multiple environmental benefits, including rehabilitation of floodplains, riparian corridors and meadows, fisheries enhancement, and wildlife habitat restoration.

9.1.4 Forest Upland

Federal, state, and some of the larger local land management agencies have active, well-defined, multi-objective forest restoration programs with established and secure funding. The Recommended Strategy focuses forest management efforts on small disturbed areas (e.g. unpaved roads, campgrounds and ski runs) where relatively high sediment particle yields and easy access make pollutant controls cost-effective. Land management activities within the forest uplands are anticipated to reduce the basin-wide fine sediment particle load by approximately one percent, which equates to a 12 percent reduction from the forest upland source in the first 15 years. To meet the TMDL numeric target, a 20 percent reduction in fine sediment particle loading is needed from the forest upland source within the estimated 65-year full implementation timeframe.

The Forest Upland load reduction analysis determined that maintenance activities (including fuel reduction projects) in the forest uplands have the potential to reduce or avoid increases in fine sediment and nutrient loads (Lahontan and NDEP 2008a).

10 Load Allocations

The TMDL process requires an allocation of allowable pollutant loads to identified pollutant sources. Water Board and NDEP staff determined the distribution of allowable pollutant loads to sources by applying Recommended Strategy load reductions to the Lake Clarity Model.

10.1 Attainment Timeframe

The Water Board and NDEP have established timeframes for achieving the interim Clarity Challenge and TMDL numeric targets . The timeframes and milestones assume that global climate change, catastrophic events and/or funding constraints do not adversely affect progress toward achieving load reduction milestones.

All implementing agencies are expected to pursue both self-funded and external funding sources to implement the TMDL. However, funding constraints due to the recent severe economic downturn and the anticipated significant decrease in federal, state and local funding levels may adversely impact the pace of implementation and the feasibility to meet load reduction goals within the timeframes specified (i.e., load reduction milestones). In this case, the Water Board and NDEP will consider amending the implementation and load reduction schedules. If necessary, modification of the timeline will be considered and implemented through the TMDL management system (see Chapter 12). While it is intended that such a decision would be made collaboratively with the Lahontan Water Board, NDEP reserves the right and authority to amend or modify the proposed implementation plan and schedules specifically related to Nevada as may be deemed necessary.

10.1.1 Clarity Challenge

The interim Clarity Challenge target of 24 meters annual average Secchi depth identifies load reduction targets to be achieved within the first 15 years of implementation. The Recommended Strategy, as described by the Integrated Water Quality Management Strategy Project Report (Lahontan and NDEP 2008b), demonstrates that if recent funding levels continue fine sediment particle, nitrogen, and phosphorus load reductions needed to meet the Clarity Challenge can be accomplished within the first fifteen years of TMDL implementation. A five year period of Secchi depth status and trend monitoring and analysis following this implementation period is expected to indicate whether the interim target has been met. The Clarity Challenge represents an ambitious goal for the 20-year planning horizon, which also lines up with updates to the 20-year TRPA Regional Plan and the US Forest Service-Lake Tahoe Basin Management Unit Forest Plan.

10.1.2 TMDL Numeric Target

Using the Lake Clarity model and the distribution of expected load reductions from the four major pollutant sources described by the Recommended Strategy, Water Board and NDEP staff have identified the magnitude of load reductions needed to meet the TMDL numeric target, which based on the best professional judgment of Water Board and NDEP staff will take approximately 65 years. This estimate assumes that load reduction rates following the first twenty years will decline as load reduction opportunities become scarcer, and that global climate change, catastrophic events and/or funding constraints do not adversely affect progress toward achieving load reduction milestones.

10.1.3 Load Reduction Milestones

The Water Board and NDEP have established five year load reduction milestones to help assess progress at meeting overall load reduction goals upon TMDL adoption. These milestones were developed under the assumption that approximately $500 million in funding would be available for each of the first three milestone periods.

Developed using the Integrated Water Quality Management Strategy analysis (Lahontan and NDEP 2008b), the first three milestones reflect an expected evolution of implementation efforts, particularly for the urban uplands pollutant source. The first five-year (year 5) milestone assumes modest load reductions as implementing agencies focus on employing current best practices and maintaining existing infrastructure. Though the first milestone will be five years from TMDL adoption, load reduction actions since the end of calendar year 2004 can be applied toward meeting the first milestone. (The source load analysis was completed with water quality data through the end of 2004). The second (year 10) milestone reductions are based on the anticipated implementation of new and innovative technologies, while the third (year 15) milestone reflects accelerated and more widespread implementation of these advanced pollutant controls.

To determine milestone values between the first 15 year implementation phase and the ultimate goal of meeting the TMDL numeric target, Water Board and NDEP staff assumed load reduction percentages would progress in a roughly linear manner. A rough linear progression between the third (year 15) milestone and the final year 65 target was used to establish load reduction milestones for years 20, 25, 30, 35, 40, 45, 50, 55, and 60. The Water Board and NDEP will work within the adaptive management framework following TMDL adoption to evaluate the appropriateness of the established milestones and, if necessary, make adjustments to the milestone schedules.

10.2 Load Allocation Tables

The following tables show the load reduction milestones for each of the four major pollutant source categories. Table 10-1 thru Table 10-3 describe the 2004 baseline loads for each source, including the source's percent contribution to the basin wide load and the needed percent reductions from that baseline load for each of the established five-year milestones.

Fine sediment particle values are presented in scientific notation. The capital "E" is an abbreviation for "times ten raised to the power." For instance, that total baseline fine sediment particle load is presented as "4.8E+20", which is an abbreviation for "4.8 x 10^{20}", or 480 quintillion fine sediment particles.

Note that because of the relatively small fine sediment, Total Nitrogen, and Total Phosphorus load contributions from groundwater and shoreline erosion, these sources are not included in the allocation tables, thus the sums of the allocated source loads are slightly different than the baseline load values presented in previous chapters.

Table 10-1. Fine Sediment Particle Load Allocations by Pollutant Source Category.

	Baseline Load		Milestone Load Reductions												Standard Attainment
	Basin-Wide Load (Particles/yr)	% of Basin-Wide Load	5 yrs	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs	35 yrs	40 yrs	45 yrs	50 yrs	55 yrs	60 yrs	65 yrs
Forest Upland	4.1E+19	9%	6%	9%	12%	12%	13%	14%	15%	16%	17%	18%	19%	20%	20%
Urban Upland*	3.5E+20	72%	10%	21%	34%	38%	41%	45%	48%	52%	55%	59%	62%	66%	71%
Atmosphere	7.5E+19	16%	8%	15%	30%	32%	35%	37%	40%	42%	45%	47%	50%	52%	55%
Stream Channel	1.7E+19	3%	13%	26%	53%	56%	60%	63%	67%	70%	74%	77%	81%	85%	89%
Basin Wide Total	4.8E+20	100%	10%	19%	32%	35%	38%	42%	44%	47%	51%	55%	58%	61%	65%

Table 10-2. Total Nitrogen Load Allocations by Pollutant Source Category.

Nitrogen	Baseline Load		Milestone Load Reductions												Standard Attainment
	Basin-Wide Nitrogen Load (MT/yr)	% of Basin-Wide Load	5 yrs	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs	35 yrs	40 yrs	45 yrs	50 yrs	55 yrs	60 yrs	65 yrs
Forest Upland	62	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Urban Upland*	63	18%	8%	14%	19%	22%	25%	28%	31%	34%	37%	40%	43%	46%	50%
Atmosphere	218	63%	0%	0%	1%	1%	1%	1%	1%	1%	1%	1%	2%	2%	2%
Stream Channel	2	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Basin Wide Total	345	100%	2%	3%	4%	5%	6%	6%	7%	7%	8%	8%	9%	9%	10%

Table 10-3. Total Phosphorus Load Allocations by Pollutant Source Category.

Phosphorus	Baseline Load		Milestone Load Reductions												Standard Attainment
	Basin-Wide Phosphorus Load (MT/yr)	% of Basin-Wide Load	5 yrs	10 yrs	15 yrs	20 yrs	25 yrs	30 yrs	35 yrs	40 yrs	45 yrs	50 yrs	55 yrs	60 yrs	65 yrs
Forest Upland	12	32%	1%	1%	1%	1%	1%	1%	2%	2%	2%	2%	2%	3%	3%
Urban Upland*	18	47%	7%	14%	21%	23%	26%	28%	31%	33%	36%	38%	41%	44%	46%
Atmosphere	7	18%	9%	17%	33%	36%	39%	42%	45%	48%	51%	53%	56%	58%	61%
Stream Channel	1	3%	8%	15%	30%	32%	34%	36%	38%	40%	42%	44%	46%	48%	51%
Basin Wide Total	38	100%	5%	10%	17%	19%	22%	24%	26%	28%	30%	32%	33%	34%	35%

*Urban upland load reduction requirements constitute wasteload allocations for the City of South Lake Tahoe, El Dorado County, Placer County, the California Department of Transportation, and the Nevada Department of Transportation, and load allocations for Douglas County jurisdictions and Washoe County.

10.3 Jurisdiction-Specific Allocations for Urban Runoff

To be consistent with the scale of the Lake Tahoe TMDL source and load reduction analyses, all pollutant loads are allocated at a basin-wide scale for each of the four major pollutant sources. Waste load and load allocations must be specified at a jurisdiction level so that they can be incorporated into respective implementation measures undertaken by the Water Board and NDEP. Jurisdiction-specific waste load allocations will be developed and incorporated into existing NPDES permits (El Dorado and Placer Counties; City of South Lake Tahoe; and the California and Nevada Departments of Transportation). Jurisdiction-specific load allocations will be developed for Washoe County and the jurisdictions comprising Douglas County.

To develop jurisdiction-specific load and waste load allocations, municipalities and state highway departments will conduct a jurisdiction-scale baseline load analysis as the first step in the implementation process. For each five year milestone, individual urban stormwater jurisdiction load reduction goals will be calculated by multiplying the urban uplands basin-wide load reduction percentage by the jurisdiction's individual baseline load.

To ensure comparability between the basin-wide baseline load estimates and the jurisdiction-scale baseline load estimates for urban runoff, urban stormwater dischargers must use a set of standardized baseline condition values that are consistent with those used to estimate basin wide pollutant loads. For example, traction abrasive application rates, street and BMP maintenance practices, and typical residential BMP compliance rates should reflect baseline conditions. More specific guidance, including references to approved modeling tools and a detailed review and approval process, will be included in California NPDES Stormwater Permits for El Dorado and Placer Counties, the City of South Lake Tahoe and the California Department of Transportation, as well as the Nevada Memoranda of Agreement between NDEP, Douglas County jurisdictions, Washoe County, and the Nevada Department of Transportation.

10.4 Expressing Allocations as Daily Loads

The Water Board and NDEP considered two different approaches to expressing allowable pollutant load allocations as daily loads. The results for a *flow range* daily load analysis and *seasonal* daily load analysis for fine sediment particles, total nitrogen, and total phosphorus are available in the *Integrated Water Quality Management Strategy Project Report* (Lahontan and NDEP 2008b).

Although the Water Board and NDEP staffs have completed the daily load analysis as required by the USEPA, the daily load values are not well suited to the variability associated with natural systems. Urban runoff, the primary source of pollutants affecting

Lake Tahoe's transparency, is highly variable in both flow volume and pollutant concentration. The other major pollutant sources, including atmospheric deposition, stream channel erosion, and forest upland runoff, are similarly variable and not well suited to daily analysis and tracking.

The *average annual* load expression remains a more useful and appropriate management tool for the Lake Tahoe basin, and that the most meaningful measure of Lake Tahoe's transparency is generated by averaging the seasonal Secchi depth data. The transparency target is an average annual water quality objective. The modeling tools used to predict load reduction opportunity effectiveness, as well as the lake's response, are all driven by average annual conditions. An emphasis on average annual fine sediment particle and nutrient loads also addresses the hydrologic variability driven by seasonal and inter-annual variability in precipitation amount and type. Finally, by emphasizing annual average conditions rather than instantaneous concentrations, implementers will have the incentive to focus action on the areas of greatest pollutant loads to cost effectively achieve required annual reduction requirements.

Daily load estimates for the Lake Tahoe TMDL, as a function of total hydraulic inflow, were developed following EPA guidelines described in the *Options for Expressing Daily Loads in TMDLs* (USEPA 2007). The Lake Tahoe Watershed Model analysis provided daily output of simulated daily loads, supplying the needed daily data sets. Table 10-4, Table 10-5, and Table 10-6 list ranges of total hydraulic inputs to Lake Tahoe, (expressed in liters per second) and an associated range of pollutant concentrations. Because the majority of the pollutant loads discharged to Lake Tahoe are carried by upland runoff, the derived daily load estimates are for upland runoff and stream channel erosion sources. The daily load estimate for the atmospheric source may be estimated by dividing the average annual pollutant loading estimate by 365 days.

Table 10-4. Fine Sediment Particle Daily Loading Estimate.

Flow Range	Associated Flow (Liters/Second)			Pollutant Concentration (Number of Particles/L)		
Percentile	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
0-10	1375.7	1011.6	1588.1	6.6E+07	2.1E+07	5.8E+08
10-20	1763.1	1588.7	1950.2	1.0E+08	1.7E+07	9.4E+08
20-30	2211.6	1950.5	2522.4	2.1E+08	1.9E+07	1.1E+09
30-40	2858.7	2523.8	3245.2	3.1E+08	3.1E+07	1.5E+09
40-50	3853.9	3246.4	4585.4	3.8E+08	3.1E+07	1.9E+09
50-60	5541.2	4591.3	6688.8	4.7E+08	4.2E+07	2.7E+09
60-70	8640.3	6696.0	11006.6	5.7E+08	5.3E+07	4.6E+09
70-80	14260.5	11022.9	18204.7	6.0E+08	7.2E+07	2.6E+09
80-90	24350.5	18209.9	34290.9	5.9E+08	1.2E+08	2.6E+09
90-100	60418.5	34368.2	165776.2	7.9E+08	2.7E+08	3.5E+09

Table 10-5. Total Phosphorus Daily Loading Estimate.

Flow Range	Associated Flow (Liters/Second)			Pollutant Concentration (mg/L)		
Percentile	Mean	Min	Max	Mean	Min	Max
0-10	1375.7	1011.6	1588.1	0.041	0.031	0.097
10-20	1763.1	1588.7	1950.2	0.044	0.027	0.133
20-30	2211.6	1950.5	2522.4	0.055	0.019	0.170
30-40	2858.7	2523.8	3245.2	0.064	0.023	0.214
40-50	3853.9	3246.4	4585.4	0.069	0.022	0.224
50-60	5541.2	4591.3	6688.8	0.075	0.025	0.229
60-70	8640.3	6696.0	11006.6	0.078	0.029	0.320
70-80	14260.5	11022.9	18204.7	0.073	0.034	0.202
80-90	24350.5	18209.9	34290.9	0.067	0.035	0.208
90-100	60418.5	34368.2	165776.2	0.062	0.036	0.185

Table 10-6. Total Nitrogen Daily Loading Estimate.

Flow Range	Associated Flow (Liters/second)			Pollutant Concentration (mg/L)		
Percentile	Mean	Min	Max	Mean	Min	Max
0-10	1375.7	1011.6	1588.1	0.10	0.06	0.70
10-20	1763.1	1588.7	1950.2	0.13	0.05	1.06
20-30	2211.6	1950.5	2522.4	0.23	0.05	1.36
30-40	2858.7	2523.8	3245.2	0.32	0.05	1.58
40-50	3853.9	3246.4	4585.4	0.38	0.06	1.64
50-60	5541.2	4591.3	6688.8	0.44	0.07	1.80
60-70	8640.3	6696.0	11006.6	0.43	0.07	1.81
70-80	14260.5	11022.9	18204.7	0.36	0.08	1.85
80-90	24350.5	18209.9	34290.9	0.28	0.08	1.81
90-100	60418.5	34368.2	165776.2	0.23	0.09	1.55

11 Lake Tahoe TMDL Implementation Plan

The Lake Tahoe TMDL Implementation Plan summarizes representative actions that are necessary for implementing entities to take to reduce fine sediment particle, phosphorus, and nitrogen loads to Lake Tahoe in order to meet established load reduction milestones, including the Clarity Challenge and the TMDL numeric target.

Using the Pollutant Reduction Opportunity analysis and the Integrated Water Quality Management Strategy stakeholder process, the Water Board and NDEP crafted a number of alternative implementation strategies to meet the Clarity Challenge. These strategies combined selected pollutant controls from each of the four primary sources of fine sediment particles and nutrients. Each of the identified strategies demonstrated the magnitude of possible load reduction opportunities from each pollutant source for a suite of quantifiable activities.

The Recommended Strategy, summarized in Chapter 9, provides the framework for the magnitude of expected load reductions from the four major pollutant sources and describes reasonably foreseeable load reduction activities that responsible parties may choose to undertake. Although the Water Board and NDEP evaluated specific load reduction actions to determine the most reasonable load reduction distribution, the Recommended Strategy does not translate to recommendations for project-scale application and implementing agencies are not required to implement the specific controls contained within the analysis. Rather, the Recommended Strategy demonstrated that the pollutant load reductions for the first 15 years of implementation appear to be achievable, but it does not establish a prescription for implementing agencies to follow in meeting load reduction goals.

Following an overview of the responsible parties describing the regulatory and implementation agencies and their respective roles in implementing this collaborative TMDL, the Implementation Plan is organized by major pollutant source. Subsequent sections on each of the four source categories list reasonably foreseeable actions that are capable of achieving the Clarity Challenge goals, and associated performance assessment measures. The final section briefly describes the adaptive management process.

11.1 Regulatory Agencies

The Water Board and NDEP are the two state regulatory agencies who will oversee implementation of this TMDL in their respective states. These two agencies may enact policy and regulations based on the TMDL analysis and key scientific findings of the TMDL. Each agency will ensure that the TMDL is implemented.

The Water Board and NDEP will each conduct the following tasks to ensure progressive implementation towards meeting the Clarity Challenge and the numeric target:

- Administer and apply the Lake Clarity Crediting Program to each of its urban stormwater programs, NPDES permits in California and Memoranda of Agreement in Nevada.

- Develop policies and procedures to consistently track and report load reduction actions with respect to the forest uplands, atmospheric deposition, and stream channel erosion source categories.

- Recommend, support and advance current and future monitoring and research programs to reduce uncertainties associated with the analyses, develop innovative load reduction options, and assess effectiveness of actions and lake transparency response.

- Develop and implement the TMDL Management System that will enable incorporation of new information and key findings to potentially update policies and assess and refine implementation strategies and actions, as needed.

- Work with implementation agencies to overcome barriers associated with implementation.

The TRPA should play a crucial role in TMDL implementation because the TRPA has the ability to incentivize TMDL implementation. As the agency responsible for zoning and permitting a wide variety of land-uses and construction projects throughout the basin, TRPA has the ability to release or restrict building allocations, additional building height, and commercial floor area. TRPA is currently in the process of updating its Regional Plan. NDEP and the Water Board are actively working with TRPA to ensure consistency with the TMDL and the incorporation of the best possible incentive and regulatory packages. The TRPA Regional Plan requires private property owners to infiltrate runoff from all impervious surfaces from a 20 year, 1-hour design storm.

11.2 Implementation Entities

11.2.1 Federal

United States Forest Service

The United States Forest Service Lake Tahoe Basin Management Unit (an agency of the U.S. Department of Agriculture) manages roughly 80 percent of the land in the Lake Tahoe basin. The land is administered by the Lake Tahoe Basin Management Unit (LTBMU), a special unit that oversees federally owned forest lands within the Lake Tahoe basin. Although the bulk of LTBMU land is undeveloped forested upland (including undeveloped urban lots), the LTBMU manages a variety of recreational facilities within the urbanized landscape such as trailheads, parking lots, and campgrounds. The LTBMU's land management activities impact each of the four major pollutant source categories.

The LTBMU Land and Resource Management Plan (Forest Plan) guides management direction. The current plan, adopted in 1988, is under revision to update portions related to ecosystem restoration, recreation management, land-use, and adaptive management. The Forest Plan update effort has been an integral part of the interagency Pathway planning process and the updated plan will include desired future conditions assessments, related goals and objectives for a 10-50 year planning horizon, and management and monitoring approaches.

Other Federal Agencies

There are a number of other federal agencies that provide critical support through the Lake Tahoe Federal Interagency Partnership. This Partnership was established in 1997 with strong local, State, Administration and Congressional support. It includes the US Army Corps of Engineers, the USDA Natural Resources Conservation Service, US Geological Survey, US Environmental Protection Agency, US Fish & Wildlife Service, US Bureau of Reclamation, and US Department of Transportation. The Partnership supports TMDL implementation through direct funding of TMDL research and regional, local, and state government water quality improvement projects.

11.2.2 California

California Tahoe Conservancy

The California Tahoe Conservancy (CTC) is an independent State agency within the Natural Resources Agency of the State of California. It was established in its present form by State law in 1984 (Chapter 1239, Statutes of 1984). Its jurisdiction extends only to the California side of the Lake Tahoe Basin. The CTC is not a regulatory agency. It was established to develop and implement programs through acquisitions and site improvements to improve water quality in Lake Tahoe, preserve the scenic beauty and recreational opportunities of the region, provide public access, preserve wildlife habitat areas, and manage and restore lands to protect the natural environment.

CTC erosion control and stream environment zone restoration programs play a critical role in TMDL program funding and implementation. Through the Lake Tahoe license plate program and bond funds authorized by Propositions 40 and 50 (and potentially other funding sources), the CTC provides essential program funding for local government erosion control projects, stream restoration efforts, and land conservation programs. The CTC owns numerous urban lots and several larger parcels and implements land management plans that will further assist in meeting Lake Tahoe TMDL load reduction goals by restoring historically disturbed areas, preventing new disturbance, providing opportunities for urban stormwater treatment, and leading Upper Truckee River and Ward Creek stream restoration efforts.

California Departments of Parks and Recreation

The California Department of Parks and Recreation is a department of the State of California Natural Resources Agency. In the Lake Tahoe basin, the Sierra District manages nine park units covering over 8,600 acres. The Sierra District Resource

Program actively protects, preserves, and manages many aspects of park resources, including forests and fuels, watershed restoration, sensitive species, invasive species, and cultural features to provide high quality recreation opportunities. The program is also actively working to address stream bank and bed erosion problems on portions of the Upper Truckee River that flow through a golf course managed by the Department.

The Department also manages a number of campgrounds, trailheads, historic sites, and other lands that require best management practices to control runoff from impervious surfaces.

California Department of Transportation

The California Department of Transportation (Caltrans), a department of the State of California Business, Transportation, and Housing Agency, is responsible for operating and maintaining the state highway system within the state of California. Caltrans' mission is to improve mobility across the state and its strategic goals include preserving and enhancing California's resources and assets. Caltrans operates 68 miles of roadways within the Tahoe basin that range in elevation from 6,250 to over 7,200 feet. The majority of the roadways are two lanes, and Caltrans performs snow management operations along all the roadways during the winter including the application of traction abrasives and deicers. Caltrans has developed a Storm Water Management Program to comply with statewide NPDES stormwater permitting requirements.

Before July 1999, stormwater discharges from Caltrans' stormwater systems were regulated by individual permits issued by the Regional Water Boards. On July 15, 1999, the State Water Resources Control Board issued a statewide permit (Order No. 99-06-DWQ, NPDES Permit No. CAS000003) which regulated all stormwater discharges from Caltrans owned stormwater systems, maintenance facilities and construction activities.

Future permit revisions or individual orders issued by the Water Board will require Caltrans to prepare and implement a Load Reduction Plan for the Lake Tahoe basin to achieve pollutant load reductions required by this TMDL.

11.2.3 Nevada

Nevada Tahoe Resource Team Agencies

The Nevada Tahoe Resource Team is an interagency team coordinated by the Division of State Lands and dedicated to preserving and enhancing the natural environment in the Lake Tahoe basin. In addition to Division of State Lands staff, the team is made up of representatives from the Nevada Division of Forestry, the Division of State Parks, and the Department of Wildlife.

The Nevada Tahoe Resource Team is responsible for implementing Nevada's share of the Environmental Improvement Program. As such, the Team coordinates and implements a wide range of projects designed to improve water quality, control erosion, restore natural watercourses, improve forest health and wildlife habitat, and provide recreational opportunities.

The Division of State Lands administers two grant programs: the Water Quality and Erosion Control Grant and the Nevada Lake Tahoe License Plate Grant, in addition to the Excess Coverage Mitigation Program and the Urban Lot Management Program. The Division is also responsible for permitting activities affecting the bed of the Lake below elevation 6223’.

Nevada Department of Transportation

The Nevada Department of Transportation (NDOT) operates and maintains the Nevada state highway system. NDEP regulates stormwater discharges from NDOT facilities under a statewide NPDES Permit (NV0023329). The permit requires NDOT to address and limit the discharge of pollutants to the maximum extent practicable. NDOT has developed a Storm Water Management Program to comply with the permit requirements and address storm water pollution related to highway planning, design, construction, and maintenance activities throughout the state. The permit also contains language requiring compliance with any established TMDLs.

11.2.4 Local

California Local Government Agencies

There are three municipal jurisdictions on the California side of the Lake Tahoe basin: one incorporated city, the City of South Lake Tahoe and El Dorado and Placer counties. Under the municipal stormwater NPDES permit (CAG616002), these three local government entities are responsible for the quality of stormwater runoff from within their jurisdictional boundaries (excepting federal and state owned lands). Federal NPDES storm water regulations require each jurisdiction to develop and implement comprehensive Storm Water Management Plans that address urban runoff problems from commercial, industrial, residential, and construction sources along with addressing runoff municipally owned facilities (roadways, maintenance yards, etc.). The municipal NPDES program also requires the municipalities to provide education and outreach to a variety of audiences to inform the public about the importance of stormwater management.

Nevada Local Government Agencies

Local government within Nevada Lake Tahoe is comprised of three counties: Washoe County, Douglas County, and Carson City. While distinct urban areas exist within portions of Washoe and Douglas Counties, Carson City is completely undeveloped forestland. Additionally, twelve general improvement districts (GIDs) have been created under Nevada Revised Statue 318 which provides county boards of commissioners the power and authority to do so. GIDs may be granted any combination of basic powers, including but not limited to furnishing streets and alleys; curbs, gutters and sidewalks; and facilities for storm drainage and flood control.

The Incline Village General Improvement District (IVGID) was created by Washoe County under State law (Nevada Revised Statute 318), effective June 1, 1961 (Washoe County Ordinance No. 97, Bill No. 57) as a body corporate and public and a quasimunicipal corporation in the State of Nevada. IVGID is chartered to provide water, sewer and trash services as well as recreational facilities. IVGID owns a number of parcels within the county to serve these purposes. IVGID was also authorized to build roads, however when the roads were completed they were dedicated to Washoe County for maintenance and are no longer IVGID's responsibility.

Eleven GIDs exist within the Tahoe portion of Douglas County: Cave Rock Estates GID, Kingsbury GID, Lakeridge GID, Logan Creek GID, Marla Bay GID, Oliver Park GID, Round Hill GID, Skyland GID, Zephyr Cove GID, Zephyr Heights GID, Zephyr Knolls GID. All of the GIDs are chartered to furnish streets and alleys; curbs, gutters and sidewalks; and facilities for storm drainage and flood control. While some of the roads have been dedicated to the county, the vast majority of roadways remain under GID ownership.

While individual roles and responsibilities cannot be specified at this time, it is clear that collaboration and cooperation between the counties and GID's will be needed to effectively reduce urban stormwater pollutant loads in the state of Nevada. Due to their technical expertise and implementation capacity, Nevada counties are well positioned to lead TMDL implementation within their jurisdictions. Because the counties already possess public works programs, the counties maintain professional staff with the expertise necessary to operate and maintain stormwater programs and to oversee the planning, design, implementation and maintenance of stormwater assets.

11.2.5 Other Stormwater Dischargers

Private property owners, school districts, and other property managers discharge stormwater runoff from building roofs, parking lots, walkways, and other impervious surfaces. These property owners and land managers have a responsibility to address stormwater runoff from existing developed areas to reduce pollutant loading and prevent erosion. Generally, infiltration is the best treatment approach for these discrete discharges and current regulations require capture and infiltration or treatment of the 20 year, 1-hour design storm. Alternatively, these dischargers may chose to coordinate stormwater treatment efforts with applicable local government.

11.3 Implementation Actions by Source Category

11.3.1 Urban Uplands

The majority of the basin-wide pollutant load discharges, and the most cost effective and efficient load reduction opportunities, are associated with urban runoff. The Pollutant Load Reduction Opportunity (Lahontan and NDEP 2008a) and the Integrated Water Quality Management Strategy (Lahontan and NDEP 2008b) analyses demonstrated that continued application of existing stormwater management practices would be insufficient to meet needed fine sediment particle, nitrogen, and phosphorus load reductions. Enhanced operations and maintenance coupled with more intensive application of treatment measures with a demonstrated ability to reduce fine sediment particle loads will be needed to achieve TMDL requirements.

Implementation Actions to Meet the Clarity Challenge and Achieve the TMDL

The following is a representative list of practices and treatment options that responsible parties might use to meet the Clarity Challenge load reductions by year 15, and achieve the TMDL in 65 years. Many of these practices are already in use by responsible parties, and an enhanced level of effort may contribute to reduced sediment and nutrient discharges to Lake Tahoe. In the future, technological advances may add other actions to this list. This list is not intended to be exclusive; implementing agencies may select other actions to achieve required load reductions.

- Stabilize and re-vegetate road shoulders
- Vacuum-sweep streets (in heavily sanded areas)
- Upgrade/enhance fertilizer / turf management practices to reduce nutrient application
- Remove impervious coverage (increase infiltration)
- Redirect runoff for additional treatment
- Install and maintain infiltration trenches
- Install and maintain prefabricated infiltration systems
- Install and maintain detention basins
- Install and maintain sand filters
- Apply advanced deicing strategies (to reduce or eliminate abrasive application)
- Upgrade/increase/enhance infrastructure operation and maintenance
- Control retail fertilizer sales within the Basin
- Recommend landscaping practices that reduce nutrient mobilization
- Install and maintain wet basins / infiltration basins
- Install and maintain constructed wetlands
- Install and maintain media filters in stormwater vaults
- Pump stormwater to more suitable treatment locations

Performance Assessment and Reporting

Following USEPA approval of the Lake Tahoe TMDL the Water Board and NDEP will update municipal NPDES stormwater permits (state highway departments and California municipalities) and establish Memoranda of Agreement (between NDEP, Washoe and Douglas Counties and the Nevada Department of Transportation) to provide the regulatory mechanisms to account for and track urban upland load reduction actions.

The Water Board and NDEP will require municipal jurisdictions and both state highway departments to prepare and submit stormwater load reduction plans (or equivalent) which describe how pollutant load reduction milestones will be met. Load reduction plans will provide the Water Board and NDEP reasonable assurance that planned implementation actions and strategies will reduce fine sediment particle, total nitrogen, and total phosphorus loads consistent with the TMDL allocation schedule.

The Lake Clarity Crediting Program provides a system of tools and methods to consistently estimate, track and report pollutant load reductions at a catchment, or sub-watershed, scale. The municipalities and state highway department will use this program to demonstrate load reduction progress. To track and evaluate load reduction progress, the Water Board and NDEP will establish annual and five-year Lake Clarity Credit targets for each jurisdiction based on the urban upland load allocation milestones.

In order to establish Lake Clarity Crediting Program targets for individual urban stormwater jurisdictions, each municipality and state highway department will develop a jurisdiction-scale baseline load estimate using consistent methods.

To calculate the baseline load estimates, each municipality and state highway department shall use either the Pollutant Load Reduction Model (Northwest Hydraulic Consultants et al. 2009) or an equivalent method accepted by the Water Board and NDEP and use baseline condition information and modeling inputs described in the Lake Clarity Crediting Program Handbook (Lahontan and NDEP 2009). The modeling tools shall provide pollutant load estimates from representative catchments and extrapolate those results to generate jurisdiction-wide baseline load estimates for fine sediment particles, total nitrogen, and total phosphorus. Should a municipality or state highway department choose to use an alternative load reduction estimation tool, it must use a continuous hydrologic simulation process (or other modeling method that demonstrably produces similar results) that incorporates stormwater discharge characteristics from established land uses, includes the effectiveness of stormwater treatment best management practices, and accounts for the changes in roadway and stormwater treatment facility condition.

The Water Board and NDEP will then each apply the percent reduction milestones shown in Table 10-1 thru Table 10-3 to each jurisdiction's established baseline to determine the number of Lake Clarity Credits targeted for each five-year milestone. Table 11-1 summarizes the implementation and reporting schedule for urban stormwater dischargers.

Table 11-1. Lake Tahoe TMDL Implementation/Reporting Schedule – Urban Uplands

Action	Schedule	Responsible Party***
Submit Storm Water Management Plans or equivalent to Water Board and NDEP describing how 5-year load reduction targets will be met	Two years after TMDL approval* and every five years following	El Dorado County Placer County Douglas County Washoe County California Department of Transportation Nevada Department of Transportation City of South Lake Tahoe
Submit jurisdiction-specific 2004 baseline load estimates for fine sediment particles, phosphorus, and nitrogen to respective regulatory authority (Water Board or NDEP) for review/approval**	Two years after TMDL approval*	
Reduce and maintain pollutant loads of fine sediment particles, total phosphorus, and total nitrogen as specified in Table 10-1, Table 10-2, and Table 10-3	Achieve the percent reduction specified for each respective 5-year milestone following TMDL approval*	

*TMDL approval is the date the USEPA approves the Lake Tahoe TMDL. Timeframe for schedule represents a best estimate, considered tentative, and may be revised based on availability of adequate funding and other feasibility factors as may later be determined germane by NDEP and/or the Water Board.
**The baseline load estimates must be done using either the Pollutant Load Reduction Methodology, or an equivalent method that uses a continuous hydrologic simulation process and other similar input values.
***Within Nevada, only counties have been listed as Responsible Parties as it is assumed that these are the municipalities that will take the lead role in cooperatively implementing the Recommended Strategy with other public and private entities and progress reporting through Lake Clarity Crediting Program participation.

11.3.2 Forest Uplands

The Pollutant Reduction Opportunity analysis (Lahontan and NDEP 2008a) identified types of disturbed areas in forest lands (e.g., unpaved roads, campgrounds, ski runs) where relatively high sediment particle yields and easy maintenance access provide cost-effective pollutant control opportunities. The implementation approach for forest uplands focuses most efforts on these easy-access, high pollutant-yielding disturbed areas.

Pollutant controls for this source can be categorized by land-use and by actions taken on various land-uses, in two categories. Standard BMP treatments are planned by federal and state land management agencies for roads, trails, campgrounds, and fuels reduction projects under their jurisdiction. More advanced treatments designed to achieve better hydrologic function and complete restoration activities to mimic natural conditions are also recommended to reduce pollutant loads.

Implementation Actions to Meet the Clarity Challenge and Achieve the TMDL

The following is a representative list of practices and treatment options that responsible parties may use to meet the Clarity Challenge load reductions by year 15, and achieve the TMDL numeric target in 65 years. Many of these practices are already in use by responsible parties, and an enhanced level of effort may contribute to reduce sediment and nutrients to Lake Tahoe. In the future, technological advances may add other actions to this list. This list is not intended to be exclusive; implementing agencies may select other actions to achieve required load reductions.

- Install and maintain (annually) full unpaved roadway BMPs (e.g. waterbars, armored swales, drainage stabilization, and stormwater treatment infrastructure)
- Revegetate and stabilize ski runs
- Implement forest treatments with low pressure and other innovative ground-based equipment and standard BMPs
- Capture and retain sediment from unpaved roadways
- Install and maintain advanced BMP measures to increase infiltration and reduce runoff from landings, ski runs, trails and paved and unpaved roads in forested areas
- Decommission and re-contour unauthorized or historic roads and trails by tilling, adding organic soil amendments, mulching, and revegetation
- Fully restore legacy roads and trails to return to native forest conditions with natural hydrologic function

Performance Assessment and Reporting

The forest upland load reductions described by the Recommended Strategy will be accomplished through continued implementation of forest management programs, policies, restoration activities, and vegetation management approaches. The United States Forest Service Lake Tahoe Basin Management Unit (LTBMU), agencies of the Nevada Tahoe Resource Team (TRT - Divisions of State Parks, State Lands and Forestry), California Department of Parks and Recreation, and the California Tahoe Conservancy (CTC) are the primary public forested land management agencies responsible for maintaining and expanding existing land management activities as needed to reduce pollutant loads from forested lands to meet the Clarity Challenge and other load reduction goals.

The Water Board and NDEP have worked with the LTBMU to include references to applicable TMDL implementation elements in the updated Land and Resource Management Plan. The Water Board and NDEP expect the revised Forest Plan to commit to ongoing maintenance of LTBMU unpaved roadways and trails; regular inspections and maintenance of trailhead and parking lot best management practices; continued efforts to identify and restore landscape disturbances; and responsible implementation of vegetation management actions with appropriate BMPs. Similarly, the

California Department of Parks and Recreation, the CTC, and the Nevada TRT agencies have programs and policies in place to implement projects and activities to reduce pollutant loads.

The Water Board and NDEP will track forest implementation partner activities to determine whether expected load reduction actions are being taken and are remaining consistent with the Recommended Strategy and the TMDL Implementation Plan. If forest management agencies continue to complete projects and activities consistent with the Pollutant Reduction Opportunity Analysis (Lahontan and NDEP 2008a), the Recommended Strategy (Lahontan and NDEP 2008b) and this TMDL, then the Water Board and NDEP expect forest upland load reduction requirements will be met.

If the LTBMU, CTC, and the California Department of Parks and Recreation fail to continue to implement needed load reductions, the Water Board maintains the authority to issue Waste Discharge Requirements or Time Schedule Orders, as needed, to be certain appropriate programs, policies, and activities continue as anticipated to reduce pollutant loading to Lake Tahoe. The NDEP has the authority to enter into Memoranda of Agreement with forest management partners on the Nevada side of the Lake Tahoe basin to explicitly define TMDL expectations on undeveloped lands in Nevada to meet Lake Tahoe TMDL pollutant load reductions should those agencies fail to implement expected load reduction actions.

11.3.3 Atmospheric Deposition

Roughly 15 percent of the basin-wide fine sediment particle load is transported and deposited on the lake surface through atmospheric deposition. The Recommended Strategy and this implementation plan focus on stationary sources of fine sediment particles within the atmospheric source category because these sources provide the bulk of the load reaching Lake Tahoe from the air, primarily as road dust. Dust sources, such as paved and unpaved roads, disturbed vacant parcels, and construction sites are responsible for more than 88 percent of atmospheric fine sediment particle emissions in the Lake Tahoe Basin (Lahontan and NDEP 2008a).

Mobile sources (such as automobiles, buses, and boats) predominantly produce nitrogen, not fine sediment particles or phosphorus. Stationary source controls for fine sediment particles and associated phosphorus are also three orders of magnitude less expensive per unit removed than mobile sources according to the *Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a).

This TMDL relies on the Tahoe Regional Planning Agency's (TRPA) air quality and transportation plans to continue managing the load of nitrogen to the atmosphere from the mobile sources; this continued management is expected to reduce the basin-wide nitrogen load by at least one percent within 15 years. A two percent reduction in nitrogen load from the atmosphere is needed to attain the TMDL numeric target. The TRPA Regional Plan update is anticipated to include an atmospheric nitrogen emission reduction strategy that meets the TMDL transparency standard attainment needs.

Implementation Actions to Meet the Clarity Challenge and Achieve the TMDL

Cost-effective treatments to reduce road dust include enhanced operations and maintenance of non-mobile dust sources including paved and unpaved roadways, parking lots, and construction sites as well as revegetation and/or stabilization of disturbed vacant land. TRPA programs for reducing emissions from residential wood burning are also expected to provide some particle reduction from this source.

The following is a representative list of practices and treatment options that responsible parties may use so the Forest Upland source could meet the basin-wide load reduction necessary to achieve the Clarity Challenge by year 20, and achieve the TMDL in 65 years. Many of these practices are already in use by responsible parties, and an enhanced level of effort may contribute to reduced sediment and nutrient discharges to Lake Tahoe. In the future, technological advances may add other actions to this list. This list is not intended to be exclusive; implementing agencies may select other actions to achieve required load reductions.

- Regularly vacuum sweep streets
- Pave or apply gravel to unpaved roads
- Limit speed on unpaved roads
- Require adequate soil moisture or other dust suppression techniques during earth moving operations
- Reduce residential wood burning emissions
- Reduce Vehicle Miles Traveled (VMT) through incentives/disincentives

Performance Assessment and Reporting

Since the majority of the atmospheric fine sediment particle load is generated by urban roadways, much of the required atmospheric load reductions and interim load allocations will be met by implementing measures to control the sources of stormwater pollutants from urban roadways under the urban upland source category. Similarly, TMDL implementation actions taken to control runoff issues from unpaved roadways (see the Forest Uplands section above) will also reduce dust from these areas. Urban and forest stormwater dischargers cannot, however, “take credit” or otherwise account for these reductions as progress at reducing pollutant loads from the urban and forest pollutant sources.

11.3.4 Stream Channel Erosion

Multi-objective stream channel restoration programs in the Lake Tahoe basin are well established. Because these programs achieve a number of environmental benefits in addition to water quality improvements, implementation efforts for this source category are based on current plans and approaches. The loading and load reduction analysis focused only on fine sediment particles (and associated nutrients) released from stream bank and bed erosion. Load reduction estimates did not consider the other potential ecological benefits available from stream or wetland restoration. The Water Board and NDEP anticipate that restoring floodplain connectivity and improving natural geomorphic function will provide additional fine sediment particle and nutrient load reductions. When research and monitoring are able to quantify these expected benefits, the load reductions will be accounted for through the adaptive management process.

Implementation Approach

TMDL stream channel erosion reduction estimates were developed based on ongoing implementation and planned restoration activities in the top three fine sediment particle producing streams in the basin, which are responsible for 96 percent of the fine sediment particle load in this source category (Lahontan and NDEP 2008a). These streams, in order of load production, are:

1. Upper Truckee River
2. Blackwood Creek
3. Ward Creek

Implementation and funding agencies have well-developed restoration plans for each of these three streams and are in various phases of planning and/or construction to implement restoration actions. Detailed, multi-agency planning for five different reaches of the Upper Truckee River was initiated in 2002. The California Tahoe Conservancy (CTC) has completed a project at the mouth of the river to remove fill placed during development of the Tahoe Keys (Lower West Side Upper Truckee River Project) and is evaluating alternatives for restoring the Upper Truckee Marsh. The CTC is also actively planning Upper Truckee restoration at the Sunset Stables property. The City of South Lake Tahoe constructed channel improvements adjacent to the Lake Tahoe Airport in 2008 and is expected to complete the restoration work in 2011. The California Department of Parks and Recreation is working to address stream bank erosion by restoring portions of the Upper Truckee River that flow through the Lake Tahoe Golf Course. Finally, the Tahoe Resource Conservation District is working with private property owners to construct stream channel improvements downstream of the Lake Tahoe Airport.

The Lake Tahoe Basin Management Unit (LTBMU) has taken the lead in planning and constructing restoration projects on Blackwood Creek. Three projects have been constructed on Blackwood Creek within the past five years, including removal of fish passage barriers, Barker Pass culvert removal and bridge construction; and floodplain rehabilitation. The LTBMU has additional plans for further channel and floodplain work to address channel instability from historic gravel mining and grazing disturbances. The CTC is also planning work on Blackwood Creek to treat channel incision at the Highway 89 crossing.

The CTC has prepared a comprehensive Watershed Assessment report (Hydro Science and River Run Consulting 2007) to evaluate both opportunities and constraints on restoration within the Ward Creek watershed. This report provides the framework for watershed and stream restoration activities to address, where appropriate, in-channel erosion and geomorphic instability within Ward Creek.

Many restoration projects are also planned for streams and riparian areas that are not within the subwatersheds of the three major streams listed above (e.g Rosewood Creek in Incline Village, Nevada, and Angora Creek in South Lake Tahoe, California). These restoration projects are expected to provide some load reduction benefit (though it cannot be quantified at this time) and will have significant benefits to other resources such as wildlife, vegetation, and fisheries.

Implementation Actions to Meet the Clarity Challenge and Achieve the TMDL

Implementation efforts for this source category are based on current plans and approaches. The loading and load reduction analysis focused only on fine sediment particles (and associated nutrients) released from stream bank and bed erosion.

The following is a representative list of stream channel restoration, rehabilitation, and bank protection measures that responsible parties may take.

Actions suitable for areas where restoration is unconstrained by existing development:

- Lower stream channel banks and reduce angle to accommodate more frequent over-bank flow and reduce bank erosion/slumping
- Increase channel length and sinuosity (over time will decrease channel bed slope) by constructing new channel segments
- Restore riparian vegetation
- Remove infrastructure (e.g., bridges) that fragments floodplains or restricts channel flow

The Water Board and NDEP expect needed load reductions and interim load allocations for the stream channel erosion source will be met when all the restoration projects and activities are completed for the three major tributaries. These restoration projects are anticipated to be completed within 15 years from the adoption of the TMDL.

11.4 Watershed Approach to TMDL Implementation

In highly complex or priority watersheds tributary to Lake Tahoe, it may be appropriate for resource management agencies to undertake a more focused, watershed approach to TMDL implementation. Watershed planning based on the analytical framework of the TMDL can help direct cost-effective implementation of necessary load reductions while providing other ecosystem services. The approach is described in U.S. EPA's

Handbook for Developing Watershed Plans to Restore and Protect Our Waters (US EPA 2008), which explains that EPA's Clean Water Act Section 319 grant funding is being directed towards implementing watershed plans consistent with TMDLs.

Watershed plans identify and prioritize load reduction opportunities and measures, and are especially helpful in situations where such strategies involve several interacting land and/or resource managers. Substantial work toward implementing the watershed approach is already occurring within the basin; examples include California Tahoe Conservancy's Ward Creek Watershed Assessment and the Upper Truckee River Watershed Advisory Group currently led by the U.S. Forest Service. The Natural Resource Conservation Service's Areawide Conservation Planning program supports private landowner and community coordination and participation in the Environmental Improvement Program and other projects at the watershed scale.

12 Adaptive Management

The United States Environmental Protection Agency (USEPA) has sponsored a project to develop the Lake Tahoe TMDL Management System (Management System). The US Bureau of Land Management approved funding for the project on November 1, 2009, under the Southern Nevada Public Land Management Act of 1998 (Public Law 105-263). This project will create the tools, templates, and standard operating procedures, then will beta-test the Management System for one-year to make refinements.

The Water Board and the Nevada Division of Environmental Protection (NDEP) intend to use the Management System for managing, tracking, integrating and evaluating new information generated from TMDL implementation actions, effectiveness monitoring, research efforts, and other factors such as climate change and wildfires. The Management System is expected to help inform decisions such as whether load allocations, milestones and/or implementation strategies and actions need to be adjusted . These decisions will be accomplished in a collaborative manner between the Lahontan Water Board and NDEP to the extent possible. However, NDEP reserves the right and authority to make independent decisions if necessary.

This chapter summarizes the development and components of the Management System, describes a number of potential environmental factors that might influence TMDL progress, and discusses how the TMDL implementation may adapt to these challenges.

12.1 Lake Tahoe TMDL Management System

The Management System will define structure, operations, and tools for a continual improvement cycle and an adaptive management process. The continual improvement focuses on tracking and evaluating program implementation and regulatory compliance while the adaptive management element outlines a process for reducing uncertainty within load estimation tools and other assumptions driving source category load allocations.

The Management System will enable the project implementers, project funders, research scientists, and other interested stakeholders to interact with the Water Board and NDEP in a structured and transparent process for continual improvement and active adaptive management. The Management System project includes four key aspects for human interaction: (1) developing relationships between agencies, implementers, and stakeholders to work together to accomplish a common goal, (2) defining the tasks and processes to enable all parties to work together, (3) defining how others will participate and provide input through a transparent and predictable set of processes, and (4) developing tools and templates to facilitate communication, and reporting.

The Management System is based on an adaptive management framework to (1) link load reduction effectiveness with project implementation monitoring to improve project design and to assess if actual environmental improvement is occurring as expected; (2) establish guidance and operational protocols for how new information will be incorporated into project designs and TMDL program implementation; (3) establish prioritized TMDL research needs to fill data gaps and reduce uncertainties; and (4) implement a process for updating and establishing pollutant load reduction credits/estimates and tracking projects during the TMDL implementation timeline. This project will create a linked series of tools, standard procedures, and feedback loops that will allow for operation of the TMDL into the future, building on projects currently under development.

The Management System diagram (Figure 12-1) depicts the primary components, framework, and procedural steps and once fully developed, will create the protocol and process to link the individual components or boxes. The "Plan" component of the diagram is the starting point with the goal (both the Clarity Challenge and the TMDL numeric target), a conceptual model to identify linkages between variables and the goal, TMDL load allocations, and associated regulatory policies and programs to achieve the goal. These components are the backbone of the TMDL and this Management System, and they drive the implementation actions that will be evaluated for effectiveness.

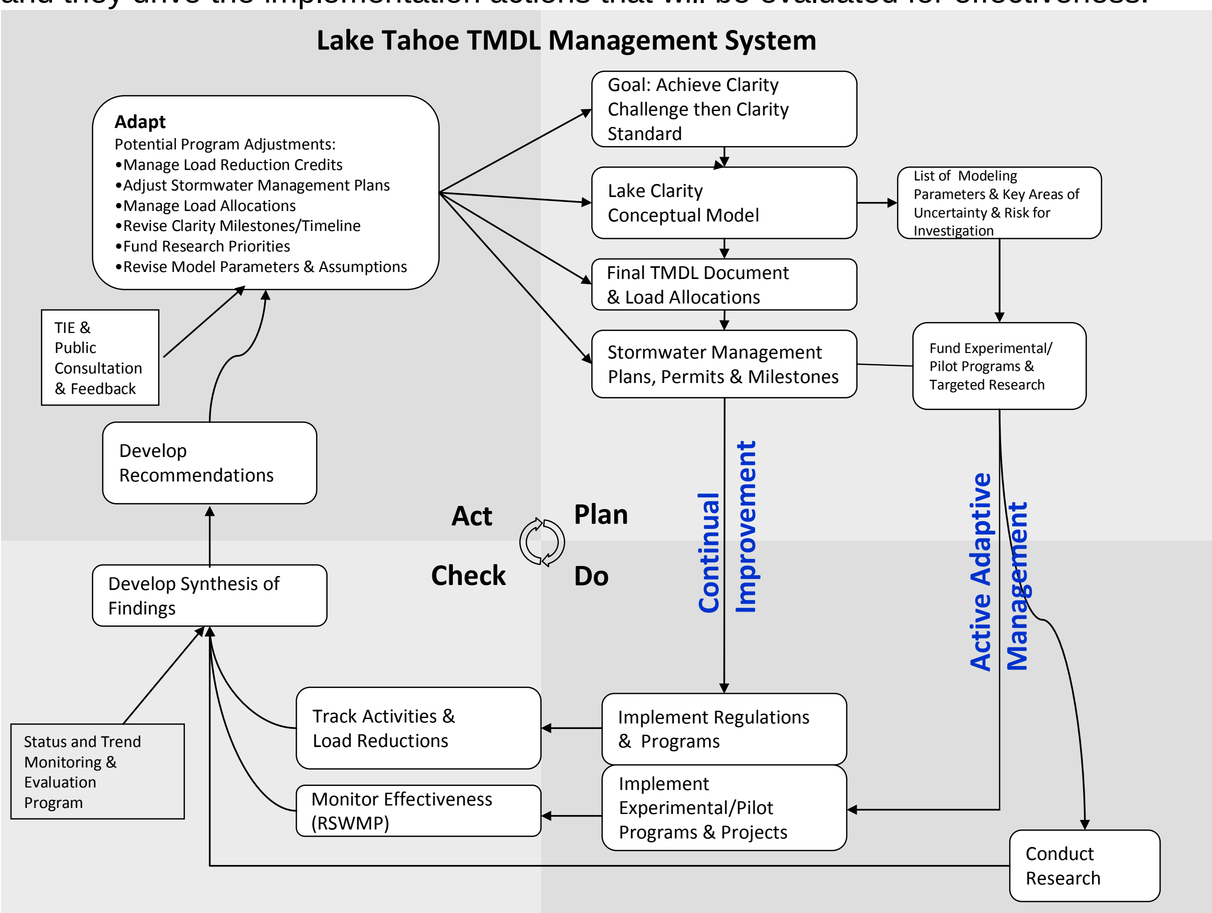

Figure 12-1. Lake Tahoe TMDL Management System diagram illustrating the continual improvement and active adaptive management cycles (adapted from Sokulsky and Beierle 2007).

The “Do” component of the diagram in Figure 12-1 comprises TMDL implementation and associated pilot projects along with research. The “Check” component is needed to verify the effectiveness of various actions at reducing fine sediment particle and nutrient loads as well as track progress at meeting established milestones. A Synthesis of Findings report will allow all entities within the basin to benefit from the findings of research and monitoring data, which will be available for public review and input, and will guide the recommendations for future investigations.

The “Act” component is where management decisions are based on the recommendations that stem from the Synthesis of Findings report. The feedback loop then continues to another annual adaptive management cycle to continue building on past efforts.

This framework provides for adaptive management cycles to occur at various time scales. For instance, the same framework provides for (1) annual review of implementation progress and research priorities, (2) five-year assessments of overall load reduction accomplishments and monitoring results, and (3) fifteen year implementation planning efforts to evaluate the need for load allocation adjustments and to establish new five-year milestones for future implementation periods.

The following sub-sections elaborate on selected components of the Management System.

Conceptual Model

The conceptual model is the visual linkage for how fine sediment particle and nutrient control actions for the different source categories will reduce pollutant loading to Lake Tahoe and will affect (or improve) transparency (see Appendix A for Lake Clarity Conceptual Model). The conceptual model clearly describes the current understanding of cause and effect linkages. The conceptual model documents and links: (1) the relationships between the goal and the associated indicator and target, as well as other points in the system that can be measured to understand the system; (2) the relationship between management actions and the goal; (3) areas of uncertainty within the understanding of the system, and (4) the different pollutant sources to the lake clarity response with various transport mechanisms. The conceptual model also identifies the most important drivers and actions related to lake transparency.

Research Needs

The adaptive management system will have a process to incorporate and manage TMDL research needs and will guide future funding priorities for specific areas of investigation. The process will allow the load reduction estimation models to be updated as needed with the latest research results regarding model input parameters, incorporate new load reduction opportunities from innovative practices, and adjust policies if necessary. The incorporation of key research findings will help reduce areas of uncertainties and adjust policies when appropriate. Future research will focus on key areas of uncertainty related to TMDL development, modeling parameters, assumptions, and potential implications from climate change or other factors.

Experimental Pilot Projects

The Water Board and NDEP will facilitate targeted research and support funding recommendations for experimental and pilot projects that evaluate and quantify benefits from innovative practices. Implementers and water quality managers will work collaboratively to implement the Recommended Strategy, which calls for advanced, alternative and innovative practices to meet the needed load reductions. These actions are often expensive and planning must be informed by up to date and scientifically sound information. Important findings from research and data collection will be incorporated in the Synthesis of Findings report.

Track activities and Load Reductions

The Water Board and NDEP have developed the Lake Clarity Crediting Program to support the Lake Tahoe TMDL. The Lake Clarity Crediting Program specifies the process and protocols enabling the urban jurisdictions to link projects, programs, and operations and maintenance activities to estimated pollutant load reductions. By defining a consistent water quality credit, the Lake Clarity Crediting Program provides flexibility for the urban jurisdictions to plan and implement actions to achieve needed load reductions using a blend of operations and maintenance practices, capital improvement projects, and restoration efforts. The Water Board and NDEP will use the Lake Clarity Crediting Program to track compliance with stormwater regulatory measures.

An Accounting and Tracking Tool has been created to track Lake Clarity Credits and associated estimates of fine sediment particle, phosphorus and nitrogen load reductions. The Tool is a database that will allow with Water Board and NDEP to easily collect, store, and manage load reduction and credit value data. In the future, the Water Board and NDEP plan to expand the database to an online system that can integrate other stormwater tracking information.

In addition to tracking load reductions and Lake Clarity Credits associated with urban actions, the Accounting and Tracking Tool includes data fields for fine sediment particle, phosphorus, and nitrogen load reductions from forest upland, stream channel erosion, and atmospheric deposition sources. However, methods to quantify the load reductions from these three sources (forest upland, stream channel erosion, and atmospheric deposition) have not been developed. Once developed, the data can be input to allow for tracking and reporting on load reduction progress.

The Management System will provide the framework to track pollutant load reductions from all source categories and report them to the public via a web portal and an annual reporting document. The Management System will also establish the venue for creating standardized protocols for estimating load reductions from the atmospheric deposition, forest upland and stream channel source categories.

Monitor Effectiveness

The TMDL Monitoring Program is a critical part of evaluating project and BMP effectiveness, project load reductions, and overall status and trends within certain sub-watersheds and the basin as a whole.

The Regional Stormwater Monitoring Program, currently under development, will be focused on characterization and effectiveness monitoring of urban stormwater runoff throughout the Tahoe basin. This monitoring program will focus on three scales; individual BMP effectiveness, project scale, and catchment/index station scale monitoring. The monitoring information will be used to calibrate and validate load reduction estimation tools within the adaptive management process.

The Lake Tahoe Interagency Monitoring Program (LTIMP) is composed of two components: the stream network monitoring and lake monitoring (in and on Lake Tahoe). The LTIMP stream monitoring will be used to evaluate watershed scale status and trends and to evaluate load reductions from actions taken in the forest uplands and stream channels. The LTIMP lake monitoring will be used to track annual average Secchi disk depth and evaluate lake response to TMDL implementation. The lake monitoring will evaluate long term status and trends for Secchi depth amongst many other parameters, including atmospheric deposition sampling. New information generated from these monitoring programs will help to assess progress in meeting load reduction goals for the forest upland, stream channel, and atmospheric source categories.

Synthesis of Findings Report

Water Board and NDEP staff will work collaboratively with researchers to generate a periodicSynthesis of Findings report that summarizes the load reduction accomplishments from the previous year and provides an integrated understanding of load reductions achieved, opportunities for innovation and efficiency, changes in Lake Tahoe's transparency, and new research findings. The synthesis will assemble and analyze new data and information to inform policy recommendations. The report will provide a mechanism to communicate with the public on progress towards meeting load allocation targets, promote ongoing load reduction activities, and document implementation achievements to support additional funding.

In addition to the periodic Synthesis of Findings report, Water Board and NDEP staff will prepare a five-year milestone evaluation report to assess whether necessary load reductions from the major pollutant source categories are being accomplished. This evaluation report will provide important information to help guide future prioritization of the most effective projects. This report will include status and trends information, and will be useful in informing potential program adjustments.

Develop Recommendations

The recommendations for management decisions will be based on the Synthesis of Findings Report which incorporates information from both the continual improvement and the adaptive management processes. The report will recommend management and executive decisions to adjust TMDL related programs, policies, or timelines as necessary. This step will involve implementer, stakeholder, and public consultation.

Adapt

As TMDL implementation progresses and new information and recommendations arise, the Water Board and NDEP will each perform adaptive management and continuous improvement to make needed program and policy adjustments. Potential adaptations may include: revising load reduction milestones, adjusting implementation strategies, and selecting areas for additional adaptive management investigations or amending the implementation schedule in response to economic conditions and funding levels.

The advantage of an effective management system is the ability to incorporate the unforeseen into future policy adaptations. An unforeseen circumstance may be a refinement, such as a more precise calculation of the number of fine sediment particles removed by a particular type of control measure, or something more complex and global, such as climate change, catastrophic events or changing economic conditions.

Lake Tahoe is vulnerable to a number of large scale events that may impact the effectiveness of the Lake Tahoe TMDL Implementation Plan.

The Management System will be designed to allow regulators and implementers the ability to adapt not only to advances in pollutant reduction accounting, but to large scale changes in the Lake Tahoe watershed condition. Climate change and catastrophic events are two large scale issues that the Water Board and NDEP will address through the Management System.

12.2 Climate Change

Climate change has the potential to affect pollutant generation and transport processes. This section examines possible climate change trends reported in peer reviewed articles and presents a climate change scenario developed for the Lake Tahoe Watershed Model. This TMDL does not assign pollutant load or waste load allocations to address potential effects of climate change. Since the impacts of climate change on pollutant loading are uncertain and cannot be conclusively determined at this time, the climate change effects will be addressed through the continual improvement and active adaptive management processes of the Management System. Potential measures for adapting to significant climate change effects may include adjustments in the Lake Clarity Crediting Program or adjustments to the implementation strategy to emphasize or de-emphasize different approaches to water quality improvement projects. The information in this section is included to describe the type of watershed changes that may necessitate program adjustments.

Climate Change Impacts on Precipitation, Temperature, and Pollutant Loading

Mountain settings such as Lake Tahoe are especially susceptible to climate change because of the large percentage of precipitation that falls as snow. Temperature recordings in Tahoe City over the last century have shown a rise in the average temperature, so much so that the average nighttime temperature has risen to the melting point. This corresponds with a decrease in the number of days with an average temperature below freezing.

An increase in winter temperature will lower the percentage of precipitation that falls as snow, shrinking the snowpack and changing the temporal patterns of runoff. A shift in peak snowmelt increases the length of summer drought with consequences for ecosystem and wildfire management (Stewart et al. 2004). At Lake Tahoe, this can already be seen in the timing of peak snowmelt in the Upper Truckee River watershed. In the past 50 years the average date of peak snowmelt has shifted earlier by almost three weeks. Furthermore, Howat and Tulaczyk (2005) predict that the Tahoe region will experience an increase in snowpack above 7500 feet, while below this elevation the dominant phase of precipitation will be rain. This differs from the historical condition where the dominant precipitation phase within all elevations of the Tahoe basin is snow.

While the ecosystem impacts from changes in snowmelt timing are themselves cause for concern, it is the greater erosion impact of rainfall that will likely lead to increased pollutant pressures on the lake clarity and transparency standards. A shortening of winter and an earlier spring snowmelt will lead to a drier, more erodible soil structure. As the precipitation regime shifts towards a higher rain to snow ratio, combined with an expected increase in rainfall intensity, the basin will experience greater rates of erosion (Bates et al. 2008, UC Davis - TERC 2008). Future raindrop erosion will not be limited to the summer and fall seasons. As the snowline climbs, raindrop erosion may occur even in winter storm events. Down-slope transport of eroded material would increase the pollutant loading to Lake Tahoe. Potential management adjustments to address this change could include increased flow capacity requirements to treat runoff or increased maintenance of existing treatment measures.

Climate Change Impacts on Lake Processes

The impacts of climate change on achieving Lake Tahoe's water quality objectives are not limited to effects on pollutant loading from the surrounding watershed. Evidence of climate change is already present in the actual lake waters (Melack et al. 1997, Coats et al. 2006, UC Davis - TERC 2008). Future impacts have the potential to alter lake dynamics with consequences for lake transparency and clarity (Sahoo and Schladow 2008).

Seasonal variation is an inherent driver of Tahoe's current lake processes. The mean annual temperature of Lake Tahoe is rising at the rate of 0.015 degrees Celsius (0.027

ºF) per year (Coats et al. 2006) (Figure 12-2). As temperatures continue to increase, the lake will likely experience increased thermal stability (Bates et al. 2008, Sahoo and Schladow 2008).

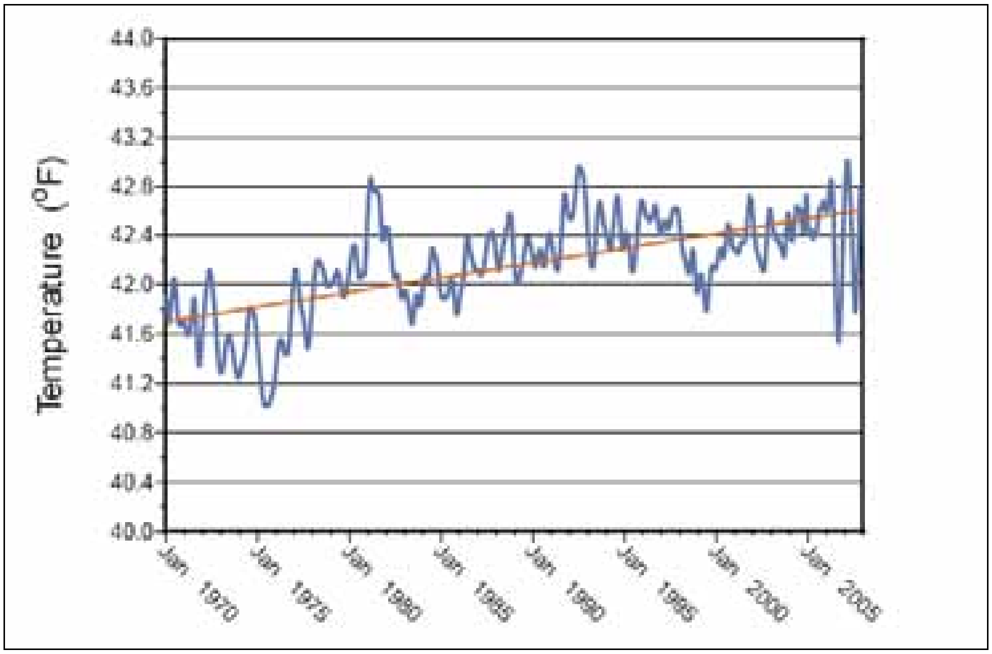

Figure 12-2. Volume-averaged water temperature for Lake Tahoe (UC Davis - TERC 2008).

Lake Tahoe historically undergoes deep mixing of the water column on average once every four years (Coats et al. 2006, Schladow et al. 2008). The depth of the mixing is dependent on thermal stability in the water column as well as the power of winter storm events with sufficient wind to promote mixing. Deep mixing is responsible for oxygenating the entire water column, and results in deep nutrient rich waters being brought to the surface. As the lake temperature rises with climate change, the lake will experience an increase in stability as waters become resistant to the mixing influence of wind and warmer surface waters resist sinking (Coats and Redmond 2008). Since 1982, Lake Tahoe has exhibited evidence to resistance to lake mixing and increased stability of stratification (Winder et al. 2008).

Increased thermal stability and lake stratification will likely reduce the maximum depth of lake mixing. Sahoo and Schladow (2008) modeled lake dynamics under a “business as usual” approach to world carbon emissions where there is no market or regulatory based efforts to reduce carbon emissions. They applied the National Oceanic and Atmospheric Administration's prediction of climate change under a “business as usual” scenario, labeled A2 by the Intergovernmental Panel on Climate Change, to the Lake Clarity Model. Sahoo and Schladow's modeling efforts, which include A2's air temperature changes and a 10 percent progressive increase in longwave radiation, predict that Lake Tahoe would cease mixing to the bottom within a period of approximately 20 years. The predicted maximum depth of mixing was on the order of 250 meters, or about half of Lake Tahoe's maximum depth.

The impacts on lake transparency may be twofold. One side effect of increased stratification is an increased residence time of fine particles in the top most stratified layer of the lake (Coats 2008, Sahoo and Schladow 2008). The other impact of increased thermal stratification is a direct consequence of reduced mixing. Such altered dynamics could result in reduced deep water oxygen concentrations. In an oxygen poor environment, soluble reactive phosphorous may be released from deep lake sediments (Schladow et al. 2008, Bates et al. 2008). When the lake experiences a deep mixing event, perhaps every twenty years, the nutrient rich upwelling may cause a significant algal bloom that could further impair Tahoe's aesthetic beneficial use.

It is acknowledged that the actual ramifications of climate change to Lake Tahoe transparency are not fully known at this time. However, the purpose of this section, as stated above was to describe the type of lake changes that might create program adjustment needs in the future. The data and analyses and climate change modeling fully support the contention that impacts could be significant. The TMDL Management System will enable the Lake Tahoe community to be 'out front' and consider and plan for any impacts associated with future climate change.

Lake Tahoe Watershed Model Climate Change Analysis

Tetra Tech, Inc. conducted an exploratory scenario examining potential impacts associated with climate change (Tetra Tech 2007). The scenario did not use a customized global climate model, but applied best modeled literature values of changes in precipitation and temperature to the watershed model as projected out to 2050. Running the watershed model with these climatic changes gives an estimate of potential pollutant loading changes to Lake Tahoe.

Based on the predictions of Dettinger (2005) and Cayan et al. (2006), 11 climate change scenarios and a baseline scenario were applied to the Lake Tahoe Watershed Model and projected to 2050. Of 11 scenarios, the Central Projection was developed from the Dettinger and Cayan estimates. Ten other scenarios were developed by applying variations of one standard deviation from the Central Projection's -10 percent precipitation change and +2ºC temperature changes. Scenario temperature ranges were from +0ºC to +4ºC above baseline in one degree increments. Precipitation values differing in magnitude from baseline are -25 percent, -10 percent, +0 percent, +15 percent. The baseline temperature and precipitation values used to generate the fine sediment particle and nutrient load estimates were also used for the climate change impact analysis. Results of the Central Projection, which includes an overall 10 percent decrease in precipitation, indicate a 61 percent decrease in basin-wide snowpack. These results agree with the snowline elevation changes predicted by other independent research (Howat and Tulaczyk 2005).

Though the modeled scenarios provide insight into the potential magnitude of precipitation events associated with the mid-century climate impacts, the scenarios do not account for adjustments in event frequency. Greater event frequency may saturate soils more frequently, decrease evapo-transpiration from increased cloud cover, and increase rain on snow events. Conversely, decreased precipitation frequency coupled with an increase in temperature would result in drought conditions, increased evapo-transpiration rates, and lowered stream flows.

Climate Change Impacts on Wildfire

Climate change may have significant implications for future catastrophic wildfire risks. The shift in snowmelt timing and the rise in temperature will result in earlier, longer, and hotter summers. A rise in temperature is expected to increase evapo-transpiration, lowering the water table and drying out soils. Dry conditions could weaken vegetation, leaving trees susceptible to expiration by water deficit or disease. Increased vegetation mortality would lead to increased fuel loading and, coupled with the fuel drying potential of higher temperatures, increased fire susceptibility.

The heightened fire condition would likely result in an increase in both fire frequency and fire intensity. Fires may become more frequent because it would be easier for the fuels to catch fire. Intensity could increase with the change in availability and condition of the fuel supply. While both of these probabilities provide concern for human health and property, fires also threaten the lake with the potential for greater rates of pollutant loading from bare soils eroding and smoke depositing fine sediment particles and nutrients into the lake.

12.3 Catastrophic Events

The Lake Tahoe watershed is vulnerable to a number of potential catastrophic events that may impact the ability to achieve Lake Tahoe's deep water transparency objective. The foremost of these possibilities is wildfire. In addition to the potential impacts of wildfire, Lake Tahoe is vulnerable to tributary flooding, seismic activity, and associated watershed impacts.

Wildfire

Wildfire has the potential to affect loading of the target pollutants to Lake Tahoe. The 2002 Gondola and 2007 Angora fires highlighted the need to address wildfire when discussing basin-wide resource management. While wildfire has the potential to impact Lake Tahoe's water quality, wildfires are also sporadic and unpredictable in frequency, area burned, and intensity.

Wildfire has the potential to contribute to Tahoe's pollutant loading both directly, through smoke deposition, and indirectly through increased particle erosion and down-slope nutrient leaching. Erosion is associated almost exclusively with precipitation and melt events, either through raindrop erosion or overland flow contributing to rill erosion (Robichaud 2000). Erosion potential after a burn is variable and depends on the site characteristics, the burn intensity, speed of vegetation recovery, and, most importantly, precipitation (Robichaud 2000). Remedial efforts, such as hydromulching, tilling, chipping, mastication, and water bar installation, can affect the erosion rates and soil loss of burned areas. Additionally, post-fire soil hydrophobicity can promote overland flow and associated increases in erosion (Robichaud 1996, referenced in Robichaud 2000). Finally, fires can cause nutrient volatilization and nutrient leaching from soils and other burned organic matter. Leached nutrients are available for down slope transport to the lake. Leaching levels can vary with soil type, vegetation, and fire intensity (Murphy et al. 2006).

Case Study: The Gondola Fire and Eagle Rock Creek

In July 2002, a fire burned in the southeastern part of the Tahoe basin, entirely within an undeveloped area. This fire, called the Gondola Fire, burned 673 acres including the Eagle Rock Creek watershed (Allander 2004).

The Lake Tahoe TMDL modeling analysis included pollutant loading from the 2002 Gondola Fire. The Lake Tahoe Watershed Model used tributary monitoring data from 1994-2004, and the Lake Clarity Model was calibrated and validated with Lake Tahoe monitoring data from 2002-2004. Because Eagle Rock Creek flows through the Gondola Fire burn area and into Edgewood Creek, any localized increase in pollutant load water transported by Eagle Rock Creek from the fire was recorded as part of the water quality samples collected from Edgewood Creek. Total nitrogen and suspended sediment concentration data from Edgewood Creek did not show any changes that may be attributed to the Gondola Fire, but total phosphorus concentration approximately doubled immediately after the fire and appeared to return to typical levels after about two years.

Allander (2004) showed post-fire increases in nutrients and sediment into Eagle Rock Creek, but sediment particle size was not analyzed. Several severe thunderstorms occurred a few days after the fire and before some erosion control measures could be implemented. A follow up study by Allander (2006) concluded that nitrogen and phosphorus concentrations in Eagle Rock Creek water quality samples post-fire were about double the pre-fire concentrations but returned to pre-fire levels by about 2006. Eagle Rock Creek monitoring data is consistent with studies examined in Robichaud (2000) which show a post-fire peak in nutrient and sediment loading, followed by attenuation, and conifer watersheds that burn at moderate to high severity can take seven to 14 years for sediment yields to return to normal.

Angora Fire

The Water Board, NDEP, CTC, and USFS LTBMU supported a monitoring project to assess the water quality impact of the 2007 Angora Fire. During the fire, atmospheric deposition of nutrients was two to seven percent higher than normal summer loading rates, but only accounted for approximately one percent of the annual load from all sources (Reuter et al. 2008). The following two years (Water Year 2008 and 2009) were both characterized by below normal precipitation, with low flow, no strong summer thunderstorms, and few significant runoff events. Average annual concentration of nitrate during these two post-fire years increased approximately 8.5 times; this is commonly reported in the literature. Total Kjeldahl nitrogen and total nitrogen concentrations were 1.6 - 2.0 times higher after the fire, total phosphorus increased 1.9 times, total suspended solids increased 2.0 times, and turbidity was 3.9 times higher (Reuter et al. 2010). Only nitrate declined between Water Year 2008 and Water Year 2009. The large increase in nitrate upstream was not observed downstream near the Upper Truckee River confluence. Levels of nitrogen were moderate during the large, May 2009 rain event. Phosphorus, total suspended solids and turbidity showed elevated spikes but similar to other peaks for these constituents. An analysis of long-term LTIMP monitoring data for annual flow and load in the Upper Truckee River (15 years), only total phosphorus was higher than expected in 2008 (Oliver et al. 2010). With just two years of data available, it is difficult to attribute this solely to the Angora Fire.

In summary there was no evidence of massive sediment or nutrient inputs from the burned urban area into Angora Creek (Heyvaert et al. 2010). However, there was evidence to suggest that urban runoff (from within the burn area) was contributing to slightly elevated concentrations in the lower Angora Creek site. It appears that the Angora restoration and Washoe Meadows areas provided a level of stormwater treatment to the runoff from the surrounding catchment. Post-fire sediment and nutrient concentrations in the Angora urban runoff and in Angora Creek itself after the fire were generally much better than observed at other urban sites around the Tahoe basin.

Ongoing monitoring of Angora Creek and the Upper Truckee River is needed to evaluate the longer-term (3-10 year) impacts of the 2007 Angora Fire. The monitoring results from these two dry years (WY 2008 and WY 2009) should not be taken as representative of conditions that will be seen after any major wildfire in the Tahoe basin. For example, this is different from initial observations following the Gondola Fire when higher loads were measured - likely due to post-fire storm conditions. Additionally, the location of the Washoe Meadows, between the burn area and the confluence to the Upper Truckee acts to reduce downstream pollutant load. Loading to the lake is likely to be considerably different if such a natural buffer was not present.

Flooding

A significant rain-on-snow event occurred in January 1997 and many areas of the Tahoe basin were flooded. Since the Lake Tahoe Watershed and Lake Clarity Models included input data from 1994-2004, the “New Years 1997” flood event was recorded in the loading analysis.

With the advent of climate change it is possible that future flood events may increase in magnitude, which may impact the ability to achieve load reduction targets. Even if the magnitude of storms does not increase, a substantial elevation increase of the snowline and an increase in rainstorm intensity will likely increase the flood frequency. The Water Board and NDEP will assess the impact of flood events through annual monitoring and the Management System.

Earthquakes and Subsequent Wave Erosion

Located on the border of the Sierra Nevada and the Carson mountain ranges, Lake Tahoe is an active seismologic area (Gardner et al. 2000). The lake is home to two major fault zones. The West Shore-Dollar Point fault zone runs north-south on the western side of the lake, and the North Tahoe- Incline fault strikes northeast, traveling along Tahoe's greatest depths to Incline Village (Ichinose et al. 2000). A third fault, the Genoa fault zone, lies just east of the Tahoe basin.

The Lake Tahoe region periodically experiences small earthquakes. While these tremors are a reminder of the seismic nature of the region's setting, quakes of the size that could impact the goals of this TMDL are rare. The geologic record shows that large earthquakes (Richter Magnitude 7+) in Tahoe have historically occurred every 3000 years (NSF Press Release 2005). Given the rarity of these events, it is highly unlikely that an event of that significance would occur during the project timeframe. However, should such an event occur the Water Board and NDEP will assess the resulting impacts in relation to load reduction milestones and make adjustments as appropriate.

12.4 Economic Conditions

The Lake Tahoe region has been extremely fortunate and successful in receiving past federal, state and local funding support to carry out the Environmental Improvement Program (EIP). Roughly half or more of the original $980 million estimate to accomplish the EIP has been spent on water quality related improvements. Consequently, the timeframes for achieving the interim Clarity Challenge and the TMDL numeric target have been based on the assumption that recent funding levels will continue into the future. However, recent economic conditions and budget constraints indicate that funding may soon become a real limitation constraining the pace of implementation. For example, the proposed Lake Tahoe Restoration Act of 2011, which builds on the federal commitment to Lake Tahoe that began under the Lake Tahoe Restoration Act of 2000, would authorize $415 million over 10 years to improve Lake Tahoe water clarity, reduce the threat of fire and restore the environment, but it has been stalled in the U.S. Congress since its introduction. Should funding constraints adversely impact the feasibility to meet load reduction goals within the timeframes specified (i.e., load reduction milestones), the Water Board and NDEP may amend the implementation and load reduction schedules.

13 Monitoring Program

Integrated and coordinated monitoring is needed by agency managers and decision-makers to determine how the Lake Tahoe TMDL implementation effort is resulting in improved water quality. In collaboration with watershed stakeholders, the Water Board and NDEP have prepared a monitoring program framework to meet this need. The team expects to further develop monitoring program components within the first few years following TMDL adoption by USEPA, and full monitoring program operation is expected to follow. Once fully developed, the monitoring program will assess progress of TMDL implementation and provide a basis for reviewing, evaluating, and revising TMDL elements and associated implementation actions. The monitoring program is both contingent and scalable based on available funding and is expected to cover the pollutant sources and will monitor the in-lake responses to the reduced pollutant loading. The source monitoring will focus on the largest pollutant source, urban uplands, but will also address the other pollutant sources: atmospheric deposition, stream channel erosion, and forested uplands.

13.1 Monitoring needs and conceptual model

The monitoring program will be developed to answer the Lake Tahoe TMDL Core Questions for TMDL implementation and operation:

1. *Are the expected reductions of each pollutant to Lake Tahoe being achieved?*

   Estimating and tracking fine sediment particle and nutrient load reductions from the four major pollutant sources (urban uplands, forest uplands, stream channel erosion, and atmospheric deposition) will help answer this question.

2. *Is the transparency of Lake Tahoe improving in response to actions to reduce pollutants?*

   The Lake Tahoe TMDL monitoring program includes ongoing Secchi depth and other in-lake water quality measurements to assess the lake's response to watershed management actions.

3. *Can innovation and new information improve the strategy to reduce pollutants?*

   The proposed program will evaluate implementation measure effectiveness with an emphasis on assessing the ability of new and innovative technologies/approaches for reducing fine sediment particle loads and nutrients.

Although several parts of the Lake Tahoe TMDL monitoring program such as in-lake monitoring have been operating for many years, other components are currently being developed. In late 2007, TRPA and agency partners with consultant involvement formed a working group to develop a Lake Tahoe Status and Trend Monitoring and Evaluation Program (M & E Program) for select resource area desired conditions in the Lake Tahoe basin. The group includes representatives from the Tahoe Regional Planning Agency (TRPA), NDEP, Water Board, USFS Lake Tahoe Basin Management Unit (LTBMU), and the Tahoe Science Consortium. The working group agreed to a charter that includes a consensus vision for the program:

> *Lake Tahoe agencies will work collaboratively with the scientific community and other partners to develop and operate a cost-effective, integrated status and trend monitoring and evaluation program for the Lake Tahoe basin. The M & E Program will reliably and systematically monitor, evaluate and report on the status and trends of the basin's environmental and socioeconomic conditions in a timely manner. Information provided through this effort will be used to improve agency decision-making and general understanding of Tahoe basin conditions.*

The M & E Program includes a series of conceptual models developed to link program actions to environmental indicators and expect to complete detailed indicator frameworks and associated monitoring and evaluation action plans by late 2009 for each conceptual model. A Lake Tahoe Clarity Conceptual Model has been developed through the M & E Program for the Lake Tahoe Clarity Desired Condition (Appendix A). The conceptual model and associated indicator framework will be used to guide monitoring of the most important drivers that affect the status of the system. For the transparency objective, Secchi depth measurements will be used to evaluate progress since Secchi depth integrates the impact of the three key pollutants of concern (fine sediment particles, phosphorus, and nitrogen), however other parameters such as dissolved oxygen saturation and primary productivity will also be monitored and tracked.

13.2 Definition of Generalized Monitoring Categories

The Lake Tahoe Watershed Assessment provides a definition of monitoring that encompasses three different forms (Murphy and Knopp 2000 [Ch. 7]). All three forms of monitoring can provide information of relevance to the management and operation of the Lake Tahoe TMDL implementation.

- *Implementation monitoring:* Considered to be the monitoring of management actions in relation to intended project plans. The purpose of implementation monitoring is to document that projects comply with regulatory conditions and meet mitigation obligations as specified in the construction plans and permit (e.g. was the project built as designed).

- *Effectiveness monitoring:* The monitoring of the effectiveness of management practices and actions in achieving desired conditions or trends. Within this TMDL, effectiveness monitoring can occur on a variety of scales, (e.g. a single BMP, multiple BMPs that form a water quality improvement project, multiple projects found in the same sub-drainage basin or the same watershed, and/or BMP improvement efforts within the entire basin). This type of monitoring is an integral part of the capital improvement, regulatory, and incentive programs and allows for the evaluation of individual or combined effects of water quality control actions. Results from effectiveness monitoring can be used by project designers to incorporate those design features that will most successfully remove the pollutants of concern.

- *Status and trends monitoring*: Broadly defined as the monitoring of the status and trends of water quality conditions and controlling factors. This is the principal type of monitoring used to gather the data that can inform us about long-term changes in water quality conditions relative to established water quality standards and/or goals. Status and trends monitoring is directly linked to effectiveness monitoring in that it evaluates water quality improvement over time at each of the spatial scales listed above (e.g. single and multiple BMPs, watershed, whole-basin).

Typically, TMDL monitoring focuses on the specific parameters related to water quality impairment. In the case of the Lake Tahoe TMDL these include Secchi depth in the lake and the amount of nitrogen, phosphorus and fine sediment particles entering the lake from the various major sources.

13.3 Source Load Reduction Monitoring

The following sections describe the various efforts underway to develop the monitoring components for each of the four pollutant source categories.

13.3.1 Urban Uplands

In 2007 the Tahoe Science Consortium began planning a Lake Tahoe Regional Stormwater Monitoring Program (RSWMP) to better understand local urban runoff conditions, evaluate the impact of erosion control and stormwater treatment efforts, and coordinate and consolidate an urban stormwater monitoring work. Agency and Tahoe Science Consortium representatives formed the RSWMP Core Working Group to develop a conceptual framework and craft a phased program implementation approach. The Core Working Group consists of eighteen individuals representing various interests, including regulatory agencies, funding groups, science community, and local and state implementing agencies at Lake Tahoe.

The RSWMP has been organized in three phases. The first phase, completed in 2008, focused on collaboratively framing the elements of a comprehensive stormwater monitoring program. The framework includes relevant agency, implementer and science considerations, an outline of the required elements for a monitoring program, the design for structural (administrative) elements, and goals and objectives for a sustainable program. This phase produced a technical document that provides guidance for the development of the detailed RSWMP technical and organizational plan (Heyvaert et al. 2008).

The second phase of RSWMP builds on the conceptual framework by designing a specific monitoring program for the Tahoe basin to meet regulatory, implementing, and funding agency needs. Phase Two components include: a quality assurance project plan; specific monitoring goals and data quality objectives; monitoring design specifications; detailed sampling and analysis plan; stormwater database development, data management and analysis details; organizational structure of RSWMP; operational costs; funding arrangements; agency roles and responsibilities; and internal and external peer-review processes. The USFS LTBMU agreed to fund the second phase which was completed in 2011.

During the second phase, a list of priority analytic constituents and physical variables was created to guide monitoring plan development. The past TMDL Stormwater Monitoring Study (Heyvaert et. al 2007) collected data on the following constituents: total nitrogen, total Kjeldahl nitrogen, nitrate, un-ionized ammonia, total phosphorus, total dissolved phosphorus, soluble reactive phosphorus, total suspended solids (or suspended solids concentration), particle size distribution, turbidity, pH and electrical conductivity. This preliminary list will be evaluated in forming the monitoring plan, and in some cases, data on additional constituents may be needed. In some cases, surrogate variables may substitute for more costly analysis (i.e. using turbidity in place for particle size distribution) depending on additional research to verify preliminary relationships.

A generalized list of consolidated monitoring goals were developed to meet the needs of all interested parties in the Tahoe basin as expressed by the agency, implementer and science representatives in the RSWMP Core Working Group.

- *Pollutant Reduction:* Quantify progress in pollutant reduction and restoration efforts. Includes status and trends monitoring and the watershed/basin scales of effectiveness monitoring.

- *BMP Design, Operation and Maintenance:* Develop information for improvements in BMP design, operation, and maintenance. Includes implementation monitoring and the BMP/project scales of effectiveness monitoring.

- *Pollutant Source Identification:* Identify and quantify specific sources of urban stormwater pollutants needed to update and refine the event mean concentrations (or characteristic runoff concentrations) for stormwater quality used in a number of the management tools.

The last RSWMP phase will be the funding and implementation of the actual stormwater monitoring program. This phase includes selecting monitoring sites and equipment, providing staff to conduct the monitoring, and developing the detailed processes and protocols for reporting monitoring results. Since the RSWMP will largely provide information for the local municipal jurisdictions and state transportation agencies to meet regulatory or other monitoring needs, it is anticipated that local funding will be needed.

13.3.2 Groundwater

As part of the Lake Tahoe Interagency Monitoring Program (LTIMP), the United States Geological Survey (USGS) (Carson City, NV) conducted groundwater water quality monitoring. Funding for this monitoring is no longer available; however, the USGS performs groundwater monitoring over limited periods of time in conjunction with specific projects in the Tahoe basin. For example, the Bijou Groundwater Project (2005-2007) characterized processes that influence nutrient transport from detention basins to shallow aquifers, estimated mass of nutrients transported by shallow ground water, and identified locations where nutrient-enriched ground water seeps into Lake Tahoe (http://nevada.usgs.gov/water/projects/bijougw.htm). Additionally, water suppliers, such as the South Tahoe Public Utility District and other Tahoe water supply agencies, monitor groundwater wells (under federal and/or state requirements) and submit detailed reports to the Water Board and NDEP.

There are no immediate plans to develop a monitoring program for evaluating groundwater load reductions related to the TMDL implementation. The fine sediment particles of primary concern for Lake Tahoe transparency are not transported to the lake through groundwater flow, and infiltration of pollutants into the shallow aquifer from BMPs may be included in project monitoring. Given the limited effect of this source on lake transparency there is no reason at this time to perform or require additional groundwater monitoring for the TMDL.

13.3.3 Atmospheric Deposition

UC Davis scientists regularly measure atmospheric deposition of nitrogen (nitrate, ammonium and total Kjeldahl nitrogen) and phosphorus (soluble reactive phosphorus, total dissolved phosphorus and total phosphorus). However, fine sediment particle deposition (< 16 µm) monitoring is not part of this monitoring program. Since atmospheric deposition is a significant source of pollutant loading to Lake Tahoe and atmospheric load reductions are a component of the implementation plan, the need for a structured monitoring program exists.

The present atmospheric monitoring program includes sample collection at three primary stations: the lower Ward Lake Level station (on-land) and two stations located on the lake – the deep water (mid-lake) Buoy station located on the northern middle portion of the lake and the Northwest Lake station located between the deep water Buoy station and Tahoe City (see UC Davis - TERC 2008 for sampling location map). Monitoring at these stations can provide lakewide estimates of total particle loading from atmospheric deposition. Additionally, the California Air Resources Board conducts monitoring of PM_{10} in South Lake Tahoe. Analysis of particles < 16 µm should be added to the TMDL monitoring program along with new techniques/methods (standard operating protocols) for collection and analysis.

The monitoring for atmospheric deposition is expected to continue and several research studies, focused on fine sediment particles, are anticipated to be completed by 2011. The results from these studies should help fill important knowledge and data gaps in fine sediment particle deposition on Lake Tahoe, including better estimates of loading from atmospheric deposition.

To assess project effectiveness for reduction of fine sediment particles by individual atmospheric source, targeted air quality control monitoring should be conducted in association with selected project implementation. For example, Gertler et al. (2006) employed a sophisticated series of measurement methods (an instrumented vehicle to measure road dust resuspension and flux towers equipped with ambient monitors for $PM_{2.5}$ and PM_{10}) to assess the effectiveness of street sweeping for controlling road dust re-entrainment along a section of Nevada Highway 28 in the Tahoe basin. Such studies will help determine whether resource management actions are effectively reducing pollutant loads transported and deposited through the air. The existing and ongoing UC Davis atmospheric deposition monitoring is needed to assess basin-wide loading along with future directed monitoring focusing on actions to determine load reductions within the atmospheric source category.

The TRPA Regional Plan (1986) contains regulations in Chapter 91 of the TRPA Code of Ordinances for the purpose of attaining and maintaining applicable state and federal air quality standards and TRPA environmental thresholds. Specifically, Chapter 91 contains emission standards related to new stationary sources for particulate matter less than 10 micrometers in diameter (PM_{10}), nitrous oxides, and other constituents. Nitrous oxides and PM_{10} are the two emission substances that are related to the pollutants identified in this TMDL. This information will be collected from TRPA on an annual basis.

13.3.4 Forest Uplands

The forest uplands comprise over 80 percent of the total upland land area in the Tahoe basin. Land management agencies such as the USFS LTBMU, California Tahoe Conservancy (CTC), Nevada Division of State Lands, California State Parks, and many local municipal jurisdictions are responsible for managing the forested uplands. Entities that manage the majority of the forested uplands have multi-objective restoration programs that are planned or currently on-going.

The LTIMP stream monitoring network will play a key role in evaluating load reduction from these land-uses, while management practice effectiveness will be assessed on a project basis. The LTIMP stream monitoring provides a long term dataset (since 1978) that the Water Board and NDEP will use to evaluate the integrated effect of forest upland watershed management improvements over time. The ten tributaries that are monitored through LTIMP will allow for status and trends analysis to evaluate if long term reductions are being seen. The LTIMP program is scheduled to undergo a revision over the next few years and any revision should include the TMDL need for non-urban uplands monitoring and additional particle size distribution analysis.

Another matter that arises with regard to forest uplands is that there are significant efforts underway in the Tahoe basin for forest management and fire and fuel management. Monitoring will need to occur to ensure these forest management actions are evaluated at either the project and/or sub-basin level to determine if the measures are not increasing pollutant loading (fine sediment and nutrients). Research is planned through Southern Nevada Public Lands Management Act funding for evaluating the potential effects from various fuel reduction practices. The Water Board and NDEP will work with groups such as the USFS LTBMU to develop these monitoring plans.

Responsible parties should document and report annually to the Water Board and NDEP on 1) previous year activities to reduce pollutant loads and 2) plans for next year load reduction activities. The activities include, but are not limited to; fuel reduction projects, BMPs on unpaved roads and trails, ski area revegetation, routine BMP maintenance, and road decommissioning.

13.3.5 Stream Channel Erosion

The USFS LTBMU, CTC, and other responsible stakeholders have prepared detailed stream restoration plans to address stream channel erosion problems on the three largest contributing tributaries (Ward Creek, Blackwood Creek, and the Upper Truckee River). Similar to the forest upland monitoring approach, the relative impact of restoration activities will be evaluated on a project basis.

Responsible agencies are encouraged to use permanent survey markers and monitor changes in stream cross-sections in relation to erosion or aggregation of sediment for stream reaches of interest. Responsible parties should document and report annually to the Water Board and NDEP on 1) progress from past year on restoration and rehabilitation projects on stream channels, and 2) restoration plans for the following year.

Research projects funded through SNPLMA are currently focusing on the benefits of natural floodplains in reducing fine sediment particles and nutrients. It is anticipated that specific research projects will be completed in 2011 and there will be valuable information and consistent protocols useful for quantifying the load reductions from certain streams under specified flow conditions. Over time the largest contributing tributaries will have a stream channel evaluation which will include analysis of long term stream monitoring offering a more comprehensive assessment of how channel restoration efforts integrate with watershed actions to improve water quality.

13.4 Tributary and Lake Response Monitoring

13.4.1 Lake Monitoring

Lake Tahoe is home to one of the longest limnological monitoring programs in the United States. In 1959, Professor Charles R. Goldman (University of California, Davis) began a program of water quality and aquatic ecology studies at Lake Tahoe that is still active, 50 years later (e.g. Goldman 1974, Byron and Goldman 1988, Jassby et al. 1995, UC Davis - TERC 2008). UC Davis has maintained this monitoring program on a continuous basis since mid-1967 (i.e. 40 years). Funds are currently provided for lake monitoring by the Tahoe Regional Planning Agency (TRPA), UC Davis, and the Water Board; with other state and federal agencies contributing over its long history.

Lake sampling is done routinely at two permanent stations (Figure 13-1). At the Index Station (location of the Lake Tahoe Profile or LTP), samples are collected between 0 - 105 meters in the water column at 13 discrete depths. This station is the basis of the > 40 year continuous data set and monitoring is done on a schedule of 25-30 times per year. Data from the Index Station has been instrumental in the establishment of the water quality standards and thresholds for Lake Tahoe and constitutes the scientific evidence upon which many land-use decisions have been made over the years. The Mid-Lake Station has been operational since 1980 and has been valuable for comparison with the Index Station. At this location, samples are taken down a vertical profile to the bottom of the lake (0 - 450 meters) at 11 discrete depths on the order of once per month. Sampling along the complete vertical depth profile allows for the analysis of whole-lake changes.

The current list of parameters at the Index and deep water Stations (combined) includes: nitrate, ammonium, total Kjeldahl nitrogen, total nitrogen, total reactive phosphorus, dissolved phosphorus, total hydrolysable phosphorus, total phosphorus, dissolved inorganic carbon, chlorophyll *a*, fluorescence, primary productivity (^{14}C), Secchi depth, light transmission, temperature, and dissolved oxygen. In addition, the lake monitoring program also includes phytoplankton and zooplankton taxonomy and enumeration, algal growth bioassays (using natural populations), and periphyton (attached) algae. Much of this monitoring is summarized in a report entitled, *Tahoe: State of the Lake Report* published by UC Davis (UC Davis - TERC 2008). Lake monitoring is critically important in assessing whether watershed management actions are having the desired impact on Lake Tahoe's transparency.

13.4.2 Tributary Monitoring

Stream water quality monitoring and suspended sediment load calculations are regularly done as part of the Lake Tahoe Interagency Monitoring Program (LTIMP). LTIMP is a cooperative program including both state and federal partners and is operationally managed by the USGS, UC Davis - TERC, and the TRPA. LTIMP was formed in 1978 and one of its primary objectives is to monitor discharge, nutrient load, and sediment loads from representative streams that flow into Lake Tahoe.

LTIMP currently monitors the following streams: Trout Creek, Upper Truckee River, General Creek, Blackwood Creek, Ward Creek, Third Creek, Incline Creek, Glenbrook Creek, Logan House Creek and Edgewood Creek (Figure 13-1) (Rowe et al. 2002). The program has monitored these tributaries since 1988 and these streams are also part of the USGS national water quality monitoring program.

Cumulative flow from these monitored streams comprises about 50 percent of the total discharge from all tributaries. Each stream is monitored on 30 - 40 dates each year and sampling is largely based on hydrologic events. Nitrogen and phosphorus loading calculations are performed using the LTIMP flow and nutrient concentration database. A list of parameters measured either permanently or intermittently since 1988 (depending on funding availability) includes nitrate, ammonium, total Kjeldahl nitrogen, dissolved Kjeldahl nitrogen, soluble reactive phosphorus, total dissolved phosphorus, total phosphorus, biologically available iron, suspended sediments, fine sediment particle (< 16 µm) distribution, dissolved oxygen, pH and specific conductance. This data is stored on the USGS website at http://wdr.water.usgs.gov/.

LTIMP tributary monitoring data provides a continuous long term dataset that can be used to evaluate water quality trends. The Lake Tahoe TMDL program anticipates the LTIMP water quality results will continue to be used as a comprehensive measure that integrates load reduction actions across all of the major pollutant sources.

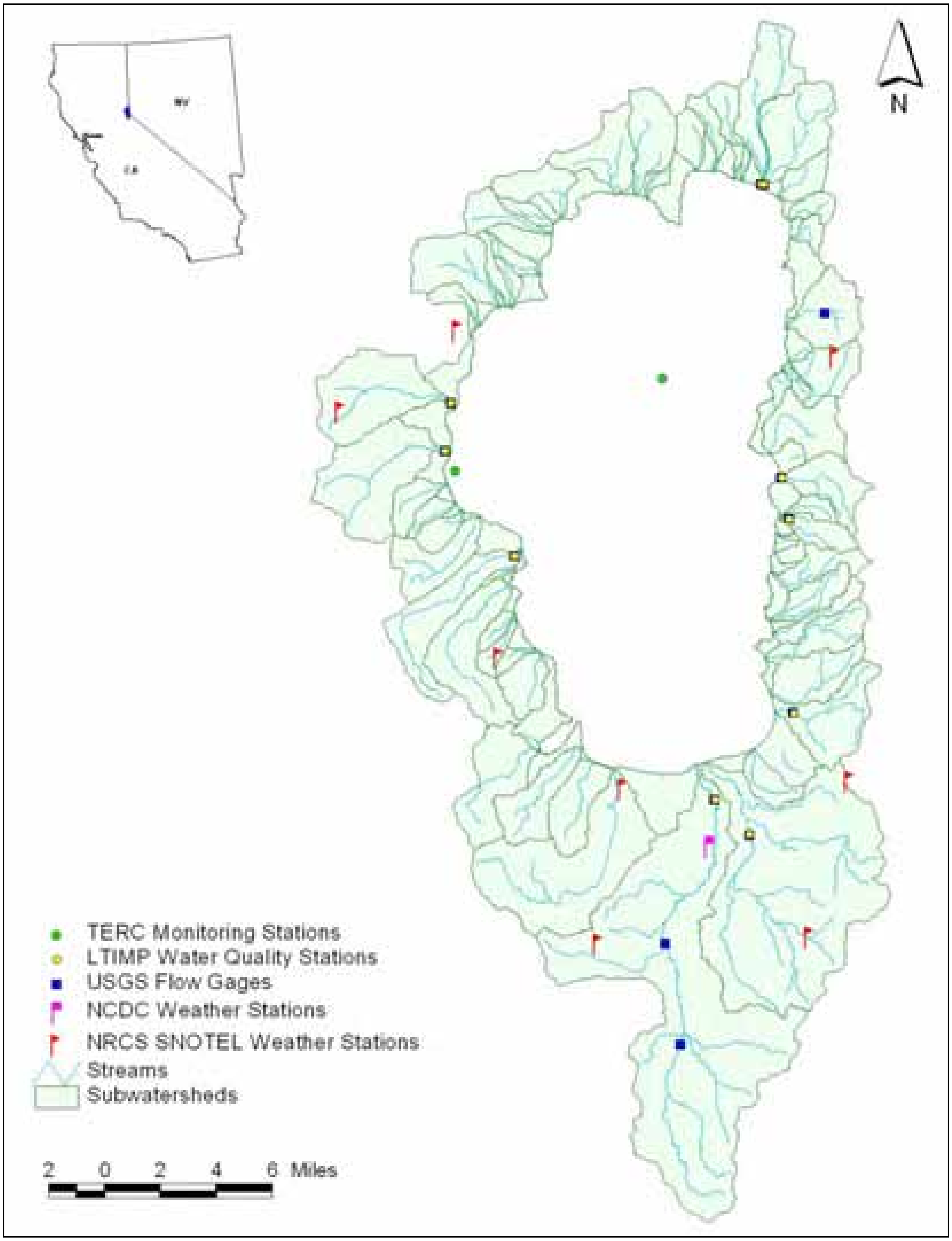

Figure 13-1. Sampling locations for LTIMP Stream and Lake (TERC) sites (Tetra Tech unpublished). The Index Station is the TERC Monitoring Station that is near the west shore, it is located 2km from the shore and is positioned over deep water (greater than 100 meters deep).

14 Margin of Safety

14.1 Introduction: MOS and its Relation to Uncertainty

The Margin of Safety (MOS), in combination with the Waste Load Allocation and Load Allocation, constitutes the TMDL. Waste Load and Load Allocations are based on the best existing monitoring data and scientific analysis. A MOS must be included in a TMDL to account for "any lack of knowledge concerning the relationship between effluent limits and water quality" (40 CFR section 130.7(c)(1)).

The MOS can be included as an explicit numeric addition to the loading allocation, or it can be included implicitly by incorporating conservative assumptions into the TMDL analysis. The Lake Tahoe TMDL incorporates the MOS implicitly.

A MOS is included in a TMDL to account for uncertainties inherent to the TMDL development process. Uncertainty is an expression commonly used to evaluate the confidence associated with sets of data, approaches for data analysis, and resulting interpretations. Determining uncertainty is notably difficult in studies of complex ecosystems when data are extrapolated to larger scales or when project specific data does not exist and best professional judgment, based on findings from other systems, must be employed. The scientific literature is replete with studies that characterize a specific aspect of an environmental characteristic or environmental process. Fully integrated investigations are much less common and much more difficult.

Within this TMDL, uncertainty was addressed using three independent approaches:

1. A comprehensive science program and science-based analysis was developed to enhance monitoring, fill key knowledge gaps and develop pollutant loading and lake response modeling tools specifically for Lake Tahoe.

2. Use of conservative, implicit assumptions, when justified, in the loading and lake response analyses.

3. Development of an Integrated Water Quality Management System based within an adaptive management framework that will allow the TMDL partners to evaluate scientific uncertainty, success of implementation projects and lake response on a regular schedule into the future and make the necessary adjustments.

14.2 Comprehensive Science Analysis

14.2.1 Science and the MOS

The intent of the comprehensive science plan was to reduce uncertainty throughout the TMDL process. Maximizing the knowledge concerning the relationship between pollutant source loading and water transparency helped limit the dependence of this TMDL on the MOS.

14.2.2 Rich History of Scientific Participation

Water quality management at Lake Tahoe benefited from an extensive science program that began in the late 1950s and which continues to grow. The Lake Tahoe Watershed Assessment (Reuter and Miller 2000) highlighted that hundreds of scientific papers and reports have been written on many aspects of Lake Tahoe, its watershed and its water quality since studies first began nearly 50 years ago. Many of these publications have been peer reviewed journal articles and technical reports while others include graduate student theses and dissertations. This has provided a unique, site-based literature to help guide scientific decision-making. In fact, almost all previous lake water quality management decisions have been based on scientific findings. Funding for science has even become a greater priority for federal and state agencies and local governments since 2000 (e.g. Environmental Improvement Plan, Southern Nevada Public Management Act, etc.). Lake Tahoe is a highly studied location and it is unlikely that this relationship between science and policy will diminish over time.

In addition to this extensive archive of available basic and applied research knowledge, a number of well-established monitoring programs exist at Lake Tahoe. These include long-term monitoring of lake clarity and transparency, water quality and biology; stream flow and pollutant loading (nutrients and sediment); and atmospheric deposition of pollutants. The Lake Tahoe Interagency Monitoring Program (LTIMP) has been collecting monitoring data for over 25 years and includes a wide range of precipitation and hydrologic conditions; i.e. it is a representative data set. As noted elsewhere in this document, the LTIMP has served as an important cornerstone for direct estimates of pollutant loading and model calibration and validation.

14.2.3 Filling Key Knowledge Gaps

Despite a historically rich science-based understanding of the ecological processes concerning the lake, the Lake Tahoe TMDL program began by identifying areas that required further investigation in order to improve our confidence. In some cases a limited amount of previous data had been collected. Therefore the associated level of uncertainty was considered too high. Further investigations included but were not limited to, (a) the Lake Tahoe Atmospheric Deposition Study (LTADS), conducted by the California Air Resources Board, (b) a detailed evaluation of stream channel erosion as a source of sediment to the lake, (c) characterization of biologically available phosphorus, (d) a detailed urban stormwater quality characterization effort, and (e) a thorough evaluation, including modeling of sources, transport, and fate of fine sediment particles. In this regard, the Lake Tahoe TMDL was able to limit the use of data from outside the Lake Tahoe basin and focus on the in-basin studies.

Development of modeling tools based on comprehensive science was considered fundamental to the application of the TMDL. Lake Tahoe and its watersheds were considered unique enough (depth, trophic status, elevation, hydraulic residence time, etc.) that specific loading and lake response models were needed to further reduce uncertainty. As a result, the Loading Simulation Program C++ (LSPC) watershed model was used to create the Lake Tahoe Watershed Model for simulating land-use based nutrient and sediment loading on a basin-wide scale. LSPC has been peer reviewed by the USEPA and it is part of its national TMDL modeling toolbox. The Lake Clarity Model was created specifically for the Tahoe TMDL Program by the University of California, Tahoe Environmental Research Center. While there is still some degree of uncertainty associated with these key models, the overall uncertainty of the TMDL would be much larger if these models were not specifically developed for this project.

14.2.4 Scientific Reliability

When science is used to guide policy, resource agencies and decision-makers must be provided with a sense of how confident researchers are with their findings.

As part of the Lake Tahoe TMDL program a number of practices were applied to ensure that the collection and interpretation of information was conducted in a scientifically acceptable manner. These include:

- Establishment of a diverse team of project scientists with national and international recognition and credentials enhances the caliber of the best professional judgment used in the Lake Tahoe TMDL.
- Use of data sets subject to high levels of quality control. The Lake Tahoe Interagency Monitoring Program (LTIMP) long-term data set on lake clarity and transparency and related limnological characteristics, stream hydrology, nutrient and sediment concentrations/loading, and atmospheric deposition was used for model calibration and validation. This data covers a wide variety of conditions given its long-term nature. The water chemistry is subject to the US Geological Survey's national quality assurance/quality control protocols.
- Availability of hundreds of scientific documents on Lake Tahoe and its watershed. Many have undergone peer review when published in scientific journals. This information was critical for establishing the conceptual model for the Lake Tahoe TMDL and many of the journal articles were used directly to inform modeling and interpretive efforts.
- Models were carefully calibrated and validated using Tahoe-specific data. Modeled results and new field measurement results were continually compared to this accepted body of knowledge.
- Peer reviews have been completed for 101 of the 221 references cited in this report and in the Tahoe TMDL Technical Report. The peer-reviewed references are specifically denoted in the references cited sections. For example, LSPC has been previously peer-reviewed by the USEPA. CARB's LTADS report has been peer reviewed by air quality researchers from the University of California system,

and in 2004, Dr. Steven Chapra (Professor and Berger Chair, Civil Engineering, Tufts University, MA) was contracted to provide a critical review that helped guide Lake Clarity Model development. Similarly, the USACE groundwater report was put out for comment following Corps protocol. Comments were received from a number of Tahoe basin agencies, stakeholders, and university researchers. Similarly, the National Sedimentation Laboratory report on stream loadings and stream channel erosion, also funded by the USACE, was subject to a similar comment process.

- A significant part of the peer review process has been the publication of research papers in scientific journals concerning new science conducted as part of the TMDL. These are noted throughout the document.

- A number of Master's Theses and Ph.D. Dissertations have come out of the TMDL science projects, e.g. lake optical model, stream particle characterization, stormwater pollutant characterization, in-lake particle sedimentation processes, biologically available phosphorus. All these were reviewed by a scientific committee at the student's institution prior to being accepted in partial fulfillment of their degree requirements.

- Finally, there are sufficient publications on Tahoe to take a "weight of evidence" approach to reduce uncertainty and increase confidence in the results. Most often, the TMDL results compared favorably with the conclusions of others.

14.3 Conservative Implicit Assumptions

In the context of the Lake Tahoe TMDL, a conservative (protective) assumption is one in which analysis would err towards a higher pollutant loading rate. An underestimate in loading will result in a slightly lower allocation. A conservative estimate would therefore provide a margin of safety to buffer lack of precision in the data or the analysis.

The Tahoe TMDL includes conservative assumptions in two areas of its development. First, conservative assumptions were made in the Lake Tahoe Watershed Model and Lake Clarity Model and pollutant load allocations. Second, conservative assumptions are used to inform pollutant reduction opportunities and the TMDL implementation strategy. Both of these assumptions contributed to the use of an implicit MOS selected for this TMDL.

14.3.1 Lake Tahoe Watershed Model

The Lake Tahoe Watershed Model, constructed using the USEPA approved LSPC modeling program, modified for specificity of the Lake Tahoe TMDL, simulates total sediment and nutrient loading based on land-use characteristics, geology, meteorology and other factors. The Watershed Model includes the following conservative assumptions in the development of the TMDL.

- A 20 percent margin of safety was added to land-use Event Mean Concentration estimates. (Lahontan and NDEP 2010).
- The Lake Tahoe Watershed Model does not account for pollutant reduction as runoff flows overland from the developed and undeveloped intervening zones directly to the lake. This transport loss in the intervening zones requires hydrology modeling and estimates of urban losses that were too fine-scaled for the existing Lake Tahoe Watershed Model. However, estimates of this 'transport loss' were accounted for by the Lake Tahoe Watershed Model in the urban subwatershed areas.
- Estimates of nutrient runoff from fertilizer application on lawns do not account for infiltration loss of nitrogen and phosphorus. Had the estimates included infiltration, less nitrogen and phosphorus would be modeled to runoff from the vegetated turf land-use (Tetra Tech 2007).

14.3.2 Pollutant Reduction Analysis and Implementation Strategy

The success of the Tahoe TMDL is predicated on the ability of implementing agencies to reduce the target pollutants. While assessing these opportunities, the Source Category Groups made a number of conservative assumptions that influenced the analysis of source reduction potential. The assumptions listed in Table 14-1 are taken from the *Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a). Because of the magnitude of the urban source and associated load reduction opportunities, the list focuses on conservative assumptions made by the Urban Uplands and Groundwater Source Category Group.

Table 14-1. Conservative assumptions included in analysis of the Urban Uplands and Groundwater Source Category Group of the Pollutant Reduction Opportunity Report (Lahontan and NDEP 2008a).

Source Category Group	Assumption	Margin of Safety Contribution
Urban Uplands and Groundwater (UGSCG)	Hydrologic Source Controls (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.* (p.97, emphasis added)	HSCs reduce runoff. This reduces down-slope erosion. The Watershed Model does not account for the reduced erosion from HSC application. Consequently, fine sediment and nutrient loads immediately downstream of HSCs will be overestimated and contribute to the implicit MOS.
UGSCG	Bypassed flows are assumed to enter surface waters (Lake Tahoe) at influent concentrations. (p.82)	As simulated in the Lake Tahoe Watershed Model, flows that bypass a stormwater treatment (SWT) do not attenuate and are not subject to transfer loss en route to the lake.
UGSCG	HSCs are flow-based pollutant control options that are designated to infiltrate urban storm water, thereby reducing flow volumes delivered downstream. HSCs are assumed to provide negligible water quality improvements to infiltrated waters. (p.112)	The Urban Infiltration Box Model used to evaluate the impacts of pollutant control options on groundwater does not model any water quality benefit to infiltrating water from the infiltration process.

14.4 Future Growth

Development in the Lake Tahoe basin is regulated by the Tahoe Regional Planning Agency, the five bordering counties, and the City of South Lake Tahoe. Due to the strict regulatory environment that governs development on vacant and built parcels, recent building trends have focused on redevelopment of existing sites. To examine the potential pollutant impact of complete, allowable development in the Lake Tahoe basin, the TMDL used the Tahoe Land-Use Change Model (Land-Use Model) developed by the US Geological Survey (Halsing 2006).

For each undeveloped parcel, two possibilities exist. One option is that the parcel is restricted from being developed through purchase of a conservation easement, purchase of the development rights, or purchase of the property. Four agencies (TRPA, USFS, NVDSL, and CTC) have programs to permanently restrict lots from being developed. The second option is that the lot is developed when the owner receives a development allocation. Development allocations are divided among the jurisdictions. To establish the worst case scenario for build-out as it relates to pollutant loads, the Land-Use Model preferentially assigns each parcel to be either conserved or developed in a way that results in a scenario that is the most harmful to Lake Tahoe. For example, if the model is presented with two parcels, one of which must be chosen for development and the other for conservation, the model will assign development status to the parcel that has greater potential to contribute pollutants to the lake (Halsing 2006). When the Land-Use Model accounted for development or conservation of all of the undeveloped parcels, this build-out scenario was input into the Watershed Model for analysis of pollutant transport to the lake. The Watershed Model simulation resulted in estimated fine particle sediment load up to about two percent greater than the total load modeled for 2004 conditions (Tetra Tech unpublished).

Actual future development in the Tahoe basin is unlikely to proceed pursuant to the idealized worst case scenario modeled. However, since it was designed to test the worst case scenario, the analysis represents a conservative estimate. Results of the Lake Tahoe Watershed Model for this conservative build-out scenario indicated that the number of fine sediment particles loaded to Lake Tahoe would increase by up to a maximum of two percent. This compares to the 32 percent reduction in fine sediment particles needed to meet the Clarity Challenge. Given the uncertainty involved in the land-use change and watershed models, an increase up to two percent of the total fine sediment particle load is considered within the range of uncertainty in the modeling analysis and, therefore, is not considered a significant increase.

14.4.1 Future Growth Mitigation

The Lake Tahoe TMDL does not specify a pollutant allocation for future growth. The Tahoe basin is subject to strict building regulations designed to address water quality impacts. Also, land-use regulations in the Lake Tahoe basin limit the area that can be built while requiring implementation of applicable measures to prevent pollutant loading. The following presents an evaluation of the potential future growth and there is a low probability that the maximum potential build-out would ever be reached because of successful on-going conservation programs.

As of 2008, a total of 4,841 parcels in the Tahoe basin were undeveloped and may become eligible in the future for being developed (Nielsen 2008 personal communication). Assuming that the 4,841 undeveloped lots have an average size of 0.25 acres and that each lot will be developed, these parcels would comprise 1210 total acres of additional developed land. Coverage on the highest capability land is limited to 30 percent (TRPA 1987, Section 20.3.A). This means that a maximum of 373 acres would be made impervious. At build out, active conservation efforts, such as the CTC urban lot program and the Forest Service Burton-Santini acquisition program, are expected to prevent a number of the lots in question from being developed by converting the private lots to public open space. Retiring these lots from development potential reduces the potential total new coverage.

The regulatory structure within the Tahoe basin includes code and policy mechanisms to prevent potential degradation of parcels. The TRPA Code of Ordinances requires that all development projects capture and either treat or infiltrate the stormwater runoff. Redevelopment on previously developed parcels, as a condition of permit approval, requires BMP retrofits on the entire parcel, including the areas outside of the construction zone (TRPA 1987, 25.2.B).

To comply with existing regulations, any additional parcel development is not permitted to significantly impact water quality. The Lahontan Basin Plan, in Chapter 5.4, includes limitations on coverage based on the assessed capability of the land. These limitations are designed to protect Tahoe's stream environment zones and other sensitive soils, and are mirrored in the TRPA Code of Ordinances and Water Quality Management Plan (208 Plan).

The potential for future growth in the Tahoe basin remains limited. Management of future growth will be informed by monitoring and continuing study to adapt to changes in the lake's response to pollutant controls. This type of adaptive management enables adjustments in management strategies and policies based on the associated impact or benefit to lake transparency and clarity.

15 Public Participation

15.1 Introduction

The Water Board and NDEP recognize public participation is a vital component for the success of the Lake Tahoe TMDL. For this reason, the Lake Tahoe TMDL program embarked on a robust public participation effort as part of developing the science supporting the TMDL load estimates (Phase One) and during the process to identify load reduction opportunities and craft an implementation plan (Phase Two). This chapter summarizes the efforts for Phase One and highlights selected public participation actions for Phase Two. Additional detail for Phase Two public participation process can be found in the *Integrated Water Quality Management Strategy Report* (Lahontan and NDEP, 2008b).

15.2 Phase One Public Outreach & Education – TMDL Technical Report

Phase One, development of the TMDL Technical Report, primarily involved scientific research and modeling efforts. Consequently, the goals for outreach to the public/stakeholders focused on disseminating the information in specific parts:

- Provide initial awareness about the collaborative Lake Tahoe TMDL effort through press releases, kick-off meetings, and quarterly electronic newsletters.
- Inform public/stakeholders about Tahoe TMDL components and process and identify the TMDL as a science-based restoration planning tool.
- Educate and provide a conceptual framework for how this TMDL program will be built on historic knowledge and supplemented with recent scientific research.
- Update the public and stakeholders about program progress.

Water Board and NDEP staff understand that stakeholder participation is critical to building a program that will be embraced and supported by agencies, policy makers, engaged stakeholders and the public. Two primary mechanisms accomplished the Phase One outreach and education efforts: 1) stakeholder and public education and 2) agency coordination. Water used a variety of methods to educate stakeholders and the general public on the status of the TMDL development: quarterly newsletters, targeted stakeholder meetings and presentations, as well as a symposium dedicated to describing the TMDL science plan and the models fashioned for this effort.

TMDL Newsletters

Between the Fall of 2002 and Fall 2006, the Water Board and NDEP staff produced ten newsletters, distributed approximately quarterly to stakeholders and made available on the Lahontan and NDEP websites. Newsletters provided information and updates for an array of scientific projects conducted to support TMDL development.

Public Forums

The Water Board and NDEP staff gave six informational presentations to the public and targeted stakeholder groups from May 2002 through early 2007. These were aimed at providing stakeholders with a background on the TMDL process in general and the Lake Tahoe TMDL in particular, the plan and justification for the science being developed to support the TMDL, and the program timeline. Two public outreach meetings were held in May and June of 2002 in conjunction with the Pathway process – one on the south shore and one on the north shore. In addition, four informational presentations and status updates were provided to the Pathway Forum between 2003 and 2007. These meetings were open to the public and featured an informational slide presentation and a question and answer session,

Targeted Stakeholder Presentations

The Water Board and NDEP staff gave more than 20 presentations to various stakeholder groups from December 2002 through December 2006. The groups included the TRPA Governing Board, Water Board, California Tahoe Conservancy, City of South Lake Tahoe City Council, Contractors Association of Tahoe Truckee, Tahoe Douglas Chamber of Commerce, local homeowners associations, and other non-governmental organizations. These presentations served to keep key stakeholder groups and agency partners abreast of program developments and request feedback on program direction.

Lake Tahoe TMDL Symposium

The Water Board and NDEP staff held a public Lake Tahoe TMDL Symposium in December 2004 in South Lake Tahoe. The 2004 Symposium featured 25 individual speakers giving presentations on research, early implementation, and regulatory changes. The Symposium also included an extensive questions and answer session.

TMDL Technical Report

Phase One TMDL efforts were summarized in a draft report and made available for public review and comment. Comments were considered in updating the Technical Report and in writing the Final TMDL Document.

Agency Coordination

Phase One TMDL development also involved intensive coordination with local, regional, state and federal agencies. Central to this effort was the formation of the TMDL Development Team (D-Team) which included representatives from the USFS Lake Tahoe Basin Management Unit, TRPA, California Tahoe Conservancy, Nevada Division of State Lands, California Department of Parks and Recreation, along with a host of other agencies that were invited to participate. The D-Team primary goal was to agree on assumptions and input to the Lake Tahoe Watershed Model using the best available information and most palatable methods and approach. A secondary benefit of the group was to achieve buy-in by the participatory agencies, since the D-Team served as an informational forum whereby the operation of the model and the rationale for using a particular approach was explained in detail. The Pathway Water Quality Technical Working Group, a subgroup of leading scientific experts in Lake Tahoe water quality issues, performed additional coordination with stakeholder agencies. In particular, the Working Group reviewed existing basin water quality standards and agreed on a TMDL Lake Tahoe transparency numeric target of 29.7 meters of annual average Secchi depth as appropriate.

Draft Lake Tahoe TMDL Technical Report

The Phase One effort culminated in the release of the Draft TMDL Technical Report in September 2007. Public comment has been solicited and accepted through the release of this Draft Final TMDL document. Comments received were considered in this document.

15.3 Phase Two Stakeholder Participation Series

Public participation during Phase One focused on outreach and education to promote awareness and understanding of the TMDL science plan and process. In contrast, Phase Two presented an opportunity for stakeholders and agency partners to take a more active role in the TMDL development process. Because many stakeholders possess a thorough understanding of the social, political, and economic issues of the Lake Tahoe watershed, the Lake Tahoe TMDL program recognized stakeholder input as a key element in developing pollutant load allocations and the associated implementation plan. By encouraging stakeholders to participate and provide feedback throughout the Phase Two development process, the Final TMDL represents a restoration plan that was developed through an intensive public participation process.

The Phase Two public participation effort relied on an interactive, iterative stakeholder feedback process. The process was launched in the fall of 2007 with the release of the *draft Pollutant Reduction Opportunities Report* (Lahontan and NDEP 2008a), which along with the *September 2007 Draft TMDL Technical Report* provided the technical basis to develop various implementation strategies. The stakeholder participation continued through the spring of 2008 to gather input on a proposed integrated implementation strategy and associated pollutant load allocation approach. While the two-part process is summarized below, please refer to the *Pollutant Reduction Opportunity Report* and the *Integrated Water Quality Management Strategy Project Report* (Lahontan and NDEP 2008b) for more detailed information.

Implementation Plan Development

The conceptual strategy and approaches that were to be used in the Pollutant Reduction Opportunity analysis required technical scrutiny by practitioners in the Basin and a general level of agreement of baseline assumptions and methods. Therefore, a series of Focus Teams were created to provide feedback on identified reduction opportunities and load reduction analysis approaches. These groups included local agency and resource professionals who were tasked with gaining a technical understanding of the analytical approach, reviewing the analysis findings and providing interim and final comments. Focus Team feedback was either used to refine the analysis approaches or was documented as potential future work to improve the analysis. Focus Team input was also used to help craft the integrated implementation scenarios. While the Focus Team evaluated the proposed load reduction opportunities from a technical perspective, the Pathway Forum evaluated both reduction opportunities and integrated implementation alternatives from an economic and policy perspective.

Part of the Pathway planning process included creating a Forum of diverse stakeholders to recommend mutually beneficial resource management options to Pathway agency decision-makers. Forum discussions promoted “enlightened self-interest” as participants worked to understand different perspectives and incorporate the interests of all in developing recommendations. Forum Members were volunteers that put tremendous effort into making sure the citizen's voice were heard. Members shared information gained from these discussions to their respective constituencies through various venues.

A series of four Pathway Forum meetings highlighting TMDL implementation strategies featured an iterative process of receiving stakeholder feedback and refinement of proposed strategies. Meetings were open to the public and Focus Team members were invited to attend and participate. This series of meetings culminated in a consensus endorsement for the Recommended Strategy, which focuses on reducing basin-wide fine sediment particle loading to Lake Tahoe and provides the basis for the Lake Tahoe TMDL pollutant load allocation distribution and for the TMDL implementation plan to achieve the Clarity Challenge.

Allocation Development

A second element of the Phase Two public/stakeholder participation series was conducted to guide load and waste load allocation development. Similar to the Forum meetings, a series of TMDL Implementer Meetings were held throughout the fall of 2007 and winter 2008. Local entities responsible for carrying out the TMDL implementation plan, as well as project funding agencies, were invited to learn about the different allocation options being considered and provide feedback on presented proposals. The resulting discussions helped the Water Board and NDEP staffs refine the preferred allocation approach. The primary purpose of these meetings was to further develop allocation options based on feedback provided by the implementation entities, but the meetings also provided a venue to discuss and understand what the allocations will mean to the various entities in terms of implementation expectations and/or requirements. Presentation material and meeting notes can be found in the *Integrated Water Quality Management Strategy Project Report* (Lahontan and NDEP 2008b).

15.4 Phase Three – Implementation and Adaptive Management

After working with the public/stakeholders on the Phase One and Phase Two portions of the TMDL project, the Water Board and NDEP staffs shifted focus to outreach efforts for the implementation and adaptive management phase. Prior to adoption of this TMDL, the team engaged consultants to develop specific programs and processes to aid regulators and implementers in the TMDL implementation. These tools include the Lake Clarity Crediting Program, a Pollutant Load Accounting and Tracking Tool, the Pollutant Load Reduction Model, and two separate urban Rapid Assessment Methodologies to help municipal jurisdictions estimate the pollutant load reduction from proposed and completed projects, consistently account for estimated load reductions, and track TMDL progress.

Additionally, NDEP staff held meetings in the fall 2008 with Nevada implementation agencies to discuss what regulatory approach that NDEP should pursue upon approval of the TMDL. The Nevada portion of the Lake Tahoe basin does not meet the population and density requirements to mandate issuance of stormwater permits for the Nevada-side municipal jurisdictions under the National Pollutant Discharge Elimination System (NPDES) Phase Two Stormwater Rule (Rule). This Rule subjects municipalities to permit requirements for the control and prevention of stormwater pollution. However, this Rule provides for the designation of municipalities as regulated small municipal separate storm sewer systems (MS4) if the permitting authority determines its discharges cause, or have the potential to cause, an adverse impact on water quality (US EPA 2000). The meetings featured discussions of the benefits and drawbacks of both an agreement-type and the permit approaches for implementation. Attendees acknowledged that the flexibility offered by the Memorandum of Agreement (MOA) approach provided the greatest likelihood for successful implementation within Nevada Lake Tahoe jurisdictions. From summer of 2009 through the time of the TMDL submittal, NDEP has met and coordinated with TMDL implementation partners to lay out a process and submit grant applications for the development of Stormwater Load Reduction Plans that specify the strategies and actions each of the Nevada Tahoe urban stormwater jurisdictions expect to implement in order to meet needed load reductions.

The Water Board and NDEP staffs presented information on how the tools can aid TMDL implementation to public stakeholders in late 2008 through 2010. Water Board and NDEP staffs expect to use these tools to follow TMDL implementation and to adaptively manage the implementation plans based on new monitoring data and scientific research. The Water Board and NDEP staffs are committed to give informative and interactive presentations as requested and needed through the adoption and full implementation of the Lake Tahoe TMDL.

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17 Appendix A – Lake Clarity Conceptual Model and Indicator Framework

Tahoe Monitoring & Evaluation Program

Title: Lake Tahoe Clarity Conceptual Model & Indicator Framework Briefing

Version 0.81

Date:	April 15, 2010
Contact Person:	Shane Romsos, M&E Program Manager, TRPA (*phone:* 775.589.5201, *email:* sromsos@trpa.org); Jeremy Sokulsky, Environmental Incentives, LLC (530-541-2980, jsokulsky@enviroincentives.com)

The Lake Tahoe Monitoring and Evaluation Program (M&E Program) is developing conceptual models (CMs) and indicator frameworks (IFs) that will be used to 1) define the current understanding of the most important drivers that affect the status of desired conditions (DCs), 2) assist in the selection and interpretation of meaningful indicators to track DC-related system status, and 3) identify the most influential actions for achieving DCs. The CM included in this briefing is based on the scientific understanding and policy context at the time that it was developed or its most recent update. The CM is expected to be adapted over time with improved scientific understanding, innovations in management actions, and changes in policy context.

This briefing includes: (1) a text description of the Lake Tahoe Clarity DC, objectives and primary chains of cause and effect, (2) the legend of symbols used in the CM, (3) the Lake Tahoe Clarity CM diagram, and (4) the Lake Tahoe Clarity IF diagram. Please contact the person(s) listed above to receive more detailed information related to this CM and IF, including a complete narrative description and tables describing each factor and indicator in the CM and IF.

Lake Tahoe Clarity Desired Condition & Objectives

Lake Tahoe Clarity Desired Condition

Restore, and then maintain, the waters of Lake Tahoe for the purposes of human enjoyment and preservation of its ecological status as one of the few large, deepwater, ultraoligotrophic lakes in the world with unique transparency, color and clarity.

This DC statement is taken directly from the results of the Pathway process and is a proposed TRPA Goal statement. The following two objectives were defined from this DC.

Deep Water Clarity Objective

Restore and maintain deep water clarity at levels measured for the period 1967-1971, which is an annual average Secchi depth of 29.7 meters.

The Clarity Challenge milestone has been defined related to this objective, which seeks a 32% fine sediment particle reduction within 15 years of the adoption of the TMDL. This load reduction is estimated to result in a Secchi depth of approximately 24 meters. The TMDL will define additional milestones both before and after the Clarity Challenge that will ultimately lead to the final Deep Water Clarity objective.

Trophic Status Objective

Preserve Lake Tahoe's ecological status as one of the few large, deepwater, ultraoligotrophic lakes in the world with an appropriate diversity of plants and animals in deep-water and nearshore environments.
To further define this objective, a Trophic Status Index must be developed, and benchmark and target values must be defined. Indicators of deep water trophic status must be integrated to develop a trophic status index that is sensitive to the variability in different nearshore environments as well as the difference between the nearshore and deep water conditions.

Nearshore Aesthetic Objective

Improve nearshore aesthetic quality such that water transparency and the biomass of benthic algae are deemed acceptable at localized areas of significance.
The following steps must be taken to further define this objective:

- Current indicators and standards for nearshore transparency must be updated
- Benthic algae indicators and standards for acceptable levels at localized areas of significance must be defined and adopted

Primary Chains of Cause and Effect

Deep water clarity, trophic status and nearshore aesthetic are affected by fine sediment particles and algae abundance. The Lake Tahoe Clarity CM diagram (Figure 18-1) uses bolded box outlines and linkage arrows to show dominant chains of cause and effect for deep water clarity and nearshore aesthetic.

Deep Water Clarity

Deep water clarity integrates the effects of pollutant loading from throughout the Lake Tahoe Basin. It is primarily driven by the number of fine inorganic particles in the water column. Surface water flows loaded with fine sediment from urban stormwater transport over 70% of the total load of fine sediment to the lake. Sources of urban fine sediment particles include the application of road abrasives, degradation of the road surface and tires, and erosion from road shoulders and unpaved soft coverage areas. Impervious surfaces contribute to increases in stormwater runoff, increases in stream peak flows, erosion and pollutant transport. Management actions that can be implemented in urban areas to prevent and/or reduce fine sediment particle loads include reducing road abrasives application, increasing street sweeping effectiveness, reducing impervious surface coverage, and treating stormwater.

Trophic Status

Trophic status is largely determined by the presence of biologically available nutrients that result in plant growth, which in turn influences dissolved oxygen levels and the diversity and type of biota able to survive in the lake. Lake mixing and circulation, both potentially changing with climate change, have the potential to significantly alter biological availability of nutrients.

Nearshore Aesthetic

Nearshore aesthetic is an inherently localized issue; different locations will have different expected levels of transparency and benthic algae abundance based on local conditions such as nutrient availability, light and temperature. Nutrient-laden urban stormwater and groundwater seepage to nearshore areas can cause localized algae blooms and affect both transparency and the abundance of benthic algae. The same management actions described to control fine sediment particles and improve deep water clarity are assumed to have a similar benefit in reducing nutrient loading to nearshore areas. In addition, restricting fertilizer usage and maintaining sewage infrastructure are nutrient controls that prevent increases of nutrients in groundwater.

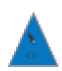
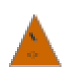
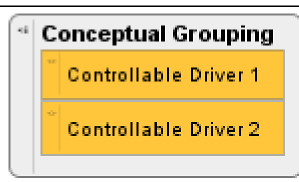
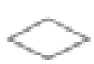
Nearshore aesthetic is an inherently localized issue, different locations will have different expected levels of transparency and benthic algae abundance based on localized conditions. Both attached and floating algae abundance are limited by the availability of biologically available nutrients. Nutrient-laden urban stormwater and groundwater seepage to nearshore areas can cause localized algae blooms and affect both transparency and the abundance of benthic algae. The same management actions described to control fine sediment particles and improve deep water clarity are assumed to have a similar benefit in reducing nutrient loading to nearshore areas. In addition, restricting fertilizer usage and maintaining sewage infrastructure are nutrient controls that prevent increases of nutrients in groundwater.

Other Factors

This Basic Lake Tahoe Clarity CM assumes that current policies and practices related to forest land management practices will be maintained. If BMPs on dirt roads and those related to fuels management projects are not maintained, the current low level of fine sediment particle input from forest uplands, 9%, could greatly increase and become a significant source.

Atmospheric deposition of fine sediment particles and nutrients, particularly nitrogen, are potentially significant. Atmospheric deposition and the related load reduction potential from this source are the area of greatest uncertainty within the TMDL analysis. Therefore, this is an active and important area for research.

Table 17-1: The symbols in this table should be used to create the CM diagram.

Name of Symbol	Visual Appearance	Description
Desired Condition Box		Represents the desired condition of a resource, and contains the more refined and specific objectives
Objective Oval		Objectives represent specific qualities of the desired condition
Driver Boxes		Controllable drivers affect the desired condition and are able to be influenced by human actions within the Tahoe Basin **Controllable drivers that are also desired conditions are shown in blue in the diagram*
		Non-controllable drivers are conditions or processes that affect the desired condition and are not controllable by human actions within the Tahoe Basin
Action Hexagon		Represent activities that humans can undertake to work toward achieving a desired condition
Linkage Arrow		Indicates a linkage between two factors. Bold lines can be added to accentuate the connection between factors that link to create a dominant chain of cause and effect.
Metrics	Status Indicator Triangle 	Represents a measure of system condition
	Driver Measure Triangle 	Represents a measurable quantity that describes the presence and magnitude of a driver
	Performance Measure Triangle 	Represents a measure of human action taken to achieve a objective
Conceptual Grouping Box		Represents a grouping of similar drivers, actions or metrics
Research Priority Diamond		Indicates a driver or action that has a high research priority (ranking of 4 or 5) as determined in the CM Table

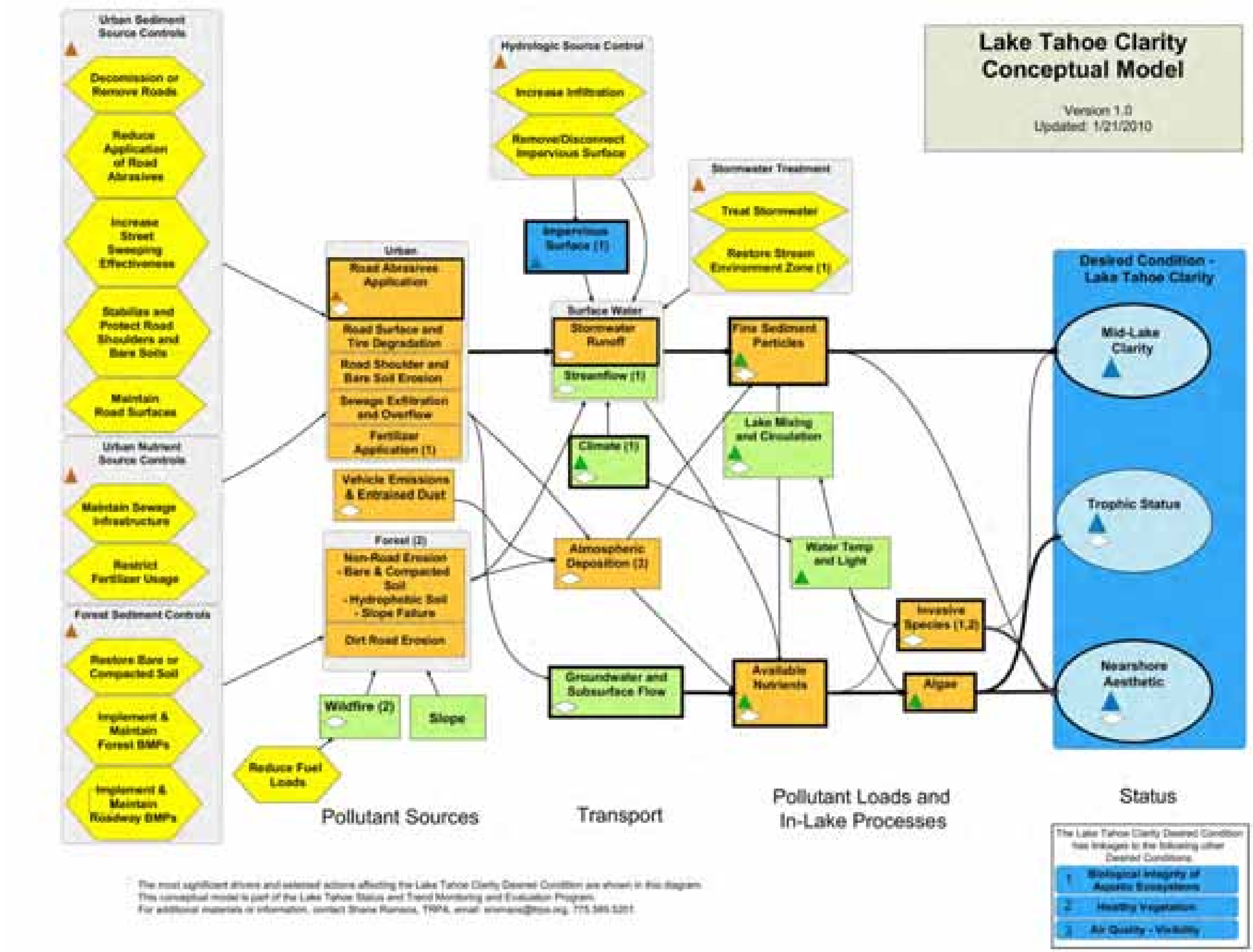


Figure 17-1. Lake Tahoe Clarity Conceptual Model Diagram.

Indicator Framework

An indicator framework (IF) describes the multiple numeric measures that are depicted in the CM and how they are synthesized to assess the overarching status of the system. An IF structures numeric information describing the percent-to-target progress of indicator values so that they can be categorized, aggregated and effectively reported to key audiences. The Lake Tahoe Clarity IF shows how water quality field measurements are analyzed to summary indicators, higher-level status aggregations and the DC. Figure 18-2 is the proposed IF for the Lake Tahoe Clarity DC.

Lake Tahoe Clarity
DC-Level Indicator Framework

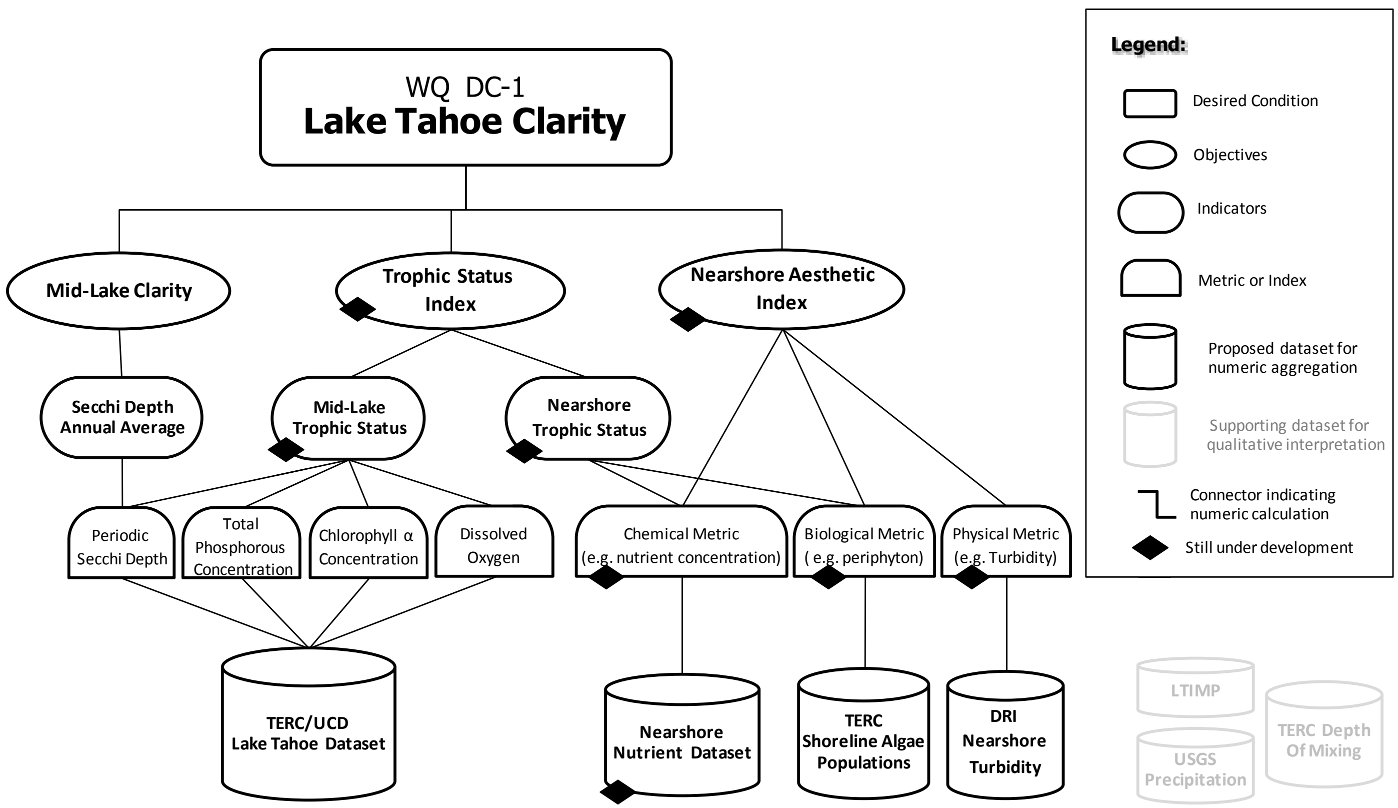


Figure 17-2. Lake Tahoe Clarity Indicator Framework Diagram.

18 Appendix B – Responses to Peer Reviews

1. Transmittal of peer reviewers……………………………………………………….B-1

2. Request to peer reviewers……………………………………………………….B-5

3. Responses to Professor Lewis review…………………………………………….B-43

4. Responses to Professor Holsen review…………………………………………...B-83

5. Responses to Professor Brezonik review…………………………………………B-99

6. Responses to Professor Elimelech review………………………………………..B-133

7. Responses to Professor Melack review…………………………………………..B-145

State Water Resources Control Board

Linda S. Adams
Secretary for
Environmental Protection

Office of Research, Planning, and Performance

Arnold Schwarzenegger
Governor

TO: Douglas F. Smith, Chief
TMDL/Basin Planning Unit
Lahontan Regional Water Quality Control Board

APR 23 2009

DFS

Gerald W. Bowes

FROM: Gerald W. Bowes, Ph.D.,
Manager, Cal/EPA Scientific Peer Review Program
Office of Research, Planning and Performance

DATE: April 21, 2009

SUBJECT: **SCIENTIFIC PEER REVIEWERS FOR LAKE TAHOE NUTRIENT AND SEDIMENT TMDL**

In response to your request for peer reviewers for the subject noted above, the University of California, through an Interagency Agreement with Cal/EPA, identified candidates it considered qualified to perform this assignment. Each candidate was required to complete and sign a Conflict of Interest Disclosure form.

After my review of the disclosure forms, I contacted selected candidates to provide clarification where necessary and confirmation they could perform an objective and independent review free of conflict of interest and bias. I forwarded to approved reviewers my latest (January 7, 2009) supplement to the Cal/EPA peer review guidelines, and am attaching it here. Please read it carefully. The approved reviewers are identified below.

1. Patrick L. Brezonik, Ph.D.
   Professor of Environmental Engineering
   Department of Civil Engineering
   University of Minesota
   Minneapolis, MN 55455

   Telephone: (612) 625-0866
   Email: brezonik@umn.edu

2. Menachem (Meny) Elimelech, Ph.D.
Roberto Goizueta Professor and Chair
Department of Chemical Engineering
Environmental Engineering Program
Yale University
New Haven, CT 06520-8286

Telephone: (203) 432-2789
Home Page: http://www.yale.edu/env/elimelech/bio.html
Email: menachem.elimelech@yale.edu

3. Thomas M. Holsen, Ph.D.
Professor
Department of Civil and Environmental Engineering
W.J. Rowley Laboratory, Box 5710
Clarkson University
Potsdam, N.Y. 13699-5710

Street Address: 8 Clarkson Avenue

Telephone: (315) 268-3851
Fax: (315) 268-7985
Email: tholsen@clarkson.edu

4. William M. Lewis, Jr., Ph.D.
Associate Director
Cooperative Institute for Research in Environmental Sciences
Professor and Director
Center for Limnology
216 UCB, CIRES
Boulder, CO 80309-0216

Telephone: (303) 492-6378
Fax: (303) 492-0928
Email: william.lewis@colorado.edu

5. John Melack, Ph.D.
Professor
Bren School of Environmental Science and Management
University of California
Santa Barbara, CA 93106

Telephone (805) 893-7363
Fax: (805) 893-7612
Email: melack@lifesci.ucsb.edu

Biographical information for the approved reviewers is provided with this memorandum.

Please contact your reviewers right away. Tell them when you will transmit the material. They have accepted the assignment based on the date of availability given in your letter of request to me. If preparation of the material is delayed, ask them if the new date is acceptable, including me as a "cc." If subsequent delays occur, inform the reviewers and me as soon as possible. I am often contacted by reviewers and the University if delays occur and reviewers are not kept up to date.

If the number of pages you plan to send the reviewers is significant, I recommend you provide them a hard copy of this material. You can enquire if any would prefer an electronic copy as well. Ask them (1) if their preferred mailing address is the same as that given above; and (2) to provide whatever additional information is necessary for an overnight delivery service.

Provide a cover letter to initiate the review process. Include with it your request letter to me, which provides a concise synopsis for your intended actions, and its three attachments. **Please inform them that their review must follow the guidance provided in Attachment 2.**

When the reviews have been completed, please let me know and send me a copy of each review and cover letter to the reviewers for the review files I keep here.

If I can provide additional help, contact me at any time during the review process.

Attachments

cc: Sheila Vassey, Office of Chief Counsel (w/o biographical material)
Rik Rasmussen, Division of Water Quality (w/o biographical material)

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Doug Smith - Lake Tahoe TMDL Peer Review Request

From: Doug Smith
Subject: Lake Tahoe TMDL Peer Review Request

Sent via email on 6/4/2009:

Hello Professor,

The Draft Lake Tahoe TMDL is ready for your review! I will send the PDFs in separate email, shortly.

Please refer to the attached Lake Tahoe Peer Review Request & Attachments REVISED 2009.pdf for details on the eight issues I am asking to be reviewed. I made some minor edits in Attachments 1 & 2 and marked those changed pages as "REVISED June 4, 2009"; all other pages remain unchanged. In Attachment 1, I changed the fine sediment particle number from < 20 micrometers to < 16 micrometers to be accurate and consistent with the research. In Attachment 2, I added a paragraph within each issue discussion to highlight where supporting information can be found in the TMDL documents.

As a courtesy to you, I am sending a hard copy of all the documents along with a CD of the documents to help your review. I will send the hard copies out on Monday June 8 to the address you provided, below, unless you direct me to send the documents to a different address. When I send the hard copies, I will email you the courier service information and tracking number.

The second attachment to this email is a two-page Word document summarizing the proposed policy changes to the Lahontan Regional Water Quality Control Plan. I am not asking you to review the proposed changes. Rather, the summary is intended to give context for potential policy changes based on the science supporting the Lake Tahoe TMDL, subject to the external peer review comments.

I am asking that your review address the issues in Attachment 2 in the sequence given. I would greatly appreciate you submitting your completed review to me between July 6, 2009 and July 20, 2009. Please do not hesitate to contact me if you have any questions or if you need help navigating through the mountain of documents. Thank you!!!

Doug

==
Douglas F. Smith, PG
Senior Engineering Geologist
Chief, TMDL & Basin Planning Unit
Lahontan Water Board
email: DFSmith@waterboards.ca.gov
web: http://www.waterboards.ca.gov/lahontan/
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California Regional Water Quality Control Board
Lahontan Region

Linda S. Adams
Secretary for Environmental Protection

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Arnold Schwarzenegger
Governor

MEMORANDUM

TO: Dr. Gerald Bowes
State Water Resources Control Board
Division of Water Quality
P.O. Box 100
Sacramento, CA 95812

FROM: Douglas F. Smith
Chief of the TMDL/Basin Planning Unit

DATE: November 12, 2008

SUBJECT: REQUEST TO INITIATE SCIENTIFIC PEER REVIEW PROCESS FOR LAKE TAHOE WATERSHED TOTAL MAXIMUM DAILY LOAD (TMDL) FOR SEDIMENT AND NUTRIENTS

Lahontan Water Board staff request that you begin the process for selection of scientific peer reviewers for the draft Basin Plan Amendment for the Lake Tahoe TMDL. The TMDL is a joint effort between Lahontan and the Nevada Division of Environmental Protection (NDEP). Lake Tahoe, located in both California and Nevada, sits between the crest of the Sierra Nevada Mountains on the west and the Carson range on the east. Sixty-three streams flow into Lake Tahoe, and the Lake's one outlet, the Truckee River, drains into Pyramid Lake located in Nevada.

Lake Tahoe is listed pursuant to the federal Clean Water Act, Section 303(d), for impairment due to an excess loading of nutrients and fine sediment particles. Lahontan Water Board staff expects the draft amendment will be circulated for public review in 2009, and brought to the Water Board for consideration in late 2009. At least four peer reviewers are requested to cover four specific disciplines: 1) limnology, with expertise in estimating load capacity and lake response to pollutant input, 2) watershed water quality/hydrology, with expertise in source load estimates, 3) water quality resources management, with expertise in non-point source assessment and best management practices, and 4) atmospheric science, with expertise in the transport and deposition of nutrients and fine sediment particles. In addition to the four disciplines listed above, peer reviewers with expertise in non-point source pollution and biogeochemistry, as related to limnology and water quality, would be appropriate additions.

Peer reviewers are asked to determine whether the scientific portion of the Lake Tahoe TMDL Staff Report and proposed Basin Plan Amendment is based upon sound scientific knowledge, methods, and practices. These documents should be available for peer review by the week of February 2, 2009. Attachment 2 provides more information on the technical and scientific issues to be addressed by the peer reviewers. Supporting information used to develop the Lake Tahoe TMDL and Basin Plan Amendment will be provided for the peer reviewers' reference, including three specifically significant documents, the Lake Tahoe TMDL Technical Report (2008), the Pollutant Reduction Opportunity Report (March 2008), and the Integrated Water Quality Management Strategy Report (March 2008). These three documents are summarized in the Lake Tahoe TMDL Staff Report and will be sent to the peer reviewers as documents in PDF format on a disk.

I understand from the California Environmental Protection Agency's November 2006 guidance document that, after reviewing the attached summaries, you will contact the State Board's contractor to arrange for identification of potential peer reviewers. Once reviewers have been identified, communication with them will be Water Board staff's responsibility. Due to the timeline for public review and Board consideration, I request that the peer review process be completed within 30 days of receipt of the review materials.

Five Attachments are provided as part of this peer review request: (1) a summary of the Lake Tahoe TMDL, (2) a summary of the technical and scientific issues that may require peer review, (3) a list of scientists, engineers, and land-use planners external to the State or Water Board involved in previous studies related to the TMDL, (4) a list of peer reviewed publications relied on for the Lake Tahoe TMDL, and (5) a list of non-peer reviewed publications relied on for the Lake Tahoe TMDL.

Please contact me at our South Lake Tahoe office if you have any questions or need further information. You may reach me at (530) 542-5453; my email address is dfsmith@waterboards.ca.gov. Thank you.

cc: David Coupe, Office of Chief Counsel, SWRCB
Rik Rasmussen, Division of Water Quality, SWRCB
Joanne Cox, Division of Water Quality, SWRCB
Jason Kuchnicki, Nevada Division of Environmental Protection
Larry Benoit, Tahoe Regional Planning Agency

Attachments

Attachment 1

Background of the Lake Tahoe TMDL

The proposed amendment is a plan to control the fine sediment particle and nutrient inputs that are impacting Lake Tahoe's famed clarity. This plan, known as the Lake Tahoe Total Maximum Daily Load (TMDL), identifies the basin-wide budget of fine sediment particles less than 16 micrometers (µm) and nutrients (total nitrogen and total phosphorus) and estimates the total load reductions for these pollutants that are needed to restore clarity. The amendment will (1) describe the impacts of fine sediment particles and nutrients on relevant beneficial uses designated for the Lake, (2) propose numeric targets to interpret narrative sediment and nutrient-related water quality objectives, and (3) provide an estimate of pollutant source loads and load reductions needed to improve the transparency and clarity to meet the water quality objectives.

The maximum allowable pollutant loads, or TMDL, will be allocated to major source categories in the Lake Tahoe basin according to land use types and estimates of sediment/nutrient control efficiencies. For the urban source category the pollutant loads will be allocated to specific jurisdictions. The amendment will include a plan of implementation, describing the general nature of actions needed to control fine sediment particles and nutrients entering the lake, and an initial monitoring plan to determine the success of these measures.

To facilitate TMDL development, Water Board staff contracted with University of California-Davis and Tetra Tech, Inc., entities which in turn sub-contracted with various academic and consulting groups, to study sediment, nutrients (total nitrogen and total phosphorus) and turbidity conditions affecting the Lake Tahoe watershed. These studies helped develop a basin-wide budget of pollutant inputs associated with each significant source category (e.g., upland runoff, atmospheric deposition). Additionally, Water Board staff contracted with Tetra Tech, Inc. and Environmental Incentives Inc. to determine types of pollutant control measures that could be used to restore Lake Tahoe. The products from these studies will be provided to the peer reviewers for their reference.

The draft Lake Tahoe TMDL document prepared by Water Board and NDEP staff is based on our interpretation of data from these comprehensive research studies. Our interpretation is that Lake Tahoe is not capable of assimilating the current loads of fine sediment particle and nutrient inputs. This phenomenon is indicated by years of clarity measurements showing the Lake is not meeting the clarity and transparency standards developed by the Water Board. Additionally, 2007 Secchi disk measurements demonstrate the Lake has lost more than seven meters of annual average clarity depth since measurements began in 1968. TMDL research indicates that fine sediment particles (< 16 µm in diameter) are a leading cause impacting the Lake's clarity: However, the importance of nutrient reduction is also recognized.

Urban runoff, forest runoff, stream channel erosion, atmospheric deposition, and shoreline erosion are all contributing factors that deliver fine sediment particles to Lake Tahoe. The largest percent contribution of fine sediment particles is generated in urban areas from its associated commercial, residential, and roadway network.

The Lake Tahoe TMDL is a plan to restore Lake Tahoe's historic transparency and clarity.

Attachment 2

Description of the Scientific Basis of the TMDL and Issues to be Addressed

The statute mandate for external scientific peer review (Health and Safety Code Section 57004) states that the reviewer's responsibility is to determine whether the scientific portion of the proposed Basin Plan Amendment is based upon sound scientific knowledge, methods, and practices.

We request that you make this determination for each of the following issues that constitute the scientific basis of the proposed regulatory action. An explanatory statement is provided for each issue to focus the review.

1. **Determination of fine sediment particles (< 16 µm) as the primary cause of clarity impairment based on interpretation of scientific studies, available data, and the Lake Clarity Model.**

Although Lake Tahoe is on the Clean Water Act 303d list as impaired due to sediment and nutrient inputs, the primary indicator of these impairments is the loss in transparency as measured by Secchi disk depth. The Lake Clarity Model, developed, calibrated, and validated by UC Davis, indicates clarity loss is primarily due to the number of fine sediment particles suspended in the water column. Specifically, the number of particles with a diameter of less than 16 µm is responsible for the majority of the clarity condition. Increased primary productivity driven by elevated nitrogen and phosphorus inputs is a lesser, but still important, factor in Lake Tahoe's clarity loss. Based on the model's predictive capability, the Lake Tahoe TMDL implementation plan emphasizes fine sediment particles as the target pollutant. Nutrient load reductions are also important but to a lesser degree as compared to fine sediment particle load reductions. All three pollutant loads will be allocated and load reductions will be tracked.

Your review for this issue should focus on the summary information in Chapters 3 and 8 in the Draft TMDL, and for detailed information, you should focus on Chapters 3.4, 5, and 6 in the TMDL Technical Report.

2. **Identification of the six sources of pollution affecting lake clarity of which urban upland areas was found to be the primary source of fine sediment particles causing Lake Tahoe's clarity loss.**

Staff, contracted researchers, and consultants created a pollutant loading budget for three forms of sediment (total suspended sediment mass, < 63 µm mass, and < 16 µm particle number), phosphorus and nitrogen. The loading budget identified six pollutant sources: urban uplands, forest uplands, atmospheric deposition, groundwater, shoreline erosion, and stream channel erosion. Of these sources, urban uplands was found to contribute more than 70% of the total fine sediment particle load as measured by the number of particles less than 16 µm in diameter. The reliability of these estimates was checked using a number of approaches including field monitoring, modeling and comparison to previously reported studies in the Tahoe basin.

Your review for this issue should focus on the summary information in Chapter 7 of the Draft TMDL and, for detailed information, you should focus on Chapter 4 of the TMDL Technical Report.

3. Determination that the Lake Tahoe Watershed Model was an appropriate model to estimate upland pollutant source loads.

The Lahontan Water Board contracted with the University of California, Davis and Tetra Tech, Inc. to determine the magnitude of fine sediment and nutrient loads from upland sources (undeveloped and developed). Building on the EPA-approved Load Simulation Program in C++ (LSPC) watershed model, Tetra Tech developed the watershed-specific Lake Tahoe Watershed Model capable of estimating average annual loads from a variety of different land use conditions, including rural and urban areas. The model results indicate approximately 9% and 72% of the average annual fine sediment particle load is generated in the undeveloped and urban uplands, respectively.

Your review for this issue should focus on the summary information in Chapter 7.5 of the Draft TMDL and, for detailed information, you should focus on Chapter 4.3 in the TMDL Technical Report. For additional detail regarding the selection and development of the Lake Tahoe Watershed Model, please see the *Watershed Hydrologic Modeling and Sediment and Nutrient Loading Estimate for the Lake Tahoe Total Maximum Daily Load* report, dated February 2007.

4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

The United States Army Corp of Engineers (USACE) completed an evaluation in 2003 to analyze available groundwater data and estimate groundwater nutrient inputs to Lake Tahoe and its tributary streams. By dividing the Lake Tahoe Basin into regional groundwater sub basins, the USACE 2003 evaluation refined previous groundwater loading estimates, evaluated ambient groundwater nutrient loading rates, and identified potential groundwater pollution sources. Based on this information, the Lake Tahoe TMDL program determined that groundwater contributes approximate 12% and 15% of the average annual nitrogen and phosphorus loads, respectively.

Your review for this issue should focus on the summary information in Chapter 7.2 of the Draft TMDL and, for detailed information, you should focus on Chapter 4.1 in the TMDL Technical Report.

5. Pollutant loading rates from atmospheric deposition directly to the lake surface were quantified and in-basin sources were found to be the dominant source of both nitrogen and fine particulate matter. Direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

Because the Lake's surface area (501 km^2) is large relative to its watershed drainage area (812 km^2), the Lake Tahoe TMDL team spent significant time and resources to quantify nutrient and particulate loading from direct atmospheric deposition. In cooperation with the California Air Resources Board (CARB), the TMDL team undertook a multi-year science program to quantify the contribution of dry atmospheric deposition. The 2006 *Lake Tahoe Atmospheric Deposition Study*, conducted by CARB, augmented long-term atmospheric data collected by the University of California, Davis. Based on these studies, the Lake Tahoe TMDL found that atmospheric deposition contributes 55% of the average annual nitrogen load directly to the lake.

Your review for this issue should focus on the summary information in Chapter 7.6 of the Draft TMDL and, for detailed information, you should focus on Chapter 4.5 of the TMDL Technical Report.

6. Pollutant Reduction Opportunity (PRO) analysis identifies fine sediment particle and nutrient reduction options that can be quantified. The PRO findings offer basin-wide pollutant load reduction estimates and costs for a range of implementation alternatives for reduction loads from urban uplands, forest uplands, stream channel erosion, and atmospheric deposition sources.

The Water Board contracted with Tetra Tech, Inc. to conduct a thorough evaluation of pollutant load reduction opportunities for the major pollutant sources. The project was organized around four Source Category Groups, led by local and regional experts in their respective fields. These groups screened potential treatment options on (1) the ability to treat the pollutants of concern and (2) the ability to quantify load reduction effectiveness. The analysis results provide the basis for the Lake Tahoe TMDL implementation strategy. The PRO analysis found the largest, most cost effective opportunities for fine sediment particle load reductions are from the urban upland source.

Your review for this issue should focus on the summary information in Chapter 9 of the Draft TMDL. Details of each Source Category Group analysis approach are described in Chapters 2-5 of the Lake Tahoe TMDL Pollutant Reduction Opportunity Report v2.0 (March 2008). Combined results summarizing the basin-wide estimated load reductions and associated costs can be found in Chapter 6 of that report. Chapter 2 of the Integrated Water Quality Management Strategy Project Report outlines the Recommended Strategy for TMDL implementation, while Chapter 3 of that document describes how the Pollutant Load Reduction Opportunity analysis was used to develop the Recommended Strategy.

7. Lake Clarity Model was the most appropriate for predicting the lake response to changes in pollutant loads.

Researchers at the University of California at Davis developed the Lake Clarity Model to predict how Lake Tahoe's Secchi depth may respond to changing pollutant input over time. The Lake Tahoe TMDL program used the Lake Clarity Model to predict how the lake's transparency is expected to change in response to the proposed implementation approach.

Your review for this issue should focus on the summary information in Chapter 8 of the Draft TMDL and, for detailed information, you should focus on Chapter 6 of the TMDL Technical Report.

8. Allocation of allowable fine sediment particle and nutrient loads is based on the relative magnitude of each pollutant source's contribution and the estimated ability to reduce fine sediment particle and nutrient loads

Fine sediment particle and nutrient loads were allocated based on the relative source loads and the ability to control fine sediment particles and nutrients from the primary contributing land uses. The efficacy of various pollutant control options was evaluated and provided the basis of the recommended implementation strategy. Because the urban landscape contributes the largest percentage of the fine sediment particle load and because urban stormwater controls represent the greatest control opportunity, urban stormwater dischargers bear the brunt of the reduction responsibility. Current programs to reduce fine sediment particle and nutrient loads from undeveloped forest areas and stream channel erosion are adequate and cost effective. Dust control measures offer further opportunities for fine particle reductions from atmospheric deposition and are included in the implementation approach.

Your review for this issue should focus on Chapter 10 of the Draft TMDL. Chapter 5 of the Integrated Water Quality Management Strategy Project Report describes the load allocation analysis methods for dividing allocations by responsible jurisdiction and summarizes the different load allocation approaches considered. Your attention should focus on Approach II, Load Source Weighted, as this was the chosen load allocation approach.

The Big Picture

Reviewers are not limited to addressing only the specific issues presented above, and are asked to consider the following questions:

(a) In reading the staff technical reports and proposed implementation language, are there any additional scientific issues that are part of the scientific basis of the proposed rule not described above?

(b) Taken as a whole, is the scientific portion of the proposed rule based upon sound scientific and technical knowledge, methods, and practices?

(c) Was the science program reasonably designed to fill in knowledge gaps: was historical data appropriately used.

Reviewers should also note that some proposed actions may rely significantly on professional judgment where available scientific data is not as extensive as desired to support the statute requirement for absolute scientific rigor. In these situations, the proposed course of action is favored over no action.

The preceding guidance will ensure that reviewers have an opportunity to comment on all aspects of the scientific basis of the proposed Board action. At the same time, reviewers also should recognize that the Board has a legal obligation to consider and respond to all feedback on the scientific portions of the proposed rule. Because of this obligation, reviewers are encouraged to focus feedback on the scientific issues that are relevant to the central regulatory elements being proposed.

<u>Additional Materials Provided to the Peer Reviewers</u>

The Lake Tahoe TMDL Technical Report references numerous projects that were funded as part of the Lake Tahoe TMDL. These numerous studies, which are listed below, are also provided for the peer reviewers since these studies were intended for direct use in the Lake Tahoe TMDL Technical Report. In some cases, the language from portions of those project reports was directly incorporated into the text of the Technical Report.

Groundwater

USACE (United States Army Corps of Engineers). 2003. *Lake Tahoe Basin Framework Study: Groundwater Evaluation*. U.S. Army Corps of Engineers, Sacramento District.

Stream Channel

Simon, A., E.J. Langendoen, R.L. Bingner, R. Wells, A. Heins, N. Jokay and I. Jaramillo. 2003. *Lake Tahoe Basin Framework Implementation Study: Sediment Loadings and Channel Erosion*. USDA-ARS National Sedimentation Laboratory Research Report. No. 39.

Simon, A. 2006. *Estimates of Fine-Sediment Loadings to Lake Tahoe from Channel and Watershed Sources*. USDA-Agricultural Research Service, National Sedimentation Laboratory. Oxford, MS.

Atmospheric

CARB (California Air Resources Board). 2006. *Lake Tahoe Atmospheric Deposition Study (LTADS)*. Final Report – August 2006. Atmospheric Processes Research Section, California EPA, Sacramento, CA.

Upland

Tetra Tech, Inc. 2007. *Watershed Hydrologic Modeling and Sediment and Nutrient Loading Estimation for the Lake Tahoe Total Maximum Daily Load.* Final modeling report. Prepared for the Lahontan Water Board and the University of California, Davis.

Shoreline Erosion
Adams, K.D. 2004. Shorezone erosion at Lake Tahoe: Historical aspects, processes, and stochastic modeling. Final report for the U.S. Bureau of Reclamation and the Tahoe Regional Planning Agency. Desert Research Institute, Reno, NV.

Adams, K.D. and T.B. Minor. 2001. *Historic Shoreline Change at Lake Tahoe from 1938 to 1998: Implications for Water Clarity.* Desert Research Institute, Reno, NV. Prepared for the Tahoe Regional Planning Agency.

Lake Clarity Modeling
Sahoo, G.B., S.G. Schladow and J.E. Reuter. 2007. *Linkage of Pollutant Loading to In-lake Effects.* University of California, Davis – Tahoe Environmental Research Center. Prepared for the Lahontan Water Board.

Water Quality Planning
Lake Tahoe TMDL Pollutant Reduction Opportunity Report. Environmental Incentives, LLC., prepared for the Lahontan Water Board and the Nevada Division of Environmental Protection. March 2008

Integrated Water Quality Management Strategy Project Report, Environmental Incentives LLC, prepared for the Lahontan Water Board and the Nevada Division of Environmental Protection. March 2008

Attachment 3

Scientists, Engineers, and Land Use Planners Involved in Studies Related to the Lake Tahoe Watershed Sediment and Nutrient TMDL

FEDERAL AGENCIES

1. ***U.S. Army Corps of Engineers***
   Meegan Nagy, Melissa Kieffer, Lewis Hunter, Timothy Crummett, Teresa Rodgers, John Baum, Elizabeth Caldwell, Scott Gregory, Suzettee Ramirez, Glenn Cox, Richard Meagher

2. ***U.S. Environmental Protection Agency***
   Jacques Landy, Jane Freeman

3. ***U.S. Geological Survey***
   Tim Rowe, Kip Allander

4. ***U.S. National Park Service***
   Lee Tarnay

5. ***U.S. Department of Agriculture (USDA), United States Forest Service – Lake Tahoe Basin Management Unit***
   Sue Norman, Denise Downey, German Whitley, Joey Keeley, Craig Oehrli

6. ***USDA – National Sedimentation Laboratory, Oxford, MS***
   Andrew Simon, Eddie Langendoen, Ron Bingner, Brian Bell, Loren Klimetz, Danny Klimetz, Mark Griffith, Charlie Dawson, Robert Wells, Amanda Heinz, Nick Jokay, Igor Jaramillo

STATE AGENCIES

1. ***California Air Resources Control Board***
   Earl Withycomb, Eileen McCauley, Leon Dolislager, Tony VanCuren, Jim Pederson, Ash Lasgari, Bart Croes, Richard Corey, Dongmin Luo, William Vance, Clinton Taylor, Steve Mara, Deborah Popejoy, Michael Fitzgibbon, Jerry Freeman, Pat Vaca

2. ***California Department of Transportation (Caltrans)***
   Jody Jones, Amarjeet Benipal, Joe Caputo, John Rodrigues, Katrina Pierce, Steve Kirkpatrick, John Webb, Douglas Coleman, Leslie Case, Bill Davis, Tom Brannon, Jody Brown, Scott McGowen, Joyce Brenner, Karl Dreher, Keith Jones, Daniela Guthrie, Mitch Mysliwiec, John Johnston

3. ***California Tahoe Conservancy (CTC)***

Judy Clot, Kim Carr

4. ***Tahoe Regional Planning Agency (Bi-state agency, California and Nevada)***
   Larry Benoit, Sean Dougan, John Stanley, Charles Emmett, Karen Fink

5. ***Nevada Department of Transportation (NDOT)***
   Steve Cooke

6. ***Nevada Division of Environmental Protection***
   Jason Kuchnicki

7. ***Nevada State Lands***
   Charlie Donohue, Elizabeth Harrison

8. ***Nevada Tahoe Conservation District***
   Matt Vitale, Doug Martin, Scott Brown

9. ***Tahoe Resource Conservation District***
   David Roberts – formerly with the California Regional Water Quality Control Board - Lead author of Draft Lake Tahoe Maximum Daily Load Technical Report, September 2007

UTILITY DISTRICT

1. ***South Tahoe Public Utility District***
   Ivo Bergsohn

STATE UNIVERSITIES

1. ***University of California, Davis – Tahoe Environmental Research Center***
   John Reuter, Geoff Schladow, Goloka Sahoo, Scott Hackley, Tom Cahill, Steve Cliff, Ted Swift, Joaquim Perez-Losada, Alan Jassby, Bob Richards, Charles Goldman, Jenny Coker, Alex Rabidoux, Mark Grismer, Andrea Parra, Colin Strasenburgh, Raph Townsend, Lev Kavvas, Michael Anderson, Patty Arneson, Mark Palmer, Tina Hammell, George Malyj, David Jassby, Brant Allen, Debbie Hunter

2. ***University of Nevada, Reno***
   Jerry Qualls, Joseph Ferguson, Anna Panorska, Wally Miller

3. ***University of Nevada, Reno - Desert Research Institute***
   Alan Heyvaert, Jim Thomas, Ken Adams, Ken Taylor, Todd Mihevc, Gayle Dana, Rick Susfalk, Melissa Gunter, Alan Gertler, Tim Minor, Paul Verburg, Mary Cablk, Erez Weinroth

ENVIRONMENTAL SCIENCE AND ENGINEERING CONSULTANTS

1. ***2NDNATURE, LLC***
   Nicole Beck, Maggie Mathias, Nick Handler

2. ***Countess Environmental***
   Richard Countess

3. ***Environmental Incentives***
   Jeremy Sokulsky, Chad Praul

4. ***Entrix***
   Steve Peck, Mike Rudd

5. ***GeoSyntec***
   Eric Strecker, Jim Howell, Andi Thayumanavan, Marc Leisenring

6. ***Hydroikos***
   Bob Coats, Matt Luck

7. ***Integrated Environmental Restoration Services***
   Michael Hogan, Kevin Drake

8. ***Kieser & Associates***

9. ***Northwest Hydraulic Consultants (nhc)***
   Ed Wallace, Brent Wolfe

10. ***Tetra Tech, Inc.***
    John Riverson, Leslie Shoemaker, Clary Barreto, Andrew Parker, John Craig, Will Anderson

11. ***Valley and Mountain Consulting***
    Virginia Mahacek

Attachment 4
Peer Reviewed Publications Cited in the Lake Tahoe TMDL Report

* Publications followed by and asterisk have been subjected to a peer review process different than that for publications in scientific journals.

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Attachment 5
Non-peer Reviewed Publications cited in the Lake Tahoe TMDL Report

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PROPOSED AMENDMENTS TO THE WATER QUALITY CONTROL PLAN FOR THE LAHONTAN REGION TO ENSURE CONSISTENCY WITH RECENT SCIENTIFIC FINDINGS AND THE LAKE TAHOE TMDL IMPLEMENTATION PLAN

The Lake Tahoe TMDL program describes a restoration plan to halt Lake Tahoe's transparency decline and restore the lake's clarity over time. To affect this change, the Lahontan Water Board is amending the Water Quality Control Plan for the Lahontan Region (Basin Plan) to incorporate the Lake Tahoe TMDL and change portions of the Basin Plan to be consistent with recent scientific information and the Lake Tahoe TMDL implementation approach.

1. Lake Tahoe TMDL Summary

Water Board staff will add a sub-section to Basin Plan Chapter 5 - ***Water Quality Standards and Control Measures for the Lake Tahoe Basin*** summarizing the Lake Tahoe TMDL. The summary will include a brief overview of the TMDL research findings, a detailed synopsis of the TMDL implementation plan, and the pollutant load allocation tables.

2. Pollutants of Concern

Current Basin Plan text emphasizes the role nutrients (nitrogen and phosphorus) play in Lake Tahoe's clarity decline. The proposed amendment will add reference to fine sediment particles in all discussions of water quality impairment and pollutant reduction efforts to highlight the role this pollutant plays in transparency decline. Amendment language will emphasize fine sediment particles as a discreet pollutant independent of nutrients while maintaining existing references to nitrogen and phosphorus as additional pollutants affecting Lake Tahoe's transparency.

3. Replace Stormwater Effluent Limits with TMDL Load Allocations

The Basin Plan currently includes concentration-based numeric effluent limits for stormwater discharges to surface waters and for infiltration facilities discharging to ground water. According to the Basin Plan, these limits are to be applied on a site- or project-specific basis in response to identified erosion or runoff problems.

The proposed Basin Plan amendment replaces the existing nitrogen, phosphorus, and turbidity effluent limits with mass-based pollutant source load allocations for fine sediment particles, nitrogen, and phosphorus to protect beneficial uses related to Lake Tahoe's transparency.

Existing concentration-based receiving water standards for oil and grease, iron, turbidity and nutrients will remain in place.

4. Replace the 20-year Compliance Date ending in 2007 with the TMDL Implementation Plan Timeline

The Tahoe Regional Planning Agency (TRPA) developed the Water Quality Management Plan for the Lake Tahoe Basin (208 Plan) which was amended in 1988. In numerous instances, the Basin Plan references the 208 Plan and the associated 20-year compliance date ending in 2007 for implementing water quality control measures in the Tahoe watershed.

The proposed Basin Plan amendment will remove references to the 208 Plan compliance schedule and replace it with the timeline for the Lake Tahoe TMDL Implementation Plan.

5. Specify Stormwater Treatment Efficiencies for Small Scale Projects

The Basin Plan currently includes a requirement for facilities to be designed to treat the 20-year, 1-hour design storm for stormwater in the Lake Tahoe Hydrologic Unit. This design guidance requires project proponents to capture and/or treat approximately one inch of stormwater runoff from the project area.

Project proponents, particularly municipal jurisdictions and other entities planning stormwater treatment facilities at the catchment or sub-watershed scale (i.e. projects typically greater than one acre), need flexibility to consider a variety of design storms for planning sub-watershed or catchment scale water quality improvements. Resource managers also need established standards for determining whether smaller projects (on parcels less than one acre) effectively meet stormwater control requirements.

The proposed Basin Plan amendment removes strict references to compliance with the treatment design standard for a 20-year, 1-hour design storm for stormwater and establishes new stormwater treatment facility guidelines.

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Lake Tahoe Sediment and Nutrient TMDL

Response to Peer Review Comments

William M. Lewis, Jr.

Peer Review Received: July 9, 2009

Review of

The Lake Tahoe Watershed Total Maximum Daily Load (TMDL) for Sediment and Nutrients

Prepared for the California Regional Water Quality Control Board

TMDL/Lahontan Basin Planning Unit

Prepared by: William M. Lewis, Jr.

Date of Preparation: 9 July 2009

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Date of Preparation: 9 July 2009

This review is designed to meet the requirements described in a memorandum prepared by Doug Smith, Chief of the TMDL/Lahontan Basin Planning Unit, California Regional Water Quality Control Board, Lahontan Basin, dated 12 November 2008 and revised 4 June 2009. The purpose of the review, as given on page 3 of the memorandum, is to determine whether the scientific portion of the proposed basin plan amendment is based upon sound scientific knowledge, methods, and practices. The memorandum specifies eight issues that are to serve as the focus of the review, and directs the reviewers to specific sections of the draft TMDL report, the TMDL technical document, and supporting documents for information to be reviewed. This review is organized around the eight issues identified in the memorandum.

I) Fine sediment particles as the primary cause for impairment of clarity.

a. Draft TMDL report: comments.

1. The TMDL text of special interest here (Section 3) is poorly crafted in that it is awkwardly presented and in some places confusing or factually incorrect. This defect does not invalidate the section as a contribution to the TMDL, but it would be better if the text were revised so that it can be understood more easily and be free of misleading or incorrect statements (see below).

2. The opening statement, on page 3-1 contains a number of errors. Nutrients are not examples of particles, contrary to the text. The reference to "floating" algae is off the mark; the main concern for Lake Tahoe would be suspended algae (phytoplankton) in open water and attached algae (periphyton) near shore. Also, it is unlikely that leaves would be among the organic particles found in Lake Tahoe; breakdown products of leaves might appear in small amounts.

3. Conventions set by the regulatory agencies appear to distinguish between transparency

Response

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3. Conventions set by the regulatory agencies appear to distinguish between transparency

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WL-1: The text in Chapter 3 of the Final Report has been revised to clarify the points about nutrients, algae, and leaves.

and clarity. This distinction, however, is not common knowledge and should be explained in the text. The report should state that, for purposes of this TMDL, transparency will be understood to refer to the secchi depth measurement and clarity will be assumed to refer to the extinction coefficient, as estimated by measurements of irradiance in the water column. The two are quite closely related, but the effect of particles on transparency is somewhat more drastic than it is on extinction coefficient, in that particles cause a cloudiness in water that interferes with the perception of objects even where there is enough light for vision.

4. The text associated with Figure 3-1 is erroneous, as is the figure itself. The text states that water does not absorb light. This is patently incorrect (see TMDL technical report). Pure water absorbs light and also scatters light. The proportion of light absorbed or scattered depends on wavelength. Particles also both absorb and scatter light, and do so differentially with respect to wavelength. Although the diagram in Figure 3-1 comes from a reputable study (PhD dissertation), it apparently misled the author of the TMDL draft, and should be either corrected or eliminated.
5. The opening page of Section 3 identifies pure water and particulate matter as factors that explain the decline of light with depth in the lake (although the relative mechanisms of decline caused by scattering vs. absorption are not explained). A key omission here is the role of dissolved organic matter, which has an additional effect on the absorption of light in water. This effect is most pronounced where humic and fulvic acids are present in water. These materials are derived from watersheds (soils) primarily. They are highly chromatic in that they cause rapid light extinction when present. They are present in all waters, but obviously are not abundant in Lake Tahoe,

Response

and clarity. This distinction, however, is not common knowledge and should be explained in the text. The report should state that, for purposes of this TMDL, transparency will be understood to refer to the secchi depth measurement and clarity will be assumed to refer to the extinction coefficient, as estimated by measurements of irradiance in the water column. The two are quite closely related, but the effect of particles on transparency is somewhat more drastic than it is on extinction coefficient, in that particles cause a cloudiness in water that interferes with the perception of objects even where there is enough light for vision.

WL-2: Though clarity is measured by the vertical extinction coefficient while transparency is measured by the Secchi disk depth, the public commonly refers to Lake Tahoe's Secchi depth as the "clarity". Therefore this TMDL uses "clarity" in the general sense to refer to the Secchi depth unless specifically stated as the clarity measurement of vertical extinction coefficient. Changes were made throughout the Final Report, Chapters 1-8, where appropriate in light of this distinction.

4. The text associated with Figure 3-1 is erroneous, as is the figure itself. The text states that water does not absorb light. This is patently incorrect (see TMDL technical report). Pure water absorbs light and also scatters light. The proportion of light absorbed or scattered depends on wavelength. Particles also both absorb and scatter light, and do so differentially with respect to wavelength. Although the diagram in Figure 3-1 comes from a reputable study (PhD dissertation), it apparently misled the author of the TMDL draft, and should be either corrected or eliminated.

WL-3: The text was modified in the Final Report, Section 3.1; and the Technical Report, Section 3.4.1, to correct the discussion. The figure was removed from the Final Report (Figure 3-1) and the Technical Report (Figure 3-8).

5. The opening page of Section 3 identifies pure water and particulate matter as factors that explain the decline of light with depth in the lake (although the relative mechanisms of decline caused by scattering vs. absorption are not explained). A key omission here is the role of dissolved organic matter, which has an additional effect on the absorption of light in water. This effect is most pronounced where humic and fulvic acids are present in water. These materials are derived from watersheds (soils) primarily. They are highly chromatic in that they cause rapid light extinction when present. They are present in all waters, but obviously are not abundant in Lake Tahoe,

2

WL-4: The issue of colored dissolved organic matter (CDOM) has been added to the text in Section 3.1 of the Final Report and Section 3.4.1 of the Technical Report. Swift (2004) measured CDOM in the lab and CDOM is included as a specific parameter in the optical sub-model for the Lake Clarity Model. Because of the ultra-oligotrophic nature of Lake Tahoe's waters, Swift found light attenuation due to CDOM to be minor; however, CDOM was measured and is part of the Lake Clarity Model.

which otherwise would not have such high transparency (see TMDL technical report). Mention of this occurs as an aside later in the Section, but a reader who is unaware of the CDOM effect may be confused.

6. Figure 3.3 is difficult to interpret. What is the assumed abundance or mass per unit volume of particles upon which this graph is based? The graph is meaningless without a more complete explanation of the underlying assumptions or of the observations that are portrayed here.

7. Figure 3-4 also cannot be easily interpreted based on the labels (see also TMDL technical report). The scattering effect of pure water is not labeled on the graph. Inorganic particles are labeled "sediment" although sediment is the name for all particles and not just inorganic particles. Organic particles are termed "algae" although it has already been stated that organic particles include other items.

8. On page 3-4, a reference is made to phytoplankton primary production before 1850. The wording of the sentence suggests that researchers were studying primary production before 1850. The author means to say that researchers have estimated production that occurred prior to 1850, but without measuring it (see the TMDL technical document).

9. On page 3-4, the box explanation of primary production is not very clear. The organisms in question need to be capable of photosynthesis. The byproduct is organic matter (a better term than "food" in this context).

10. On page 3-7, the last sentence in paragraph two could be a bit misleading. "Mixing" is used in two ways here: with reference to the seasonal mixing, which does not always reach the bottom of the lake, and with reference to mixing of the entire water

which otherwise would not have such high transparency (see TMDL technical report). Mention of this occurs as an aside later in the Section, but a reader who is unaware of the CDOM effect may be confused.

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3

Response

WL-5: The text was modified to clarify this graph (Figure 3-2) in the Final Report in Sections 3.1 and 3.2 and in the Technical Report for Figure 3-8 in Section 3.4.1.

WL-6: The figure and captions have been revised in both the Final Report (Figure 3-4) and Technical Report (Figure 3-11).

WL-7: The text has been revised in the Final Report, Section 3.4.1 to state that researchers estimated phytoplankton primary productivity before 1850.

WL-8: The text inside this 'call-out' box in the Final Report, Section 3.4.1 has been revised with more details explaining primary production.

WL-9: The text in Section 3.5 of the Final Report has been revised to clarify the difference between annual deep mixing and mixing of the lake's entire volume. Additional text and a new figure (Figure 3-16) with the historic time series for annual depth of lake mixing has been added to the Technical Report in Section 3.4.2.

column, which occurs at multiyear intervals. The last sentence seems to say, but does not intend to say, that seasonal mixing occurs on an irregular basis. It would be better to state that Lake Tahoe shows an annual deep mixing that has seasonal regularity, but that mixing of the entire lake volume occurs on an irregular basis at multiyear intervals.

11. Page 3-8. At the bottom of page 3-8, periphyton is defined as "attached filamentous algae." Periphyton includes all attached algae, not just filamentous species. References to "excessive" algae and "extra" nitrogen or phosphorus are a bit difficult to interpret. It would be better to say that the amount of periphyton in a given environment may increase if concentrations of phosphorus and nitrogen increase.
12. Section 8 comes through more clearly than Section 3, although it does raise a number of questions, as explained below.
13. On page 8-1, the first of a number items refers to the simulation of "secchi depth clarity." Because Section 3 made a distinction between transparency (secchi depth) and clarity (extinction coefficient), the reversion to use of secchi depth as an index of clarity in this chapter is confusing and inconsistent.
14. In Figure 8-1, the output of the upper part of the flow diagram is shown as total pollutant load. Actually, this load is more correctly referred to as total load. Only a portion of this total is traceable to pollution. We cannot count every ounce of phosphorus, nitrogen, or suspended solids as pollution. Also, in the same diagram, there is a reference to CDOM, which comes in from the watershed mostly. It is good to have this component in the model, but the means of estimating it is not given in the text, nor is any information given on the treatment of CDOM in the model.

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4

Response

WL-10: The text in Section 3.6 of the Final Report was revised to clarify that periphyton amounts may increase if phosphorus and nitrogen concentrations increase.

WL-11: Changes have been made throughout the Final Report to be consistent in terminology between clarity and transparency and specifically, the word clarity has been deleted from Section 8.1 in the Final Report. (See response WL-2)

WL-12: Not all nutrient and fine sediment loading to Lake Tahoe (and to other waterbodies) is a pollutant. The word 'pollutant' was removed from Figure 8-1 in the Final Report and Figure 6-1 in the Technical Report. The term 'pollutant' is used in the TMDL to include both the nutrient and sediment material because the TMDL allows for reduction of these materials regardless of its ultimate source (i.e. surface runoff can include both anthropogenic and natural sources) and treatment/control applies to the combined load. The CDOM (colored dissolved organic matter) term in the conceptual model (Figure 8-1 Final Report)) is supported by laboratory experiments using water from Lake Tahoe. The value used in the model for absorption due to CDOM is given in Table 6-4 in the Technical Report along with a reference.

Presumably it is trivial, but some explanation is required.

15. Table 8-2 is given as proof of validation for the lake clarity model. The model predicts secchi depths within a very narrow range (23.1-23.9) whereas the observations fall in a considerably broader range (20.5-23.8). The model shows a consistent directional bias, which is problematic for any model. Furthermore, the observed and the modeled values are not significantly correlated with each other, i.e., the model is not capturing the causes of variation, which is its main purpose (Figure 1).

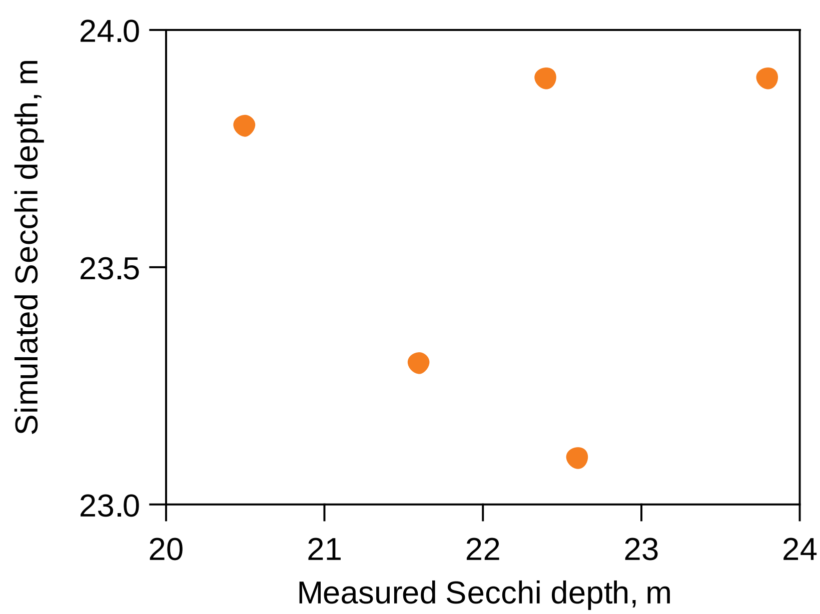

Figure 1. Plot of secchi depth measurements predicted from TMDL Report Section 8. R^2= 0.01; relationship not significant (p>> 0.05).

16. Figure 8.2 also poses some problems. Years 2000-2005 are reported to show good agreement, but there are some reasons to question this conclusion, as mentioned above. More troubling is the very wide variation of predicted secchi depths after 2005. The range of variation seen here for predictions is not found anywhere in the previous record of observed secchi depths. Certainly secchi depth observations must

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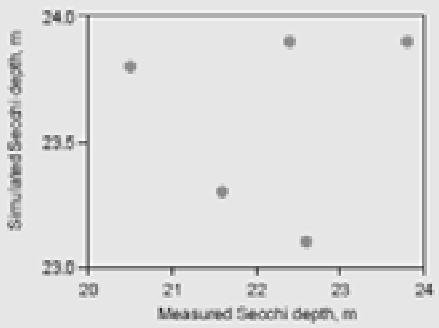

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Response

WL-13: The period 2000-2004 included in Table 8-2 (Final Report) and Table 6-6 (Technical Report) was a period of relatively uniform Secchi depth when viewed in terms of both monitoring and modeling data. However, plots of simulation runs done to evaluate the resulting Secchi depth under conditions of sustained load reduction (see Section 6.4.2 in the Technical Report) show that the Lake Clarity Model (LCM) produces a much broader range of values, i.e. the LCM is capable of detecting a change in Secchi depth under changing conditions. We are also encouraged by the observations that (1) the change in particles needed to achieve the TMDL target was very similar based on LCM output and the empirical relationship between measured in-lake particles and measured Secchi depth (Technical Report, Figure 6-26) and (2) the LCM prediction that if all sources of urban particles were eliminated that the resulting Secchi depth would be near what is considered as the historic baseline (see Section 6.5 in the Technical Report). The LCM can detect changes in Secchi depth that are relevant to management needs; the period 2000-2004 was too similar (in Secchi depth) for the model to capture small differences.

WL-14: The modeled values after 2005 were based predominantly on the precipitation values used to populate the Lake Clarity Model. Since there is no way to know these values before the fact, the modelers based their selection on past trends and records. This is discussed in detail in Section 6.4.1 of the Technical Report and in the Lake Clarity Model technical report (Sahoo et al. 2006 and Sahoo et al. 2009). The recurrence interval of annual precipitation years was preserved for the simulation of future precipitation (i.e the same fraction of wet, average, dry, etc. years). However, the order of occurrence of these years was purely random. So a very wet year could be followed by a very dry year, which could be followed by another very wet year. In reality there are likely to be multi-year cycles (influenced by factors such as the Pacific Decadal Oscillation) that would act to constrain the year-to-year variability. However, we believe the longer term trends associated with implementing the TMDL will be captured. This was considered the least potentially biased approach. The results allow resource managers to initially establish the TMDL from a reasonable position. To the extent that future precipitation conditions do not turn out to be similar as the ones selected in this TMDL analysis, adjustments can be made during the TMDL adaptive management process in the future.

be available now for years 2006-2008. How do the predicted large variations over this span of years compare with the observations for these years?

17. On page 8.6, it is mentioned that phosphorus and nitrogen control are more effective than phosphorus control alone in eliminating phytoplankton biomass. Some explanation should be added, particularly since Section 3 makes the argument that the lake is under substantial phosphorus control at present due to an increase in atmospheric loading of nitrogen. In fact, the two nutrients are nearly co-limiting in that addition of phosphorus is predicted to cause a phytoplankton biomass response, but this response has substantial limits because of depletion of inorganic nitrogen when phytoplankton biomass is increased by increasing phosphorus.

b. TMDL Technical Support Document. A number of the comments given above on the TMDL apply also to the TMDL support document, and need not be repeated here.

1. It seems strange that particulate phosphorus, mentioned on page 3-13, shows a sedimentation rate 1/40 of the sedimentation rate for fine particulate matter, mentioned on page 3-14. Perhaps some explanation should be offered.

2. On page 3-16, first full paragraph, the text seems to say that phosphorus and nitrogen nutrient limitation can be diagnosed accurately form the ratio of total N to total P in the water column of a lake. This is patently untrue. Total nitrogen and total phosphorus consist of mixtures of particulate, dissolved organic, and dissolved inorganic forms of nitrogen and phosphorus. These forms vary greatly in their availability to phytoplankton, and the ratio of available nitrogen to available phosphorus does not follow the ratio of total nitrogen total phosphorus. Furthermore, the picture is complicated by the ability of algae to store phosphorus and nitrogen

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6

Response

WL-15: For management purposes the issue of nitrogen versus phosphorus limitation is not as important as it might appear. First, algal growth in Lake Tahoe appears to be co-limited, since the addition of nitrogen and phosphorus combined nearly always results in a larger stimulation than either nitrogen or phosphorus additions singly. Second, as shown in Table 8-4 of the Final Report, mitigation efforts to control nutrient loading will include both nitrogen and phosphorus. Third, as discussed in the Final Report the major emphasis will be placed on fine sediment reduction as this has such a large effect on transparency and phosphorus comes primarily from fine sediment.

WL-16: The settling rates cited for nitrogen and phosphorus represent the average residence time for nitrogen and phosphorus in the water column, and not the residence time of the particles with which they are associated. Many of the nutrients associated with particles are mineralized by bacteria and effectively recycled before settling to the bottom (Paerl 1973). Consequently, the residence time for nitrogen and phosphorus in the water column will be longer than that for the actual particle. The text was revised in the Technical Report in Section 3.4.1.

WL-17: While the Technical Report recognized and discussed bioavailability in Section 3.4.2 of the Technical Report, and factors were used in the Lake Clarity Model to account for this (values for nitrogen were taken from the literature and values for phosphorus were directly analyzed as part of the TMDL science program at Lake Tahoe), the text has been revised in the Technical Report in Section 3.4.2 based on a recent paper by the reviewer (Lewis and Wurtsbaugh 2008).

beyond their immediate needs. The text that follows the opening paragraph gives a more realistic view of the many qualifications that one must attach to the ratios of total nitrogen to total phosphorus.

3. Page 3-17 paragraph 4. There is a problem with the units that are given in this paragraph. The author seems to be equating chlorophyll a with carbon, which is incorrect. Chlorophyll makes up about one percent of algal dry mass, whereas carbon makes up about fifty percent of algal dry mass. This needs to be straightened out.
4. Page 3-24. Somewhat contrary to what one might expect from the text, there seems to have been no significant change in periphyton abundance between 1982 and 2003. There is a contrast here with phytoplankton.
5. Chapter 5, page 5-1, third paragraph. It is surprising that the TMDL technical support document relies here on pure speculation as to how much of the particle load is organic and how much is inorganic. There probably is some relevant literature on this matter, and certainly a few measurements would help.
6. Page 5-3 to 5-7. The method used for estimating the source strength for particles coming from the watershed follows a logical path but it mostly unpublished (partly because it is new) and therefore has not been as much scrutinized as the work on Lake Tahoe.

c. Summary of opinion on question 1: Fine sediment particles are the primary cause of clarity impairment.

The TMDL document and the parallel text of the technical support document summarize the evidence in support of the conclusion that fine sediment particles are the main cause for impairment of clarity in Lake Tahoe. The text of both documents contains beyond their immediate needs. The text that follows the opening paragraph gives a more realistic view of the many qualifications that one must attach to the ratios of total nitrogen to total phosphorus.

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Response

WL-18: The text in the Technical Report, in Section 3.4.2 under the heading *Primary Productivity, Phytoplankton and Algal Growth Bioassays* has been corrected, the units are grams of carbon per meter squared per year.

WL-19: The increase in phytoplankton was as primary productivity and not as biomass. A new figure and text was added to the Technical Report (Section 3.4.2, Figure 3-14) showing no discernable trend in annual average chlorophyll *a* concentrations since 1984. This difference between productivity and biomass accumulation may be related to picoplankton community that is composed of very small, yet photosynthetically active cells (see recent paper by M. Winder, doi:10.1093/plankt/fbp074, available online at www.plankt.oxfordjournals.org). With regard to periphyton biomass, the historic data do not account for increases in the localized range of colonization or the biomass distribution outside the confines of the established monitoring station. Recently, the UC Davis monitoring program has been expanded to investigate these considerations; however, the data is limited at this time.

WL-20: Research to test this assumption is not yet completed; however, according to Alan Heyvaert (personal communication 2009) at the Desert Research Institute, preliminary and limited data suggest that on average organic matter constitutes only about 10-20 percent of the total sediment in the < 1,000 µm size class for urban runoff. Since organic matter is subject to pulverization by vehicular traffic in urban landscapes, the percent contribution by fine organic particles in streamflow should be smaller. The text in the Technical Report, Section 5.1.1 has been updated to include this preliminary information.

WL-21: The topic of fine sediment particles sources and the relationship to transparency is relatively new at Lake Tahoe. The science team has been working on academic papers and a number of them are in progress. A critical part of the external peer review of these TMDL documents was to allow for a high level of scrutinization.

a number of errors and misleading statements, which can be easily revised, but the underlying information is very sound scientifically. The key discovery, published by Jassby et al. in 1999, is that attenuation of light in the upper portion of Lake Tahoe by fine particles is more important than attenuation of light by phytoplankton biomass, which had earlier been considered the main cause for declining clarity of Lake Tahoe. The study was followed by additional studies of particle size distribution, seasonality, and proportionate contribution of other factors contributing to light attenuation. Publication of the Jassby paper and some of the other research in peer review outlets adds to the credibility of the analyses and interpretations.

A logical final step leading to the use of information on light attenuation factors as part of the TMDL is the development of a lake clarity model, as presented, by Swift and others. While there is no reason to doubt the predominant importance of particles in causing increased light attenuation through time in Lake Tahoe, as shown by empirical relationships derived from lake sampling, evidence for the soundness of the lake clarity model is still mixed. As indicated above, lake clarity model produces an accurate estimate of the mean clarity across years based on contributing factors, including fine particles, but fails to capture interannual variation. The concern here is that a secular change in mean might not be captured for the same reason that interannual variation is not captured by the model. The handicap for the modeler is that the range of variation is not very great, and the model simply may not be sensitive enough to depict interannual variation, but this matter needs attention.

Even if the model cannot be made to capture more variation interannually, there can be little doubt that measures taken through the TMDL process to reduce the loading of a number of errors and misleading statements, which can be easily revised, but the underlying information is very sound scientifically. The key discovery, published by Jassby et al. in 1999, is that attenuation of light in the upper portion of Lake Tahoe by fine particles is more important than attenuation of light by phytoplankton biomass, which had earlier been considered the main cause for declining clarity of Lake Tahoe. The study was followed by additional studies of particle size distribution, seasonality, and proportionate contribution of other factors contributing to light attenuation. Publication of the Jassby paper and some of the other research in peer review outlets adds to the credibility of the analyses and interpretations.

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8

Response

WL-22: When trying to model interannual variability it is critical that the timing of events is captured with some accuracy. As shown in both Jassby et al. (1999) and Swift et al. (2006) Secchi depth in Lake Tahoe is affected by both fine sediment particles and to a lesser extent phytoplankton that is brought into the surface waters from the deep chlorophyll maximum, as the thermocline begins to erode in the fall and early winter. Modeling of each antecedent condition in the lake over a more resolved time scale is difficult, especially when the lake may not respond immediately to pollutant loading. Since regulatory standards that guide this TMDL are based on annual averages, interannual patterns were not considered critical; the 29.7 meter target set by the State of California is based on a multi-year average. Documentation of the actual achievement of the desired TMDL target will not be based on model outcomes but rather on Secchi depth monitoring data, which shows significant intra- and interannual variation in lake response. Based on management needs the Lake Clarity Model's performance on an annual time scale (Table 6-6 in the Technical Report) meets the TMDL's objective. Finally, the observations that (1) the model simulation without fine sediment particle loading from urban areas is very similar to what is considered the historical baseline for Lake Tahoe Secchi depth (Technical Report, Section 6.5) and (2) model results for fine sediment reduction correspond to agree with the results of empirical observations of fine sediment particle levels and measured Secchi depth (Figure 6-26 in Technical Report) elevates our confidence that the Lake Clarity Model is functional at the appropriate time scale.

fine particles to Lake Tahoe would improve its clarity, provided that the presently substantial efforts to control nutrient loading are maintained.

II) Sources of Nutrients and Particles.

a. TMDL report.

Section 7 of the TMDL Report gives a clear overview of the results of studies contributing to quantitative partitioning of nutrients and particles for Lake Tahoe.

b. TMDL Technical Support Document.

1. Apparently no quantitative error estimates have been made.

c. Answer to question 2: Identification of the six sources of pollution affecting lake clarity.

The methods for estimation of sources of pollution (nitrogen, phosphorus, particles) as described in the TMDL Report reflect the state of the art, and incorporate both modeling and empirical analysis of sampling data. Although at least some of the modeling components were calibrated with empirical data, there is no clear presentation of the expected error for each of the estimates. Even so, the great observed difference between mean concentrations of particles emanating from upland urban areas and other areas insures that the final conclusion is quite secure qualitatively. Thus, for TMDL purposes, a strong focus on particle release from upland urban areas is warranted.

Overall, the partitioning work was done very conscientiously and should be viewed as reliable for TMDL purposes.

III) Lake Tahoe watershed model.

a. TMDL report.

1. The TMDL report contains only a sketch of the water quality modeling. The validity of the modeling must be judged entirely from the technical support document and

fine particles to Lake Tahoe would improve its clarity, provided that the presently substantial efforts to control nutrient loading are maintained.

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c. Answer to question 2: Identification of the six sources of pollution affecting lake clarity.

The methods for estimation of sources of pollution (nitrogen, phosphorus, particles) as described in the TMDL Report reflect the state of the art, and incorporate both modeling and empirical analysis of sampling data. Although at least some of the modeling components were calibrated with empirical data, there is no clear presentation of the expected error for each of the estimates. Even so, the great observed difference between mean concentrations of particles emanating from upland urban areas and other areas insures that the final conclusion is quite secure qualitatively. Thus, for TMDL purposes, a strong focus on particle release from upland urban areas is warranted.

Overall, the partitioning work was done very conscientiously and should be viewed as reliable for TMDL purposes.

III) Lake Tahoe watershed model.

a. TMDL report.

1. The TMDL report contains only a sketch of the water quality modeling. The validity of the modeling must be judged entirely from the technical support document and

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Response

WL-23: The Lake Tahoe Watershed Model analysis did not evaluate error associated with each of the model's components. Rather, load estimates were determined based on model calibration using empirical analysis and field data. Excepted error was evaluated based on a direct comparison of simulated versus monitored data. As stated in the Technical Report (Section 4.3.6 under the heading *Lake Tahoe Watershed Model versus Lake Tahoe Interagency Monitoring Program Loading Comparison*), while there was some difference between the LTIMP and Lake Tahoe Watershed Model (LSPC) values for certain tributaries and for certain nutrient species (e.g. Blackwood Creek dissolved inorganic nitrogen and Ward Creek soluble reactive phosphorus, there was very good agreement, especially when considering the combined sum for the 10 tributaries (Table 4-41). The relative percent difference (LSPC-LTIMP)/(mean of LSPC and LTIMP) was between 10 − 14 percent with the exception of soluble reactive phosphorus which was much higher at 60 percent.

modeling report.

b. TMDL Technical Report.

1. Tetra Tech, which did the modeling, chose LSPC, an EPA approved watershed model for application to the Lake Tahoe basin. Because this model is approved by USEPA for TMDL applications, it seems likely that the model is appropriate for use. As is the case for widely used models of this type, LSPC is quite flexible with respect to number of watershed components and other features that are specific to any given basin.

2. The LSPC model apparently was customized for the Lake Tahoe project because of the specific importance of particles less than 63 µm for Lake Tahoe. Apparently, as explained on page 4-25, the model is able to produce predictions of total suspended solids, and it was assumed that the observed fractionation of total suspended solids in the watershed, as shown by monitoring, could be applied to the predicted TSS. This seems reasonable, although it means that there are no mechanistic components of the model that specifically deal with fine particles. Similarly, nutrient species were not actually predicted by the model, but rather were assumed to reflect currently observed speciation in streams.

3. There was no allowance in the modeling for uptake or immobilization of nitrogen and phosphorus in transit. The modelers argue that the transit time and the velocity of flow indicate the insignificance of these processes. More secure would have been some empirical demonstration that this is a correct assumption, but it does seem reasonable.

4. Scaling factors (adjustment factors designed to correct erroneous predictions) are

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4. Scaling factors (adjustment factors designed to correct erroneous predictions) are

10

Response

WL-24: There are no known watershed models that can directly predict the number of fine particles (0.5-16 µm diameter) in runoff from an area as large as the Lake Tahoe basin with the level of confidence needed for the Lake Clarity Model. Because appropriate values for mechanistic parameters are not available - especially from mountainous regions with complex terrain - it was decided to calibrate with empirical monitoring data. A significant monitoring effort was undertaken as part of this TMDL to collect fine particle data for both streamflow and urban runoff. This monitoring effort for fine particles was vital for the modeling approach taken. The LTIMP stream data is very extensive and comprehensive. Given the complexity of mountainous landscape and the fact that the Lake Tahoe basin consists of 63 independent watersheds it was decided that calibration to the high-quality LTIMP dataset was the best approach.

WL-25: The goal of the model was to obtain a good match at the mouth for the nutrient species. Because of the shape of the watershed and nature of its tributaries, most of the stream times of concentration were faster than the rates at which these transformations would likely occur. If the Lake Tahoe Interagency Monitoring Program data were not available from the stream mouth regions (i.e. near point of discharge to the lake), the uptake/immobilization of nitrogen and phosphorus would have required further consideration.

surprisingly large, as shown in Table 4-25. It would be reassuring have some explanation of these corrections based on monitoring.

5. The comparisons of modeled and observed concentrations show wild divergences on individual dates (often 1 order of magnitude). If hydrology is known, concentrations generally can be predicted fairly well for a given land use mixture. Perhaps the hydrologic modeling is introducing some unsuspected high degree of variation. Although the model is adjusted to produce means that reflect reality, predictions for individual dates show that the model does not understand the processes that control concentrations.

c. Answers to question 3: Lake Tahoe watershed model.

The choice of watershed model by Tetra Tech seems quite defensible. In addition, a great deal of monitoring information is available in support of modeling. Even so, the requirement for large adjustment factors and the large absolute value of deviations for concentrations between observations and predictions on specific dates shows that the model does not have a high degree of skill. The model is essentially forced by the adjustment factor process to produce means that correspond reasonably well with means for monitoring data. A lingering question is whether reliable predictions for changes in land use or control measures can be drawn from modeling, or whether they would be better drawn from direct use of data from monitored watersheds. I suspect the latter, although standard practice would be the former.

IV) Estimates of groundwater nutrient loading.

a. TMDL report.

1. The description of groundwater loading estimates in the TMDL report is insufficient

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IV) Estimates of groundwater nutrient loading.

a. TMDL report.

1. The description of groundwater loading estimates in the TMDL report is insufficient

11

Response

WL-26: As stated in both the Technical Report and the companion watershed modeling report (Tetra Tech 2007), the Lake Tahoe Interagency Monitoring Program (LTIMP) stream dataset allowed the modelers to calibrate to actual field measurements. The scaling factors used to distinguish loading by the four watershed quadrants (Table 4-18) are based on actual stream monitoring data. The scaling factors are empirical, but were necessary to account for differences seen in loads from streams in different locations of the lake. These quadrant scaling factors came from the calibration process. The sensitivity of the Lake Tahoe Watershed Model and the nature of the stream monitoring data provided by LTIMP (10 monitored streams) was not sufficient to customize loading for each of the lake's 63 tributaries and assumptions were required. New text was added to the Technical Report in Section 4.3.5 under the headings *Model Parameterization by Land-use* and *Water Quality Calibration Process* to make this step in the analysis more clear. Scaling factors are difficult to avoid unless more individual streams were directly monitored.

WL-27: There is room for improvement in the watershed model and there can be a high degree of variation between modeled versus measured observations for individual dates. However, it is of the greatest importance to the TMDL that both the model seasonal and annual load estimates were similar to the values derived from the observed values (Tetra Tech 2007). Unlike BMP stormwater design where it is critical that individual storms and even peaks in loading within a single storm be identified (i.e. needed for project design), daily resolution of loading to Lake Tahoe is not critical for the Lake Clarity Model to simulate annual lake Secchi depth.

WL-28: The Lake Tahoe Watershed Model was selected for source analysis phase of the TMDL because the model had to apply to the entire drainage area of the Lake Tahoe basin, with its mountainous terrain, strong east to west rain shadow, geological differences, etc. For this large-scale approach, certain averaging assumptions were required. It was important to calibrate to the high-quality Lake Tahoe Interagency Monitoring Program data set that best reflects actual conditions. There is no intent to use the full basin-scale version of the Lake Tahoe Watershed Model to predict changes in loading based on changes in land-use or control measures. Modelers working for the Water Board and NDEP have recently developed a different model to specifically predict load reduction associated with individual urban stormwater control projects. The Pollutant Load Reduction Model (PLRM) is a customized interface to the EPA's Storm Water Management Model version 5 (SWMM5) and was created as part of the TMDL program for use at Lake Tahoe. Information related to PLRM is available at http://tiims.org/TIIMS-Sub-Sites/PLRM.aspx.

in detail to support a review. This review is focused on the technical support document.

b. Technical support document.

1. General agreement between two separate studies (Thodal's 1997 study and the USACE's 2003 study) increases confidence to the estimates for groundwater loading of nitrogen and phosphorus to Lake Tahoe.
2. On page 4-8, at the top of the page, the technical support document distinguishes between aquifer types. Shallow aquifers, which make contributions to streams, are assumed to be reflected in estimates of tributary loading to the lake, which seems quite reasonable and is standard. Groundwater, according to this paragraph, is treated as originating from deeper aquifers that enter the lake at rock faces well below the water surface. Unless something is missing in this description, it seems that a third component is not considered. While tributaries pick up shallow alluvial flow, some of the shallow alluvial flow is intercepted by the lake itself without reaching a tributary. Obviously, the importance of this source varies with topography, but it seems wrong not to mention it at all.
3. Table 4-4 and other parts of the text for the groundwater portion of the report are confusing in use of the term "ambient." Ambient means characteristic of a specific place and time. The word "background" means natural or without superimposed influences. In this case, the authors are using the word ambient to mean background.
4. The background concentrations for phosphorus in groundwater are surprisingly high. They align well with stream concentrations for undisturbed or minimally disturbed areas summarized by the Tetra Tech study, however.

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Response

WL-29: Section 4.1.1 of the Technical Report has been modified to mention the shallow and deeper groundwater contribution directly to the lake.

WL-30: The USACE (2003) *Groundwater Evaluation* report defined ambient nutrient loading as the amount of nutrients that would discharge into Lake Tahoe regardless of anthropogenic sources. "Background" is a more appropriate term, so the word "ambient" was changed to "background" in the Technical Report, Section 4.1.3 and in the Final Report, Section 7.2.

5. The modeling approach used by USACE is standard. A specialized model was used only for the south Tahoe Basin. The general modeling was done by application of Darcy's Law, with numerous adaptations to the characteristics of individual sub-watersheds, as determined by sampling. The underlying problem, which plagues all groundwater flow estimates, is the applicability of Darcy's Law. Preferred flow paths, such as bedrock layers or cracks, may facilitate much faster flow than would be estimated from sampling based on bore holes. There is no easy fix for this problem, but it introduces tremendous uncertainty in estimates that cannot be calibrated or validated with actual observations at the discharge point.

c. Conclusions about question 4: Groundwater nutrient loading rates.

Estimation of groundwater nutrient loading reaching the lake follows standard practice and is backed up by substantial sampling. The groundwater contribution is small as a proportion of the total load, which means that even substantial errors in this estimate, which might occur through some unavoidable problems in estimating groundwater flows, would not likely change the overall conclusion. Given the literature on nutrient partitioning, a relatively small contribution of groundwater sources directly to the lake would be expected.

V) Atmospheric deposition as a source of particles and nutrients for Lake Tahoe.

a. TMDL report.

1. The availability of two separate studies, which appear to provide mutually consistent results, is advantageous.

b. Technical support document.

1. Figure 4-51 and associated text do not match up very well. TSP does not seem to

Response

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WL-31: Estimating groundwater inflow and nutrient loading is complicated in mountainous terrain where the natural geology does not result in uniform flow paths. Since the discharge of groundwater into Lake Tahoe will most likely be diffuse, validation is difficult. The flow and nutrient loading estimates used in the TMDL source analysis are similar to other independent estimates as discussed in the Technical Report (Section 4.1). The uncertainties associated with these values are primarily at a moderate level.

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WL-32: Figure 4-51 was removed and replaced with Table 4-45. The table is much easier to understand and according to CARB (2006) the data in the Table 4-45 was derived from data presented in Figure 4-51; therefore relevant information is not lost.

appear on Figure 4-51, nor are the axes explained. Too bad not to present more clearly what appears to be some very good work.

2. The procedure for allocating particles of a given size range to functional categories is not clear (page 4-121). For this reason, it is not easy to understand the basis for the third paragraph on page 4-121, which gives detailed information on the partitioning of particles within size classes. The apparent absence of any information on black carbon is unfortunate.
3. The good agreement mentioned on page 4-137 for CARB and TERC give confidence to the overall estimates, but only if CARB was fitted with deposition velocities that were developed completely in isolation of any information on the expected outcome based empirical data collection.
4. Estimates of loading from wet deposition for nutrients is accomplished in a rigorous manner with the benefit of a long term data record at one station. Although data for multiple stations are scarcer, they are sufficient to indicate relatively uniform deposition rates. This is somewhat surprising, given the potential for stagnation of polluted air in mountainous terrain, particularly during winter. However, comparison with NADP measurements in other states at locations of similar climatology is supportive. Absence of data collection on the lake's surface over extended periods of time is a disadvantage, especially in that precipitation over the lake might be cleaner than precipitation over terrestrial portions of the watershed, both the pollution sources and the natural terrestrial sources are associated with land. Altogether, however, the final estimate is responsibly made and is unlikely to be grossly erroneous.
5. The predominance of local sources of nutrients and fine particulate matter, as

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5. The predominance of local sources of nutrients and fine particulate matter, as

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Response

WL-33: The section of the Technical Report entitled *Estimated Particle Number and Deposited Fraction,* contained in Section 4.5.2, was revised and expanded. Investigating black carbon was not in the scope of LTADS. Ross Edwards at the Desert Research Institute has recently made some preliminary measurements of black carbon in Lake Tahoe, but only on particles < 0.5 µm. The distribution of black carbon in Lake Tahoe is still largely unknown and its potential impact on lake transparency has yet to be evaluated.

WL-34: CARB did not fit deposition velocities for nutrients using the empirical deposition data collected by UC Davis - TERC. As stressed in text on atmospheric deposition, these were independent approaches. Their close agreement in part lead to the high level of confidence associated with this component of the loading budget (see Table 4-67).

WL-35: While the concentrations of nitrogen in wet deposition from a limited number of stations around the basin are similar, they are not identical. The levels of dissolved inorganic nitrogen (DIN) did vary by a factor of two. Section 4.5.4 of the Technical Report has been revised to include a comparison of nitrogen and phosphorus deposition and noted that the wet deposition rate of DIN at the Saghen Creek location (located just north of Lake Tahoe) was virtually identical. Though there were no actual measurements of wet deposition on the lake, there were measurements for dry and bulk deposition. The current monitoring program does not fund wet deposition measurements. The approach taken in the Technical Report was done based on previous synoptic (around-the-lake) measurements and on precipitation differences across the lake.

discussed in section 4.5.5, is somewhat surprising. One would think that air movement across the Lake Tahoe basin from adjacent watersheds would have some influence on air quality. Certainly the results were arrived at in a careful way, but they are difficult to critique because the computations that are involved in producing the estimates cannot be followed. The validity of the is conclusion is rather important, as controls on loading that derived from the TMDL will be more or less effective according to the proportion of local sources in governing loading to the lake.

c. Answers to question 5: Atmospheric deposition of nutrients and particles.

The atmospheric component of the TMDL study was done at the state of the art for data collection and modeling and is backed up by a diversity of empirical studies. Inevitably, the dry deposition contribution to loading is more difficult to estimate than wet deposition, but the agreement between empirical and modeling studies is reasonably good, which offers some assurance that the overall conclusion is not severely flawed.

VI) Pollutant load reduction opportunities.

a. TMDL report.

1. Section 9.2.1 is confusing with respect to ground water. In the technical document, the term groundwater is used with reference to water that is pumped from wells bellow the surface alluvium. There is no indication in the results from the groundwater analysis, as presented in the technical document, that groundwater is universally polluted, as suggested in the text shown within section 9.2.1. There is some kind of terminology error or misunderstanding here.
2. Because the origin of fine particles in runoff is focused on urban uplands, it is unclear why it is cost effective to spend restoration dollars on forested upland or stream

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2. Because the origin of fine particles in runoff is focused on urban uplands, it is unclear why it is cost effective to spend restoration dollars on forested upland or stream

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Response

WI-36: The text in Section 4.5.5 of the Technical Report was revised to provide more background on how the evaluation concerning locally-generated versus regionally-transported atmospheric sources was made. The LTADS Report, done by CARB (2006) provides a detailed explanation. Since the Recommended Strategy includes control of urban stormwater runoff and street sweeping to reduce the soil particle loading to both runoff and the atmosphere, this management strategy would not be significantly changed.

WL-37: The text in Chapter 9 of the Final Report has been revised and no longer notes that groundwater is universally polluted.

WL-38: There are a variety of land management and restoration programs that are currently in place within the Lake Tahoe basin. These programs and projects are undertaken for a variety of reasons, including but not limited to habitat restoration, vegetation management, riparian restoration, soils and wetland restoration, and trail and road rehabilitation. Many of these actions have ancillary water quality benefits. The Lake Tahoe TMDL implementation plan acknowledges that these actions will occur regardless of the TMDL effort and accounts for the pollutant load reductions expected from ongoing restoration and land management activities. Although the expected load reductions from stream channel restoration and forest management activities are relatively small at the basin-wide scale, the water quality benefits are very cost effective. The Lake Tahoe TMDL Pollutant Reduction Opportunity Report provides additional detail regarding the relative cost/benefit of various load reduction activities.

channels.

b. Appendix: Pollution control opportunities.

The pollution control opportunities appendix gives details of the rationale and estimation procedure for various pollution control opportunities. This is a methodical and thoughtful component of the TMDL. There are enormous uncertainties, through no fault of the estimators, but a number of the more important opportunities are among the most confidently predicted.

c. Question 6: Pollution control opportunities.

The methodological text on pollution control opportunities is difficult to evaluate item by item. Overall, the approach seems comprehensive and defensible, and makes good use of the available information. As noted in the text, however, the predictions are uncertain in some cases. Given that the cost of the pollution control program can only be described as shocking, it is important that that an adaptive management procedure (as mentioned in the text and diagrammed) be a consistent feature of this program. Adaptive management is used in many long term environmental activities managed by government, but it is seldom implemented successfully. It is critical that evidence of ineffectiveness of a specific pollution control protocol lead to a redesign of the protocol. Acting against this enlightened way of proceeding is a natural but harmful entrenchment of attitudes and practices along lines that are preconceived at the beginning of the process.

VII) Appropriateness of the lake clarity model.

a,b. Comments on the TMDL report and the TMDL support document relevant to this question are as given above in Section I.

c. Answer to Question 7, lake clarity model.

Response

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VII) Appropriateness of the lake clarity model.

a,b. Comments on the TMDL report and the TMDL support document relevant to this question are as given above in Section I.

c. Answer to Question 7, lake clarity model.

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WL-39: Chapter 12 in the Final Report describes the adaptive management details, including the development of the Lake Tahoe TMDL Management System and how that system is critical to the TMDL Implementation Plan.

There is no question as to the appropriateness of using a model based on the absorbance of particulate and dissolved constituents of water for explaining observed light absorbance in the water column of Lake Tahoe. The conceptual basis for the Lake Tahoe water clarity model is sound, and there is a considerable amount of underlying empirical information. The usefulness of a model in anticipating future conditions, however, is measured by the degree to which the model captures year to year variation over a period of validation. As mentioned in Section I above, the Lake Tahoe water clarity model in its present form fails to capture a significant amount of year to year variation in transparency of Lake Tahoe. Some explanation is needed for this failure to capture variability. Adjustments to the model that allow it to capture variability better could be a second step in model development. If not, the limitations of the model in predicting future conditions must be acknowledged. The model is certainly on the right track conceptually, but there are signs of an unresolved problem.

VIII) Allocation of allowable fine sediment particle and nutrient loads.

a,b. Comments on the allocation system are as given above under VI.

c. Answer to Question 8: Suitability of approach 2, load source weighted allocation.

Approach 2 is rational and is a significant step toward optimizing results per unit of expenditure. It may fall short of maximum cost effectiveness, however, in allocating some resources to the capture of nutrients or fine particulate matter from sources that are diffuse, such as non-urban upland. Resources allocated to controlling these sources may not return significant results, in which case it would be better to allocate these resources to the more potent sources (e.g. urban areas). In context of the full budget, this is not a major issue because the proportionate allocation of dollars is certainly weighted toward

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Response

WL-40: Please refer to the Response WL-13. The year-to-year variation between 2000-2004 was relatively small compared to the > 9 meters improvement needed to meet the TMDL target of 29.7 meters. Section 6.4.1 of the Technical Report shows that the Lake Clarity Model is able to capture magnitude of Secchi depth changes needed for management purposes. Distinguishing between interannual monitored annual Secchi depth measurements with a high degree of certainty is unlikely because of the year-to-year differences in precipitation. This is why the TMDL milestones have been placed on a 5-year basis and not more frequently. The results of the simulated model runs based on fine sediment and nutrient reduction suggest that changes in lake transparency will be seen. This is further supported by the discussion in Section 6.5 of the Technical Report. The Secchi values in the period 2000-2004 were too small for the model to capture; however, a lake response much larger than that narrow range will be needed to meet the TMDL. Model results indicate those changes can be detected.

WL-41: Working within a framework where watershed protection benefits aquatic resources, the Lake Tahoe basin community considers a modest investment in non-urban upland restoration an overall benefit to riparian/wetland/stream channel function and consequently watershed health. Also, given the inherent complexity involved in a restoration program that virtually relies on the control of non-point sources, there is no reason to exclude non-urban uplands. As a result of the work done for the Lake Tahoe TMDL to date, agencies and stakeholders in the Lake Tahoe basin are very aware of the need to treat urban pollutant sources. It will take load reductions from all sources that receive an allocation to meet the long-term goals of the TMDL, while the focus will be on the urban sources.

the strongest sources, but the millions to be spent on weak sources may be wasted.

IX) Overall, the TMDL and its supporting documentation is a very impressive body of work. It is rare that such a strong fundamental scientific basis is combined with a detailed analysis of source control, prediction of outcomes, and allocation of resources. There are a few significant weaknesses, as mentioned above, but these can be investigated and perhaps mitigated. Modeling of clarity and loads is more problematic than other aspects of the TMDL.

My overall concern about the implementation phase of source control is its enormous cost. Given the financial realities of the current economy, it might be good to have a companion document, of small size, outlining the results that could be obtained for expenditures of 50 percent or 25 percent of the proposed expenditure. Thus, in the event of a financial hardship, source control could proceed, and still could be meaningful.

My final point is to reiterate what is explained in VI c concerning adaptive management. It is critical that the true success of the projected methods of source control be assessed in a realistic way as time goes by. It is further necessary that any evidence of failure in a specific control strategy lead to the cessation and reformulation of the control strategy, rather than inertial continuation of expenditures on an ineffective strategy. Projects such as this often founder on the inflexibility of the action plan once implementation begins.

Congratulations to the contributors to this work, who did overall a very impressive job in addressing a complicated problem.

William M. Lewis Jr.
9 July 2009

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18

WL-42: The Water Board and NDEP estimate that the resources necessary to achieve required load reductions from the urban uplands will be roughly $100 Million per year for the next fifteen years. While the Water Board and NDEP acknowledge the challenge of dedicating such resources in the current economic climate, the magnitude of the commitment is similar to the amount spent during the past ten years of erosion control, stormwater treatment, and restoration efforts in the Tahoe Basin. The TMDL Implementation Plan requires each implementer to assess its baseline load and devise its own pollutant load reduction strategy to meet the load reduction requirements. Therefore, each implementer can weigh cost as a factor when choosing its load reduction actions for each year.

WL-43: If the annual required monitoring shows that some of the assumptions are incorrect, and if projects and modeling assumptions are not as predicted, adjustments will be made as part of the adaptive management process in the TMDL Management System. The adaptive management component is to evaluate new information and create annual recommendations for adjustments and changes where needed. New text was added to Chapter 12 of the Final Report.

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Lake Tahoe Sediment and Nutrient TMDL

Response to Peer Review Comments

Thomas M. Holsen

Peer Review Received: July 24, 2009

Thomas M. Holsen
Professor
Clarkson University
holsen@clarkson.edu

TO: Douglas F. Smith

FROM: Thomas M. Holsen

SUBJECT: Lake Tahoe TMDL

DATE: Friday, July 24, 2009

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The *Draft Lake Tahoe Total Maximum Daily Load (June 2009)* is a well-written document that explains, synthesizes and summarizes an extremely large and complex group of studies. Leading up to this report separate, extensive investigations of many aspects of the Lake Tahoe ecosystem with regards to water clarity were carried out. Portions of this prior work have undergone extensive peer-review (for example the Lake Tahoe Atmospheric Deposition Study). Clearly there are still many unanswered questions however, taken as a whole, I believe the scientific portion of the proposed rule is based upon sound, state-of-the-art, scientific and technical knowledge, methods, and practices. Given the amount of money available the science program was reasonably used to fill in knowledge gaps and when available, historical data was appropriately used. One criticism of this report is that data from the peer-reviewed published literature was rarely compared to the measurements and modeling results presented (see specific comments below). Never-the-less, the proposed course of action is reasonable and will likely improve the clarity of Lake Tahoe in a cost-effective manner.

Answers to the questions posed to the reviewers are detailed below however it should be noted that my expertise, as it pertains to this study, is in atmospheric deposition. It is that portion of the report that I read the most critically and that generated the most comments.

1. Determination of fine sediment particles (<16 micrometers) as the primary cause of clarity impairment based on interpretation of scientific studies, available data, and the Lake Clarity Model.

The Lake Clarity Model which indicates that clarity loss is primarily due to the number of fine sediment particles suspended in the water column is reasonable based on the data presented. In other lakes inorganic, or minerogenic particles have also been found to make substantial, and in some cases dominant, contributions to light scattering (Davies-Colley et al., 2003; Kirk, 1985; Peng and Effler, 2005, 2007). In a very recent paper nonspherical clay mineral particles in the 1–10 mm size range were found to be the dominant form of light scattering and turbidity in interconnected reservoirs and the intervening creeks in New York (Peng et al, 2009).

References

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2. Identification of the six sources of pollution affecting lake clarity of which urban upland areas was found to be the primary source of fine sediment particles causing Lake Tahoe's clarity loss.

The finding that urban upland areas are the primary source of the fine sediment particles causing Lake Tahoe's clarity loss is justified based on the data and analysis presented. Since this region is relatively remote with limited amounts of traffic and industry this finding makes sense. One shortcoming noted in the discussion of this finding is the lack of comparison to other similar studies in other locations.

3. Determination that the Lake Tahoe Watershed Model was an appropriate model to estimate upland pollutant source loads.

The Lake Tahoe Watershed model is based on an EPA-approved watershed model. It contains a complex system of sub-models including hydrodynamic, ecological, water quality, particle and optical. As with any of these types of models that attempts to simulate complex environmental systems, the underlying physical processes are approximated using mathematical descriptions. A large number of variables are needed to characterize the physical processes, many of which are unknown or poorly constrained. In addition there are usually missing or poorly known input data which also contains errors. To overcome these challenges the error (direct and cumulative) produced in the model prediction is minimized by calibration and the calibrated model is validated using an independent data set. Typically values in the literature are used for variables not known.

Based on the description of the model development, calibration, variables used and validation using an independent data set I believe the model is appropriate for estimating upland pollutant source loads. The model was able to simulate most of the seasonal trends over the five-year period and the results of the sensitivity analysis were reasonable.

4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

Given the fact that two different approaches (USACE and Thodal (1997)) generated loadings estimates that were very similar gives confidence that the loadings estimates are reasonable.

5. Pollutant loading rates from atmospheric deposition directly to the lake surface were quantified and in-basin sources were found to be the dominant source of both nitrogen and fine particulate matter. Direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

Accurately quantifying particle and nutrient deposition, and particularly dry deposition, is extremely difficult. Overall the work summarized and synthesized in this section is a credible effort to quantify these loadings. The shortcomings and uncertainties in the

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Response

TH-1: Characterizing fine particle loading to lakes and reservoirs, for the purpose of understanding light scattering and modeling light attenuation and Secchi depth transparency, has not been widely reported with the notable exception of Steven Effler, Feng Peng (i.e. Peng and Effler (2007) and Peng et al. (2007)) and their colleagues at the Upstate Freshwater Institute in Syracuse, New York. Studies related to understanding fine sediment particle size in urban runoff at Lake Tahoe will be continuing under the Lake Tahoe Regional Stormwater Monitoring Program and research on this topic is currently underway with funding from the Southern Nevada Public Lands Management Act.

approaches used are generally adequately discussed. However often there are too many significant figures used (up to five in Table 4-56 for example) which conveys a sense of certainty that is clearly not justified. Since there is no generally accepted method to measure or model deposition it would be very useful to compare the deposition estimates with the wealth of similar information that is available in peer reviewed literature and also as part of U.S. EPA sponsored networks. For example there are NADP wet deposition data for several sites relatively near Lake Tahoe. A quick review of the NADP CA50 site suggests wet deposition ammonia fluxes are very similar at that site as estimated for Lake Tahoe. There are also CASTNET sites in Yosemite and at high elevations in the Rockies that estimate dry N deposition (although not to water surfaces so they would have to be adjusted accordingly). Both NADP and CASTNET data are available on the web and easily accessible. As another example Ahn and James (Water Air & Soil Pollution, 126,1-2, 2001) discussed P deposition measurements made in S. Florida since 1974. The average mean and standard deviation of the estimated P deposition rates for 13 sites were 41±33 mg P m^{-2} yr^{-1} – virtually the same as estimated for Lake Tahoe. Given the inherent uncertainties in the estimates used in this work comparing them to other measurements would increase the confidence in the results presented.

Other specific comments:

The importance of indirect atmospheric deposition is not clearly addressed. Page 4-111 indicates that pollutants that fall on the land are included in the evaluation of groundwater and upland loading however this topic is not clearly addressed in those sections either.

For completeness there should be more discussion on the importance of what might be called "natural sources" (forest fires, pollen, leaves, pine needles, bird droppings etc) on loadings to the lakes. These sources may be important, although difficult to quantify and control.

Loadings from fugitive dust from vehicular traffic on both paved and unpaved roads may be important. Although this source is discussed in other sections there is limited or no discussion of this source in the atmospheric deposition section.

There was no real source apportionment work done to characterize in-basin vs. out-of-basin sources of atmospheric contaminants. I find this to be a fairly serious short-coming of this work since it could directly address important questions about locations of sources and source-apportionment of atmospheric sources is a fairly well developed science. However the conclusions that most of the dust, N and P is probably from in-basin sources is reasonable given Lake Tahoe's geography and meteorology.

P 4-120 last paragraph. How was it determined that the values are "adequate first estimates"?
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Response

TH-2: Literature was consulted to address this comment and new text was placed in the Technical Report (Section 4.5.4) to acknowledge that the rates of atmospheric deposition of both nitrogen and phosphorus to Lake Tahoe were very similar to values measured in California, the western United States and other places in the world. This comparison with other studies provided high confidence in these findings. As noted in the Technical Report (Section 4.6.2), there is less confidence in the fine sediment particle deposition rates, which led to CARB addressing deposition rates through the LTADS study.

TH-3: Although these quantities are not explicitly quantified, atmospheric deposition to the land is implicitly included in the runoff event mean concentrations (EMCs). It was beyond the scope of the source category analysis to distinguish between atmospheric sources and land-based sources when considering loading from surface runoff. In particular, the sediment and nutrient content in runoff depends on the nature of atmospheric deposition, and changes dramatically as rain or snowmelt travel over the landscape and accumulates pollutants from soil erosion and urbanized land-uses. Furthermore, pollutants that either (1) enter the surface runoff by atmospheric deposition or (2) are entrained into the atmosphere from the terrestrial environment require land-based controls.

TH-4: Based on decades of monitoring and research it was determined that urban and vegetated uplands, atmospheric deposition and groundwater dominate nutrient and sediment input. As part of the new TMDL research stream channel and shoreline erosion were considered for the first time. Inputs such as leaves, pollen, bird droppings, etc. typically will travel through the upland environment (i.e. transported in surface flows) before entering the lake. These should be captured to the extent possible by stream and urban runoff sampling. Colored dissolved organic matter is very, very low in Lake Tahoe (Swift 2004). In smaller lakes where shoreline vegetation is more dominant, these could have a large affect. Because of its great depth and near oval shape (not a dendritic shoreline) and the fact that the subalpine vegetation does not extend to the lakeshore, these "natural sources" were not considered to be critical. Forest fires could have an effect and they have been evaluated during development of the land-use layer for Veg-burned, see Section 4.3.5 under the heading *Model Parameterization by Land-use*. There have only been two large wildfires that have been monitored in the Tahoe basin and wildfires are not only infrequent but largely unpredictable. Finally, the watershed modeling team considered pollutant loading from areas that have been subject to controlled burns and/or wildfires during the 1996 – 2004 modeling time period. A six-year linear recession curve to zero-impact is used to compute the diminishing effects of the burn over time.

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TH-5: Fugitive dust from vehiclar traffic was not studied directly, however analysis was conducted in the Pollutant Reduction Opportunities Report for certain control measures, the load reductions that are potentially achievable and the cost associated with those control measures. Text was added in the Technical Report, Section 4.5.1 to include discussion of why the source category did not distinguish between atmospheris sources and land-based sources when considering loading from surface runoff.

TH-6: The CARB (2006) report acknowledged that a complete characterization of in-basin versus out-of-basin sources of atmospheric contaminants could not be done as part of LTADS. However, the data presented in Chapter 4 of the Technical Report does not depend on the source since the data was intended to estimate atmospheric deposition in comparison with other major sources. The LTADS report gives a good initial estimate of locally generated and regionally transported sources, and this work strongly suggests in-basin sources. It was considered most pragmatic to focus on those air pollutant sources in the basin that could be locally addressed through the TMDL, EIP and TRPA Regional Plan. Since the majority of fine sediment particles come from urbanized sources within the Lake Tahoe basin, it is logical to focus controls in the urban areas.

TH-7: Section 4.5.2 (Page 4-120) of the Technical Report, as well as in other sections (e.g. Section 4.6) emphasized that the estimate of fine soil particles coming from atmospheric deposition contains uncertainty. The phrase "adequate first estimates" was used to signify that while this contains uncertainty, and that replication of these estimates would add to overall confidence, field data was actually collected at Lake Tahoe to look at this very issue. The LTADS data, while a first estimate, was based on site specific data and not theoretical considerations.

TH-8: Results from the DRI dry nitrogen deposition modeling are presented in Section 4.5.2 under the heading entitled, *Comparison to Other Studies*, and as stated, - could not be used in the annual estimates. The DRI data in the Technical Report supports the findings for dry nitrogen deposition made by CARB and UC Davis - TERC. At least for the summer months when there was temporal overlap, the three separate estimates of CARB, UC Davis - TERC and DRI were comparable. This agreement increased the level of confidence in the CARB and UC Davis - TERC estimates of nitrogen deposition used in the Technical Report to calculate whole-lake deposition. In the Technical Report, Section 4.5.2 under the heading *Overview of Dry Deposition Estimation Methodologies*, the units for Equation 3 have been corrected and more information is provided.

TH-9: Text was modified in Section 4.5.2 under heading *Results of Dry Deposition* to present the findings of Liu (2002) and related those to LTADS results.

two sentences of this paragraph are very important and deserve their own paragraph (and probably should be expanded on).
P4-147 last para. I do not believe including unpublished data (Hackey) without a description of how it was collected and a critical evaluation of its accuracy is warranted in a report of this type.
P4-150 bottom. The discussion of only the Lake Tahoe emission inventory is not germane to the section topic of "regionally transported vs local sources." To be useful the total emissions in the basin would need to be compared to regionally emissions.
P4-151 2nd para. "…LTADS also concluded….. It is not clear what "also" is refereeing to. It implies that ammonia deposition it primarily of local origin which is in conflict with the preceding sentence.

P4-152. The statement that constituents of road dust are less soluble than fine particles from wood smoke or other combustion sources needs a reference.

6. Pollutant Reduction Opportunity (PRO) analysis identifies fine sediment particle and nutrient reduction options that can be quantified. The PRO findings offer basin-wide pollutant load reduction estimates and costs for a range of implementation alternatives for reduction loads from urban uplands, forest uplands, stream channel erosion, and atmospheric deposition sources.

The evaluation of pollutant load reduction opportunities for the major pollutant sources is well documented and thorough. The project organization around the four Source Category Groups, led by local and regional experts in their respective fields is well conceived and lends credence to the results obtained. The finding that the largest, most cost effective opportunities for fine sediment particle load reductions are from the urban upland source is a reasonable, well justified conclusion.

7. Lake Clarity Model was the most appropriate for predicting the lake response to changes in pollutant loads.

The Lake Clarity Model, used for estimating Secchi depth in Lake Tahoe, accounts for a number of variables, including algal concentration, suspended inorganic sediment concentration, particle size distribution, and colored dissolved organic matter. The model is a complex system of sub-models including hydrodynamic, ecological, water quality, particle and optical. Some (but not all) of these sub-models have been published in the peer-reviewed literature. Similar to the Lake Tahoe Watershed model the model was calibrated and then validated using an independent data set.

Based on the description of the model development, calibration, variables used and validation using an independent data set I believe this model is appropriate for predicting the lake response to changes in pollutant loads. The model was able to simulate historical Secchi depths and the predicted responses to changes in loads are reasonable. The discussion on pages 6-42 through 6-44 that substantiate the reasonableness of the model are convincing.

8. Allocation of allowable fine sediment particle and nutrient loads is based on the relative magnitude of each pollutant source's contribution and the estimated ability to reduce fine sediment particle and nutrient loads.

two sentences of this paragraph are very important and deserve their own paragraph (and probably should be expanded on).
P4-147 last para. I do not believe including unpublished data (Hackley) without a description of how it was collected and a critical evaluation of its accuracy is warranted in a report of this type.
P4-150 bottom. The discussion of only the Lake Tahoe emission inventory is not germane to the section topic of "regionally transported vs local sources." To be useful the total emissions in the basin would need to be compared to regionally emissions.
P4-151 2nd para. "…LTADS also concluded….. It is not clear what "also" is referencing to. It implies that ammonia deposition it primarily of local origin which is in conflict with the preceding sentence.

P4-152. The statement that constituents of road dust are less soluble than fine particles from wood smoke or other combustion sources needs a reference.

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Response

TH-10: The data is contained in Hackley et al. (2004, 2005) and the text in Section 4.5.4 of the Technical Report has been updated. These data are part of the Lake Tahoe Interagency Monitoring Program (refer to Chapter 1 for a brief description of this program).

TH-11: The text in Section 4.5.5 of the Technical Report has been modified to include a discussion of locally-generated and regional-transportation of atmospheric pollutants, based on the LTADS report (CARB 2006).

TH-12: The word 'also' has been deleted in Section 4.5.5 of the Technical Report under the heading *Summary of LTADS Conclusions Regarding Atmospheric Sources*.

TH-13: Section 4.5.5 of the Technical Report was revised and unsupported statements were deleted from the text.

The Recommended Strategy for achieving load reductions builds on the Pollutant Reduction Opportunity analysis and incorporates detailed scientific investigation and extensive stakeholder input. Because the urban landscape contributes the largest percentage of the fine sediment particle load and because urban stormwater controls represent the greatest control opportunity, urban stormwater dischargers rightly bear the brunt of the reduction responsibility (approx 25% of the 32% total reduction or approx 75%). Forest upland, stream channel erosion and atmospheric deposition load reductions make up the remaining 25%. Overall the findings are well documented and reasonable.

Other minor comments:

The 3rd paragraph on page 3-7 (vertical mixing increases transparency) contradicts the last paragraph on page 6-3 (mixing decreases transparency). This should be rectified.

Page 8-5. There are several typos in the 1st paragraph

Table 8-3 page 8-6. Why are N+P controls less effective than N and P controls by themselves? (Maybe there are too many significant figures used in this table.)

Page 9-5 and elsewhere. It is indicated that street sweeping will be used to capture 10 µm particles – don't you mean particles <10 µms?

Response

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Table 8-3 page 8-6. Why are N+P controls less effective than N and P controls by themselves? (Maybe there are too many significant figures used in this table.)

TH-14: The modeled values for nitrogen, phosphorus, and nitrogen plus phosphorus in Table 8-3 in the Final Report, Section 8.3.2 are not significantly different from each other. Therefore, no difference in effectiveness is implied in the table. However, these three modeled values are significantly less than fine sediment alone and much less than the combination of fine sediment and nutrient load reductions together. The number of significant figures has been corrected in Table 8-3 of the Final Report.

Page 9-5 and elsewhere. It is indicated that street sweeping will be used to capture 10 µm particles – don't you mean particles <10 µms?

TH-15: Considering the variability in street sweeping technologies, the Lake Tahoe Total Maximum Daily Load report has been edited to replace references to capture of a specific particle size with references to "PM10-efficient street sweepers."

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Lake Tahoe Sediment and Nutrient TMDL

Response to Peer Review Comments

Patrick L. Brezonik

Peer Review Received: July 25, 2009

Lake Tahoe Total Maximum Daily Load
Review

Patrick L. Brezonik

Overview

The Lake Tahoe TMDL study and its reports associated are evidence for the highly complicated and extensive efforts underway to protect and restore water clarity in a lake that is a national treasure. The technical efforts have involved hundreds of scientists, engineers, and other professionals in studies encompassing most of the present decade. The analysis leading to the recommended goal and strategy to achieve it relied on collection of new data, analysis of old and new data, and especially an extensive modeling component. Overall, my conclusion is that the work was performed carefully with considerable amount of oversight and review. State of the art techniques were employed in data collection and analysis and in the various modeling efforts. The reputations of the leading participants are sound, and many of the individuals, firms and institutions involved are well known internationally and highly respected in their fields. The study has involved considerable public input and stakeholder involvement, and much attention has been paid to developing a long-term strategy for the implementation plan that appropriately involves a sophisticated adaptive management strategy.

The watershed and in-lake modeling efforts used current modeling techniques and are impressive in their attention to detail. Although I describe some technical issues and concerns about the methods and results of these modeling efforts later in this review, I want to emphasize here that I recognize the huge amount of work that went into these components of the TMDL study and believe they constitute a "state-of-the science" effort.

This review first addresses some important technical issues and concerns I found in reading the TMDL document and associated technical report. Next, based on my reading of the documents and in reference to the technical issues mentioned above, I address the eight issues posed to reviewers in the June 4, 2009 revision of Attachment 2 to the memorandum from Douglas Smith, Chief of the TMDL/Basin Planning Unit to Gerald Bowes, State Water Resources Control Board (dated November 12, 2008). Finally, I list some smaller technical issues, wording problems and typographical/formatting issues I found in the TMDL documents. I want to emphasize that I did not view my responsibilities as a reviewer to focus on the latter problems, and the list is not intended to be a comprehensive enumeration of such errors in the report.

Important Technical Issues

1. ***Is the goal really reasonable given climate change is occurring?*** Given the scenario painted on pages 12-7 and 8 of the TMDL, I wonder whether it is reasonable to have a clarity standard based on historical climatic conditions. Would it not be more realistic to accept that the described changes in climate—e.g., on the mix of snow/rain in precipitation, on increasing erosion from the greater proportion of precipitation falling as rainfall, and the other climate change impacts described in this section—would cause Lake Tahoe to have a different transparency even if there were no people living in the basin? I believe the TMDL should be written explicitly to account for this likelihood. Perhaps the initial target value does not need to be changed, but the documented climate changes in the region over the past 20-40 years (mentioned in the second paragraph on p. 12-8 of the TMDL) suggests that perhaps this should be considered. At the least the TMDL should acknowledge that the target should be a "climate-normalized" nondegradation standard.

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Response

PB-1: Scientific investigations regarding the potential impact of climate change on Lake Tahoe water quality have only recently started. There is a strong dataset on historic lake temperature (Coats et al. 2006) to show a statistically significant change since measurements began in 1970. The science community - while working on this issue - is currently not in a position to predict the actual limnological impacts of climate change on Lake Tahoe with an acceptable degree of certainty. The concern of how the TMDL will operate within an environment where climate change can affect lake processes led to the climate change section in the Final Report. The transparency target will be 'climate normalized' and will be evaluated within the adaptive management process. As discussed in the Final Report the intent is to establish 5-year milestones for transparency. These milestones will be supported by estimates of pollutant load reduction (based on modeling and field data). If the predicted Secchi depth is different from the measured values during those five years, the adaptive management process will consider possible reasons for the difference (e.g. model refinement needed, estimates of pollutant load reduction need refinement). Another possible reason for a difference could be an affect from climate change. The lake monitoring program is sufficiently robust to identify changes in lake mixing resulting from temperature changes. Lake Tahoe has a rich history of research and monitoring which is expected to continue well into the future. However, it is understood that an alteration to lake may not be evident for 20+ years. Instead of trying to use a prediction of climate change to develop the TMDL, science and monitoring data will be relied on to inform the adaptive management framework for the TMDL.

2. ***Optical modeling in Lake Tahoe.*** Because the TMDL is based on a loss of water clarity (or transparency) in the lake, work related to predicting the effects of various lake conditions and concentrations of substances affecting Secchi depth are of critical importance to the credibility of the conclusions and goals stated in the TMDL document. The optical model thus is a critically important aspect of TMDL development for Lake Tahoe, and it needs to be described in much greater detail than it is in the TMDL document (hereafter referred to as "the TMDL"), where it is mentioned only in passing on page 8-2, or in the Technical Report (hereafter referred to as TMDL-TR), where it is described in one short sentence on page 3-14, paragraph 3. Readers (and reviewers) should not have to go to the original literature for such an important component of the study. The TMDL-TR gives a table of parameters used in the optical model in section 6, which helps a little to give an understanding of what is involved in the model, but this still is not sufficient to be able to evaluate the model.

3. ***Accuracy of predicted Secchi depth values and effects of stratification***. I consider the difference between measured and simulated in 2000 in Table 8-X (TMDL, p. 8-4) to be quite large, in spite of the fact that the table heading states the numbers are in good agreement. Overall, comparing the differences as percentages of the measured values is not very useful because the measured values (the denominator term) are high, leading to seemingly small percentage differences that actually are large (> 1 m, on average) in an absolute sense. A more appropriate analysis would indicate that the simulated values consistently overestimate SD, and the average overestimation is 1.4 m over the five years. Giving a standard deviation for the difference also would be useful. This difference is fairly large relative to the overall change in SD over the period of record and even larger relative to the hoped-for improvement in transparency over the next 20 years.

The effects of thermal stratification on lake transparency and timeframe of particle settling in relation to stratification are discussed in several places in the TMDL and TMDL-TR, but the statements are not always in agreement. For example, the last statement in the second paragraph on page 3-14 of the TMDL-TR seems to contradict the statement on the previous page about a decadal time frame for particle settling. It would seem to me that settling should be even more rapid in the quiescent waters below the thermocline than in the upper (mixed) layer. It is important that the discrepancy between these two statements on settling times be resolved. Similarly, the statement on page 3-20 (third line from bottom) seems to contradict earlier arguments about the slow settling of particles and about the negative impacts that deep waters have on transparency.

I also am concerned that the TMDL makes it sound like increased thermal stability and lake stratification can only make matters worse relative to lake transparency (page 12-9). I do not accept this. Increased stratification could decrease the residence time of fine particles in the top most stratified layer, particularly if the increased stability leads to a shallower thermocline. No evidence is provided that the bottom waters would become anoxic or even hypoxic in 20 years, and those are the critical conditions for increased P release from sediments. Although an infrequent (every 20 years) deep mixing event may cause a significant algal bloom, it most likely would be short-lived—a transient phenomenon.

4. ***Watershed modeling***. Overall, the TMDL and TMDL-TR have very detailed coverage of the extensive modeling that was done on export of nutrients and fine particles from the Lake Tahoe watershed, but I have several concerns and questions. First, I am aware that all municipal wastewater is exported from the drainage basin, but I wonder what happens to solid residuals (sludge) from water treatment plants. Also, many water treatment plants add phosphate to water to prevent corrosion problems and many plants also add ammonium as part of chlorination. If either of those practices occurs in water treatment within the Lake Tahoe drainage basin, they could contribute N and P loadings to the lake since not all the municipally treated water gets exported from the basin (e.g., some is used for lawn watering, etc.). Table

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Response

PB-2: Text has been added to the Technical Report in the beginning of Chapter 6 indicating where more detailed information can be found on the Lake Clarity Model. Readers who are interested in a detailed description of the actual development of the Lake Clarity Model, including model structure, algorithm development, selection of rate coefficients and model parameters are encouraged to read Sahoo et al. (2006). Sahoo et al. (2006) built upon Perez-Losada (2001), the original source that documented the development and structure of the Lake Clarity Model. Sahoo et al. (2006) was provided to the external peer reviewers as a supplement document.

PB-3: Given that the seasonal swing in Lake Tahoe's Secchi depth can be as much as 15 meters and that the annual average value is sensitive to annual precipitation conditions, the agreement between the annual modeled and measured Secchi depth in four of the five years analyzed was considered very good. The mean percent difference during those four years (2001-2004) was less than five percent. This corresponded to a value of just less than one meter (0.98±0.71 meters) in terms of an absolute difference. While one meter of Secchi depth is very large for most lakes, it is not necessarily the case for Lake Tahoe with its mean annual value of 20-25 meters. Jassby et al. (1999) compared two independent viewers recording Secchi depth simultaneously based on 217 sampling dates. Based on visual observations, the difference in Secchi depth reading could be on the order of 0.32-0.40 meters. The year 2000 appeared to be an anomalous year when the relative difference between modeled and measured average annual Secchi depth was 16 percent of 3.25 meters. The text in Section 6.2.2 of the Technical Report discusses possible factors leading to the difference seen in 2000. As part of the TMDL management strategy this model will not be used to predict Secchi depth; rather, the detailed field measurements will continue to be taken and the actual field data will be used to monitor progress towards meeting TMDL goals whether they are the 20 year Clarity Challenge or the effort to return transparency to its existing water quality standard of nearly 30 meters. Consequently, the goal of the Lake Clarity Model is to help guide a reasonable control strategy. As discussed in the Final Report, the ability of the Lake Clarity Model to predict transparency based on actual, implemented pollutant controls will be evaluated within an adaptive management framework.

PB-4: There is a distinction between the estimated settling time of a few months for particles and the longer settling velocities for nitrogen and phosphorus. As noted, nutrients are mineralized from particulate organic matter and recycled as they settle in the water column. As a result there is a longer residence time for these nutrients in the water column. The transport of particles as reported by Sunman (2001) refers only to the particle matrix itself and not the associated nutrients. Jassby (2006) modeled particle deposition for Lake Tahoe and found that particle aggregation increased the rate at which particles themselves settled. Text was added to the Technical Report in Section 3.4.1 to clarify this issue.

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Response

PB-5: A new scientific paper came out (Sahoo and Schladow 2008) since this section was written that models the expected future lake mixing patterns in Lake Tahoe under climate change conditions, new information has been added to the text in Section 12.2 of the Final Report. While there has yet to be research on the topic of whether or not the bottom waters of Lake Tahoe will go anoxic over a 20 year period of no mixing, the purpose of this section is to identify areas that might require attention under an adaptive management framework.

PB-6: Text has been added to the Technical Report, Section 4.1.5 to indicate that all sewage (solid and liquid) is exported out of the basin, so the exported materials were not counted as a source. The municipal water purveyors do not add ammonium as part of chlorination but at <1.0 parts per million (ppm) sodium hypochlorite for disinfection into their water delivery system. Most water purveyors do not add phosphate for corrosion protection, except about 10% or less of all water lines have zinc orthophosphate added, usually at concentrations <1ppm. USACE (2003) concluded that exfiltration is not a significant source of nutrients to Lake Tahoe. Adding low concentrations of zinc orthophosphate to <10% of all water delivery pipes is considered an insignificant potential source of phosphorus.

4-2 and associated text of the TMDL-TR at least should mention these potential sources and also should note that wastewater wasn't considered because it is exported from the basin.

Second, the EMC multiplying factor used to calibrate fine sediment loads (pages 4-62 and 63 of the TMDL-TR) seems rather arbitrary and empirical, and no explanation is provided for its basis (other than that it seemed to work). Some effort to explain the need for this empirical factor would seem to be appropriate. I note that the factor has a large range (> 6) and so it has a large effect on predicted loads. The same criticisms apply to the scaling factor based on quadrant.

Third, I always find graphs like Figures 4-27 to 4-29 of the TMDL-TR troublesome, especially when they are presented to illustrate "how well" the simulations fit to measured data. It is difficult to tell from the figures, especially in any quantitative sense, how good or poor the fit actually is, but it appears that the fit is not good in terms of simulating either the timing of events or the variability in the data. This is especially the case for 2000-2001 for all three modeled constituents. About the best one can say from these figures is that the simulated values are in the "same ballpark" as the measured values. Perhaps that is sufficient for the purposes of the TMDL study, but if that is the case, I doubt that the time and effort that went into developing such a comprehensive and detailed modeling approach can be justified. Simpler approaches that didn't try to model and portray short-term variability would have been sufficient. If the authors want to show how well (or poorly) the model simulates reality, they should present plots of simulated versus measured concentrations (scatter plots) and show the statistics (r^2 values) that quantify the degree to which the simulations explain the variance in the measured data. I suspect such plots would show poor fit of individual simulated values to measured values. I accept the arguments made in various places in the TMDL-TR that the goal was not to simulate individual measurements and that it is very difficult to achieve that, but some larger-scale statistics could and should be produced to show whether the simulations capture key features of the measured values at the time scale of a year (e.g., annual means and ranges, and annual variance).

Finally, the regressions of Rabidoux (2005), described on p. 5-5 of the TMDL-TR, to predict particle fluxes as a linear function of stream flow involve a self-correlation. Particle flux (P) is a product of particle concentration, C_P, (in stream water) and stream flow, Q; i.e.:

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The regressions thus implicitly are C_P*Q versus Q, which is a correlation of a variable with a function of the same variable. Depending on the ranges of C_P and Q this could lead to spurious self-correlations. The authors need to examine whether in fact this occurred in Rabidoux's analyses. There are straightforward statistical techniques for deciding whether this is a serious problem or not.

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Response

PB-7: The reasoning behind these multiplication factors was empirical and based on the observation that the behavior of granitic and volcanic soils are different. In a series of papers by Grismer and Hogan (2004, 2005a,b) who studied soil erosion in the Lake Tahoe basin using a portable rainfall simulator, they reported that runoff rates, sediment concentrations and sediment yields were greater from volcanic soils as compared to that from granitic soils for nearly all vegetated cover conditions tested. The first set of multipliers was therefore related to the soil composition, to account for areas with volcanic soils having larger unit area loads than areas with granitic soils. Given that Grismer and Hogan (2004) found that sediment yield from bare volcanic soils ranged from 2-12 g $m^{-2}mm^{-1}$ as compared to 0.3-3 g $m^{-2}mm^{-1}$ for granitic soils, the range of multipliers determined in Figure 4-26 appears reasonable. The second set of multiples, by quadrant, is empirical, but was necessary to account for differences seen in loads from streams in different locations of the lake. These quadrant multiplication factors came from the calibration process. The sensitivity of the Lake Tahoe Watershed Model and the nature of the stream monitoring data provided by the Lake Tahoe Interagency Monitoring Program (10 monitored streams) was not sufficient to customize loading for each of the lake's 63 tributaries and assumptions were required. New text was added to the Technical Report in Section 4.3.5 under the headings *Model Parameterization by Land-use* and *Water Quality Calibration Process* with the above information.

PB-8: There is agreement that papers/reports on water quality modeling often show plots of observed and simulated results without further analysis. This is often unsatisfactory to readers and reviewers and it is why a more direct comparison of the output from the Lake Tahoe Watershed Model versus the measured data from the Lake Tahoe Interagency Monitoring Program (LTIMP) was developed and presented in Table 4-41. The goal was not to simulate individual measurements. Given the changes measured in Lake Tahoe and the high interannual variability in precipitation and hydrology, an annual comparison was chosen considering the monthly-seasonal values were realistic. As stated in the Technical Report (Section 4.3.6 under the heading *Lake Tahoe Watershed Model versus Lake Tahoe Interagency Monitoring Program Loading Comparison*), while there was some difference between the LTIMP and Lake Tahoe Watershed Model (LSPC) values for certain tributaries and for certain nutrient species (e.g. Blackwood Creek dissolved inorganic nitrogen (DIN) and Ward Creek soluble reactive phosphorus(SRP)), there was very good agreement, especially when considering the combined sum for the 10 tributaries (Table 4-41). The relative percent difference (LSPC-LTIMP)/(mean of LSPC and LTIMP) was between 10 − 14 percent with the exception of SRP which was much higher at 60 percent. The difference between LTIMP field data and LSPC modeled output for SRP was greatest for the Upper Truckee River, Ward Creek and Blackwood Creek. While these differences require further investigation, the Lake Clarity Model considers biologically available phosphorus which is derived from both SRP and a fraction of total phosphorus. Assuming all SRP is bioavailable and that approximately 20 percent of the remaining phosphorus is bioavailable (Ferguson 2005), an approximation of bioavailable-phosphorus from the10 monitored streams shows the relative percent difference between LTIMP and LSPC was reduced to 25 percent.

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Response

PB-9: Rating curves were constructed with measured particle size data and the corresponding instantaneous streamflows using the Bradu-Mundlak Estimator, which is a statistically unbiased rating curve method (Cohn et al. 1989). Rabidoux (2005) considered this issue of self-correlation. Initially particle concentrations (C) were regressed against instantaneous flow (Q); however, the R^2 values were very low ranging from 0.00 - 0.74 (mean±sd = 0.24±0.22) and this range is not unlike what is seen in other systems (e.g. Braun et al. 2000; Schoellhamer and Wright 2003). Instead, particle flux (#/sec) was regressed against Q yielding higher R^2 values. As noted, this may in part be due to auto-correlation since Q is considered as part of particle flux. There is a large amount of natural variability in sediment transport measurements compared with the transport of dissolved constituents. This is exacerbated since the LTIMP monitoring program deliberately attempts to capture high flow events when variability in sediment transport is the largest. The impact of hysteresis, which can never be adequately resolved by episodic measurements (as opposed to continuous measurements), results in a large degree of scatter in the data (the same flow rate yielding different concentrations during different events). Consequently, a straight regression of C vs Q, while strictly correct, does not necessarily add much meaning in this particular circumstance. Considerable variability has been seen by others when comparing streamflow total suspended sediment concentration. The finest fraction (<16 microns) is considered and little is known about the variation in that range.

An approach explored by Rabidoux was to use the correlations of C vs. Q and then simply multiply by Q to get the flux. This yielded essentially the same fluxes as when CQ vs. Q correlations were used (with their seemingly higher correlation coefficients). Therefore, for ease of use, this second approach was adopted.

PB-10: A brief overview of methodology used to distinguish between local and regional sources for wet deposition has been added to Section 4.5.5 of the Technical Report. The Lake Tahoe Atmospheric Deposition Study (CARB 2006) provides the detailed analysis used to distinguish between local and regional sources for wet deposition. While particulate matter shows a large increase in the relative contribution (i.e. percent of total deposition) from regional sources in the summer and fall (Table 4-64), the absolute amount of each of the particulate matter size classes during this period was only 15-20 percent the total annual load from wet deposition (Table 4-61). Given that the minimum, long-term, Secchi depth typically occurs in Nov-Dec and again in May-June regional particulate matter deposition in the summer-fall is having an important affect on lake transparency.

Second, it is not entirely clear to me what the basis is for the expectation that watershed management will be sufficient to meet atmospheric load reductions, as is stated in the TMDL on page 11-13. The text notes that the majority of fine particles from the atmosphere are generated by urban roadways. As a minimum, the effectiveness of controls on particle loads from these roadways in decreasing atmospheric loadings will depend on the nature of the controls on stormwater from the urban roadways. If the controls primarily involve treatment of roadway runoff in detention/retention ponds, this will have no effect on the extent to which the roadways generate fine particles that are swept into the atmosphere during periods when it is not raining. Increased frequency of street sweeping could help decrease atmospheric loadings of fine particles derived from roadways, but it would have been useful to see a more thorough analysis of this.

6. ***Feasibility of adjusting the management plan in response to wildfires and climate change.*** Just because wildfires are sporadic does not to me seem adequate justification for excluding them from consideration in loading targets and management plans, as the TMDL states on page 12-11, first paragraph. It seems likely, given what the report describes concerning the consequences of climate warming, that wildfires will be more prevalent in the future than they have been in the past. At least the TMDL should acknowledge this and indicate that it will be considered as a part of the adaptive management program.

It will be very difficult to adjust the management plan to changing climate over the 20-year timeframe of the clarity challenge because of inherent noise in climate data. For example, five years of above average temperatures and below average precipitation could be followed by five years of below average temperatures and/or above average precipitation. The signal of increasing global CO_2 is apparent at near annual resolution from the long-term record in Hawaii, but the signal of climate change is not apparent anywhere near this level of resolution, especially for specific geographic areas. At best, I think the managers might be able to see a change in climate at the end of the 20-year challenge period and adjust their goals and management plans for the next 20 years accordingly. However, even this is not a certainty. The text should be modified to reflect the strong likelihood that we will not be able to see long-term climate changes within the timeframe of the initial implementation period (really the first 15 years of the challenge period).

7. ***Consistency in methods for long-term data.*** The report uses some of the valuable long-term data collected on Lake Tahoe, but it does not indicate whether consistent methods were used to obtain the results over the entire period of record. For example, in discussing trends in primary production, the report indicates a significant increase over time since Goldman's original measurements in the 1959 (TMDL, page 3-4, line 2 from bottom; Figure 3-5). I wonder whether the same measurement methods were used throughout this time period. Are the earlier results really comparable with the later ones? The text should comment on this. Similarly, the TMDL-TR (page 4-18, first paragraph) compares fertilizer use in the basin in 1972 with current or recent rates. One wonders whether the 1972 data were underestimates. If so, perhaps fertilization rates have not increased so markedly in the basin. Some attention to this possibility seems in order.

8. ***Monitoring issues.*** Future monitoring activities on Lake Tahoe are described in the TMDL in the second paragraph on page 13-8. I recommend that the monitoring program add pH, specific conductance, and DOC/TOC as routine measurements and annual measurements of major ions (including alkalinity), iron and manganese. None of these is expensive to measure, and they will add greatly to the usefulness of the long-term database. Specific conductance and pH are very basic limnological parameters measured in nearly all chemical studies. DOC is related to transparency, at least indirectly.

Given the huge budget problems facing the state of California, one wonders how certain the authors of the document are (or can be) that the LTIMP tributary monitoring described on page 13-9 of the TMDL

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Response

PB-11: Although the Water Board and NDEP cannot specify how responsible parties will achieve needed load reduction within the urban areas, greater street sweeping frequency with efficient vacuum sweepers is expected. Unpaved parking areas, construction projects, and unpaved forest roadways have also been identified as significant sources of fine sediment particles that reach the lake through atmospheric deposition. Existing regulations that require best management practices for construction activities and for commercial properties are expected to reduce the atmospheric fine sediment particle load. Similarly, the U.S. Forest Service LTBMU and other forest management agencies have active programs to reduce the number of unpaved forest roadways in the Lake Tahoe basin. The Lake Tahoe TMDL Implementation Plan relies on these existing plans and polices to achieve needed atmospheric deposition pollutant load reductions.

PB-12: Since the early 1900s, the occurrence of large wildfires in the Lake Tahoe basin has been significantly reduced due to an effective fire control program (Heyvaert 1998). Consequently, (1) there are very few instances where the affect of wildfire on water quality has been documented and (2) our confidence in knowing how a future wildfire would affect sediment and nutrient loading to Lake Tahoe is limited. As discussed in Section 12.3 of the Final Report, only the Gondola Fire (2002) and most recently the Angora Fire (2007) have been monitored. The water quality studies associated with these two events are much too limited to allow us to predict pollutant loading at any location in the Tahoe basin. As is the case for climate change, that there was too much uncertainty to directly incorporate wildfire into loading targets. Most importantly, wildfires are stochastic events and not predictable. In light of this there would be no basis for including the timing, duration, coverage, severity, or location of a wildfire in simulations of future conditions. Instead, it was the intention of the Final Report to convey that wildfires will be considered as part of the 5-year milestones within the adaptive management program. Data collection from the Angora Fire is only two years old at this point; however, should another wildfire occur the Gondola Fire and Angora Fire data along with site-specific monitoring data and an updated fire component to the Lake Tahoe Watershed Model will all be used to evaluate potential ramifications to load allocations within the TMDL.

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6. ***Feasibility of adjusting the management plan in response to wildfires and climate change.*** Just because wildfires are sporadic does not to me seem adequate justification for excluding them from consideration in loading targets and management plans, as the TMDL states on page 12-11, first paragraph. It seems likely, given what the report describes concerning the consequences of climate warming, that wildfires will be more prevalent in the future than they have been in the past. At least the TMDL should acknowledge this and indicate that it will be considered as a part of the adaptive management program.

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Response

PB-13: The natural variability in precipitation could create multiple years of wet or dry conditions and this could mask the more subtle year-to-year changes caused by climate change. It is difficult to incorporate climate change directly into the formulation of a clarity standard-TMDL target. The 20-year time table for the Clarity Challenge is based on what has been determined to be a reasonable goal to confirm a noticeable improvement in lake transparency. Actions to require additional pollutant reduction will extend beyond that 20-year period until the water quality standard of 29.7 meters is reached. Consequently, the time frame for considering the impact of climate change on Lake Tahoe will extend well beyond the initial 15-20 year implementation period. Continued long-term monitoring as well as using the existing Lake Clarity Model to predict the possible magnitude and timing of a climate change induced impact to Lake Tahoe will be important to support. The Lake Clarity Model is currently being used for this purpose as part of a research grant funded by the Southern Nevada Public Land Management Act (SNPLMA). When complete, this work will inform us as to what might be expected and over what time frame. All this type of information will be incorporated in the TMDL Management System (adaptive management program) and if needed in the future, adjustments to the program will be made based on new knowledge.

PB-14: Regarding limnological methods such as primary productivity and Secchi depth measurements, the protocols have largely remained consistent over the period of record. Programs with long-term data collection must face the fact that as technology improves and improved approaches for making field and lab measurements are developed, a switch in methods can possibly affect trends if the new and old data sets are not comparable. The UC Davis Lake Tahoe limnology program is very aware of this and has been careful to eliminate these types of uncertainties to the extent possible. Additional text has been added to the Final Report in Section 3.4.1 regarding consistent data collection methodologies for the long-term data. It is difficult to know if fertilizer application was under or over estimated in either the 1972 or the 2003 studies. The calculations for fertilizer application are relatively straightforward, i.e. loading estimates in both studies were primary based on the land-use specific recommended application rates, the nutrient content of the fertilizer in use, and the amount of land receiving fertilizer. The availability of GIS allows the estimation of the amount of land that could receive fertilizer to be more accurate. While the USACE (2003) Groundwater Evaluation report liberally assigned fertilizer use to a portion of the land area of all single-family homeowners in the Lake Tahoe basin, the values from the remaining land-use areas were considered by USACE (2003) to be based on realistic rates. This is discussed in Section 4.1.5 of the Technical Report. The USACE report stated that "the method for determining the percent fertilized land area for each category was based on historical reports (Mitchell 1972) and sound judgment." Furthermore, it is important to note that the current TMDL analysis does not depend on an increase in fertilizer use over time, but rather on the current use. The goal of the TMDL, in part, is to develop an approach for reducing existing pollutant loading.

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Response

PB-15: An investigation by Swift (2004) showed that CDOM had very little influence on Secchi depth and other lake optical properties in the open-water pelagic zone. Consequently, sampling for DOC/DOM has not been done in that region. However, depth profiles for particulate carbon and nitrogen are routinely taken as part of the UC Davis/Lake Tahoe Interagency Monitoring Program (lake sampling). In addition, it is possible that DOM/DOC may affect lake clarity in the nearshore region as urban stormwater and wetland flow drain into Lake Tahoe. Resource agencies and researchers in the Lake Tahoe basin are currently (2010-2011) designing a more detailed nearshore monitoring plan that should include this constituent. Furthermore, a UC Davis graduate student is currently measuring DOC/TOC in the lake and its water sources as part of a research project. Data from that study will help to determine if the current monitoring program requires revision. *In situ*, specific conductance is also measured routinely by UC Davis limnologists using and submersible sensor (Seahbird). However, pH is not routinely measured and the lake is well-buffered compared to other regional lakes.

PB-16: Monitoring and research in the Lake Tahoe basin has been funded and highly supported for decades at the local, state and federal levels. Resource agencies, in partnership with the Tahoe basin scientists and the Tahoe Science Consortium (http://www.tahoescience.org/) are currently involved with an extensive re-evaluation of the resources available for funding monitoring as compared to agency/science needs. The Regional Stormwater Monitoring Program (RSWMP – as discussed in Section 13.2.2 in the Final Report) is also considered a very high priority. The details associated with any need to modify monitoring programs will be discussed among implementing partners and stakeholders to ensure the data is providing for loading (or load reduction) evaluations.

will continue to provide data that can be used to assess the effects of load reduction measures. I think this issue needs to be addressed explicitly in the report.

9. ***Need for more specificity and examples in citing shifts and trends.*** In several places the reports the report describes shifts that apparently have occurred in certain characteristics in the lake but the text is vague on the magnitude of the shift. Inclusion of some numbers would be useful to put the comments into perspective. An example related to thermal stratification is on page 3-8, line 3 of the TMDL. Similarly on line 9 of the same page, the text is vague about the shift in the deep chlorophyll maximum. Some vertical profiles illustrating the change would be useful (or referencing where they may be found in an accompanying document would help).

Review Issues Requested by California Regional Water Control Board—Lahontan Region

The request to review the Lake Tahoe TMDL and associated documents requested responses regarding eight issues of primary concern. In each case the reviewer was requested to determine whether the scientific portion of the proposed Basin Plan Amendment (related to the stated issue) is based upon sound scientific knowledge, methods, and practices. The eight issues are listed in bold below followed by my analysis and conclusions.

1. Determination of fine sediment particles (< 16 µm) as the primary cause of clarity impairment based on interpretation of scientific studies, available data, and the Lake Clarity Model.

The reports provide sufficient evidence based on field studies and analysis of historical data that fine particles (< 16 µm in diameter) are the primary cause of clarity impairment in Lake Tahoe. Actually, the reports provide evidence that clarity is affected primarily by particles ≤ 5 µm in diameter. The reports also demonstrate that the clarity reduction is caused by fine (mostly inorganic) particles exported from the watershed and also deposited directly onto the lake surface by atmospheric wet and dry deposition, as well as by in-lake generated particles produced by phytoplankton growth. To some extent, the study relies on the seminal findings of Jassby et al. 1999 to make the case for the importance of inorganic particles of watershed and atmospheric origin, but I think sufficient data are presented in the TMDL documents to make the case. By use of the Lake Clarity Model, the researchers were able to make predictions of what would happen to lake clarity under a range of scenarios of nutrient and fine particle loadings to the lake. The work related to this issue is based on sound science and widely accepted scientific methods.

2. Identification of the six sources of pollution affecting lake clarity of which urban upland areas was found to be the primary source of fine sediment particles causing Lake Tahoe's clarity loss.

Based upon my review of the TMDL and TMDL-TR, I conclude that the study adequately and appropriately identified the six main sources of pollution affecting Lake Tahoe water clarity and was correct in assessing urban upland areas as the most important of these sources. The work described in the reports was based on sound and currently accepted scientific methods, as described elsewhere in this review. I agree that the reliability of the estimates was checked, where possible, by using several independent methods of analysis or calculation. Of course, there is a stronger database and much longer historical record available to assess the contributions of nutrients than fine sediment particles, but my assessment is that the study was adequate to address this specific issue.

3. Determination that the Lake Tahoe Watershed Model was an appropriate model to estimate upland pollutant source loads.

Response

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PB-17: New text and figures were added to the Technical Report, Section 3.4.2 to include information on annual Chlorophyll *a* concentrations (or phytoplankton) (Figure 3-14), the annual deep chlorophyll maximum data and trends (Figure 3-15), the annual depth of mixing (Figure 3-16), and the volume averaged temperature with trendline.

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PB-18: As highlighted in the Technical Report in Section 3.4.1, it was the optical model developed by Swift et al. (2006) that created the supportive documentation that (1) validated the hypothesis in Jassby et al. (1999) that fine sediment particles were important with respect to Lake Tahoe transparency and (2) developed the optical submodel that was incorporated into the larger Lake Clarity Model.

2. Identification of the six sources of pollution affecting lake clarity of which urban upland areas was found to be the primary source of fine sediment particles causing Lake Tahoe's clarity loss.

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3. Determination that the Lake Tahoe Watershed Model was an appropriate model to estimate upland pollutant source loads.

The Lake Tahoe Watershed Model is based on several existing components that have been accepted and used by others and were adapted and further developed for application to the drainage basin of Lake Tahoe. As indicated elsewhere in this review, the reports describe in considerable detail the work done to develop and use this model. Although I have a few specific concerns about the way the model was used (e.g., see item 4 of the previous section), I do not have any concern that the model was inappropriate or represents a less than "state-of-the-art" approach to modeling pollutant export from watersheds. The university and firm that conducted much of the watershed modeling work are well respected institutions, and based on evidence provided in the text, I conclude that the model development was carefully done.

4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

I preface my conclusions on this issue with two initial remarks. First, I do not consider myself to be an expert on ground-water modeling. Second, the TMDL and TMDL-TR documents rely heavily on the U.S. Army Corps of Engineers study (USACE 2003) and mostly summarize what is reported in that document. The TMDL documents do not provide the level of detail on ground-water loading estimates provided on watershed modeling. Consequently, I was not able to perform a thorough, independent review and analysis of the technical details on ground-water nutrient loadings. Nonetheless, the descriptions provided in the reports indicate that the USACE work was competently and carefully performed, with attention to issues of heterogeneity in the ground-water aquifers of the basin. The concentrations of nutrients reported for the aquifers and the nutrient loading rates appear to be reasonable. It also was reasonable for the study to assume that ground water is not a source of fine particles to Lake Tahoe.

5. Pollutant loading rates from atmospheric deposition directly to the lake surface were quantified and in-basin sources were found to be the dominant source of both nitrogen and fine particulate matter. Direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

The studies undertaken to quantify nutrient (N and P) and fine particle loadings to Lake Tahoe from atmospheric deposition directly to the lake's surface were extensive, and they appear to have been competently done. Both historical and new data were used to make the assessment. In my opinion, the conclusions related to rates of N and P deposition and the fraction of annual fine particle load contributed by direct deposition of dust are based on sound scientific knowledge, methods, and practices.

I am unable to make the same statement about the conclusion that in-basin sources were found to be the dominant source of nitrogen and fine particles. As noted in item 5 of the previous section, I found the report deficient in its description of how CARB reached this conclusion. This is not to say that the wrong conclusion was reached or that the work was scientifically unsound or based on unsound methods. I simply am unable to evaluate these issues on this topic because the report lacks sufficient detail. Additional documentation should be added to the TMDL-TR to describe how this was done. In addition, the high variability in local versus regional contributions across the seasons suggests that merely looking at the annual loadings may not be adequate. The data in Table 4-64 of the TMDL-TR indicate that most of the atmospheric loadings in summer are from regional rather than local sources, and this could impact water clarity negatively during this period, which is critical from lake-user perspective.

6. Pollutant Reduction Opportunity (PRO) analysis identifies fine sediment particle and nutrient reduction options that can be quantified. The PRO findings offer basin-wide pollutant load reduction estimates and costs for a range of implementation alternatives for reduction loads from urban uplands, forest uplands, stream channel erosion, and atmospheric deposition sources.

Much of the work done on this issue was not highly technical (at least not of the nature of the analyses and modeling efforts that led to the loading estimates, targets, and allocations), and a somewhat different

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Response

PB-19: The methodology used by the US Army Corps of Engineers for the Lake Tahoe groundwater investigation was specifically defined in their *Groundwater Evaluation* report (USACE 2003). This report is available through the Lahontan Water Board and provides the technical details for their estimates of groundwater loading. It is highly recommended that those interested in the methodology refer to that document. There are a number of studies that were used to inform the Technical Report; however the details of particular studies do not appear in the report, just the important findings are summarized.

A summary of the approach taken to estimate nutrient loading is provided below. The loading estimates were separated into five regions based on political boundaries and major aquifer limits. The five regions included South Lake Tahoe/Stateline, East Shore, Incline Village, Tahoe Vista/Kings Beach and Tahoe City/West Shore. Depending on the amount and type of groundwater data available, discharge estimates were developed using one or a combination of three methods; groundwater flow modeling, Darcy's Law and/or seepage studies. The South Lake Tahoe/Stateline aquifer discharge was based on existing data of sufficient quality and quantity to develop a groundwater flow model. The remaining four regional aquifer seepage estimates were developed using either Darcy's Law or existing seepage data. Once the groundwater discharge estimates were calculated, nutrient concentrations were applied to determine annual loading to Lake Tahoe.

The nutrient concentrations used to determine the loading estimates were based on either average nutrient concentrations for a region, measured down gradient concentrations for a region or land-use weighted concentrations. The land-use weighted concentrations were used in areas with little monitoring data available or areas that did not have meaningful placement of wells in relation to land-use.

PB-20: The Technical Report text in Section 4.5.5 has been modified to provide additional information about in-basin sources of nitrogen and fine sediment particles.

basis is appropriate to address its adequacy. The PRO analysis and related IWMS involved a wide range of experts from many stakeholder groups and extensive amounts of review of preliminary findings. I am not an expert on the processes whereby pollutant reduction options have been analyzed in other TMDL studies, but I found the approach used in this study to be thorough, objective, and open. The results presented in the PRO appear reasonable to me, although I also am not an expert on many of the load reduction technologies. The costs associated with the implementation efforts needed to achieve the clarity challenge are truly daunting in this day of (many) billion dollar state deficits and trillion dollar national deficits.

7. Lake Clarity Model was the most appropriate for predicting the lake response to changes in pollutant loads.

Insofar as the Lake Clarity Model (LCM) was developed specifically for Lake Tahoe, which is a highly unusual lake with respect to water clarity, I agree that this is the most appropriate model for predicting responses of the lake to changes in pollutant loads. The LCM is based on a hydrodynamic sub-model that has been tested internationally and is widely accepted as appropriate. This sub-model produced reasonable simulations of thermal stratification and related patterns in the lake. The LCM takes a comprehensive approach to simulating the behavior (and formation) of light scattering and light absorbing particles in Lake Tahoe. The component dealing with phytoplankton growth is explained thoroughly in the report and appears to use appropriate mathematical formulations.

In some respects, however, the core of the LCM is the optical model that was developed by Swift and coworkers. Unfortunately, as indicated in item 2 of the previous section, the reports do not provide sufficient information for a technical review of this critically important component.

8. Allocation of allowable fine sediment particle and nutrient loads is based on the relative magnitude of each pollutant source's contribution and the estimated ability to reduce fine sediment particle and nutrient loads.

Although limitations in the field data cause a fair amount of uncertainty to remain in the estimates of particle contributions from specific sources, the study did a creditable job of estimating these contributions for each pollutant source. This was a very difficult task, and the researchers recognized the limitations in the data and compensated as best they could by using (where feasible) independent methods of analysis and calculation to reach their conclusions. Overall, I conclude that the work on this issue was based on state-of-the-art techniques and involved extensive review and oversight. Based on my review of the reports, I conclude that allocations of allowable loads were done objectively based on the relative magnitude of source contributions with proper attention to technological and economic constraints in the ability to reduce loads from various sources. Nonetheless, some issues should be addressed, as noted in items 1, 5, and 6, and the last paragraph of item 4 in the previous section.

Smaller Technical Concerns and Editorial Issues

(Note: "fb" in the column for "line" denotes "from bottom" of the page; ¶ denotes paragraph number)

Page	¶/Line	Comment
ES-2	4fb	It would be clearer if the values were given as percentages of the required reduction (e.g., 24.5*100/32 = 76.5% of the reduction should come from urban uplands.)
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PB-21: The location map, Figure 2-1 in the Final Report has been replaced with a more accurate figure.

		Placer County. The middle county in NV is labeled Ormsby, but the text (p. 11-7) refers to it as Carson City Rural.
2-2	11fb	There should be no spaces between the dash connecting a range of numbers and no apostrophe for pluralizing numbers (should read: 1900s-1950s). This is a consistent problem in the text and should be corrected in the final report.
2-3	3-4	The text does not agree with what the map shows. Much of the west shore is developed; only the SW end appears undeveloped. Similarly, much of the east shore appears to be developed except for a few stretches on the northern third of the east shore.
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	6fb	This is an understatement. The figure shows that ~70% of the scattering is due to particles < 5 µm in diameter.
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	10	Use of double slashes is incorrect and a mathematically ambiguous way to display areal rates. The report should use either g $C/m^2 \cdot yr$ or g C m^{-2} yr^{-1}.
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PB-22: The spaces between the dash connecting a range of numbers and the apostrophe for pluralizing numbers have been removed throughout the document.

PB-23: Figure 3-2 in the Final Report has been updated and the R^2 and p-value has been added to the caption.

PB-24: The text refers to Figure 3-4 and not Figure 3-3 in the Final Report

PB-25: The text in Section 3.4.1 of the Final Report has been updated and the new percent value given is more general.

PB-26: The text has been corrected, the use of double slashes was incorrect, the units are correctly displayed in the Final Report (Section 3.4.1).

PB-27: The term data is plural, the text has been updated in Section 7.5 of the Final Report and throughout both the Final Report and Technical Report.

PB-28: The text has been updated in the Final Report (Section 7.5), the terms are now "provided" and "estimated".

PB-29: The text in the Final Report, Section 7.6 has been updated, and the statement regarding organic verses inorganic source origin has been deleted.

PB-30: The text has been removed and/or corrected for Chapters 9-11.

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PB-31: The Figure 2-1 has been replaced, the text is correct, it is Carson City Rural County.

PB-32: The text has been removed and/or corrected for Chapters 9-11.

PB-33: New text was added to the Final Report, Section 12.2.

PB-34: A new figure was added to the Technical Report (Figure 3-16) that displays the annual depth of mixing from 1973 – 2008. New text was also added to the Final Report (Section 12.2) to include additional information on an analysis conducted on the possible impacts of climate change on lake mixing and stratification.

PB-35: The stormwater samples will be collected as specified in the Regional Stormwater Monitoring Program. Both composite (event-integrated) samples and grab samples will be analyzed in the monitoring program. The text has been corrected in the Final Report, "unionized" has been changed to "un-ionized".

PB-36: The text in the Final Report (Section 13.3.2), has been updated to include how far the index station is located from shore (2 kilometers).

PB-37: The text has been updated, and the reference to $10 Million dollars being spent on research has been deleted in the Final Report (Section 14.2.1).

PB-38: The uncertainty was not determined explicitly; rather it was evaluated relatively amongst the different source category estimates and not for any specific models.

PB-39: The text has been updated in the Final Report (Section 14.3) to include the word "conservative" in the sentence.

assumptions in the two areas are described in subsequent paragraphs (although there is not a lot of information provided) or are described in detail in the technical report).

Lake Tahoe Total Maximum Daily Load Technical Report

Page	¶/Line	Comment
3-1	¶ 2	There is no "typical value" of watershed/lake ratio. I will grant that the watershed/lake ratio for Lake Tahoe is small, but the value of the ratio ranges widely, and it is misleading to imply that there is such a thing as a typical watershed that has a watershed/lake ratio of 10.
3-4	Fig. 3-2	This is a better map than Fig. 2-1 in the TMDL report. The authors should consider replacing Figure 2-1 with this or a similar figure.
3-11	Fig. 3-9	Authors should give the r^2 and equation for the line of best fit. One wonders what a linear fit would look like. The data are sufficiently scattered that it is dubious whether a curvilinear fit is really appropriate.
3-13	¶ 1	One wonders at what depths the sediment traps were deployed and whether the settling velocities are representative of the entire water column. Given the fact that N- and P-containing particles are undergoing continual degradation on their downward journey, the point made in the last sentence (about mineralization and recycling) is especially pertinent.
3-15	1	Figure 3-13 does *not* show that lake clarity increased. One can infer that it likely increased from the trends in mass sedimentation rates, biogenic silica fluxes, and inferred primary production, but the figure itself does not have any transparency parameters on it. The authors need to be careful in how they phrase the text on such an important and sensitive issue.
	¶ 2	The decline in transparency has *not* been caused primarily by the gradual accumulation of pollutants over time, but is caused by *continuing* inputs of the specific pollutants. Again, this is a matter of being precise in the use of language. As written, this paragraph implies that pollutants accumulate in the lake for long periods of time. I don't want to get into arguments about the meaning of "long," but as the text in paragraph 1 on this page indicates, reductions in loadings of sediment and nutrients likely leads to increased transparency in relatively short periods of time.
3-16	3	Saying that algae "require" N:P in a ratio of 7:1 is at best simplistic. This should be restated after consultation with a limnologist who understands the nuances of nutrient ratios.
	9	The text should replace total Kjeldahl nitrogen (TKN) with total organic nitrogen (TON). I doubt that laboratories analyzing Lake Tahoe samples actually use the Kjeldahl method anymore; most limnologists and environmental laboratories converted to a more sensitive alkaline persulfate oxidation method 10-20 years ago, which gives accurate results for total N (from which TON is calculated by subtracting separately measured values for nitrate-N and ammonium-N).
	¶ 4	"Bioavailability" depends on the method used to determine it. The text should give some indication of how bioavailable P was determined.
	4fb	The range 16-56% is so large that it is not very meaningful to say that the value of 40% found by Hackley et al. agrees with the results of Dillon and Reid.
4-1	¶ 3	It would be more appropriate and accurate to state that Reuter et al. developed the first nutrient budgets for Lake Tahoe. Nutrients (N and P) are not pollutants per se, although there is widespread agreement that excess nutrient inputs are a type of pollution. Even pristine Lake Tahoe requires some nutrient input to survive as an ecosystem. In addition, I think it would be more accurate to use the term fine particles rather than fine grained sediment because not all the particles are (or have been) sediment; atmospheric particles certainly fall in this category. I think the terminology used in this paragraph is a

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PB-40: The text in the Technical Report, Section 3.1 has been updated to reflect that the watershed/lake surface area ratio of Lake Tahoe is small but that there may not be a 'typical' value.

PB-41: Figure 3-1 in the Technical Report has been replaced with a more accurate figure.

PB-42: The Figure 3-9 has been replaced with a more accurate figure in the Technical Report (Figure 3-8), the R^2 and p-value have been added in the caption.

PB-43: There were three sediment traps placed in the water column at depths of approximately 175 meters, 290 meters and 400 meters with the lake bottom at 435 meters. This provides good vertical coverage throughout the water column. The text has been updated in the Technical Report (Section 3.4.1) to include these values.

PB-44: The text was updated in the Technical Report (Section 3.4.1) to correctly express what Figure 3-13 demonstrates.

PB-45: The text was updated in the Technical Report (Section 3.4.2) to specify that the decline in transparency is not from gradual accumulation of pollutants, rather continued loading of the pollutants.

PB-46: The text stating that algae require a N:P ratio of 7:1 was a simplification, however this discussion was to explain that nitrogen and phosphorus are required at different amounts for algae growth. The text in the Technical Report (Section 3.4.2) was updated and a new citation was added that cautions the reader that using the stoichiometric ratio of 7:1 (by weight) to assess nutrient limitation can be problematic.

PB-47: The TERC labs still conduct the total Kjeldahl nitrogen method. The total Kjeldahl nitrogen equals total organic nitrogen plus ammonium.

PB-48: Ferguson and Qualls (2005) employed an approach where both chemical phosphorus-fractionation and algal bioassays were used to estimate bioavailable phosphorus. In the bioassays, particulate phosphorus was trapped on a filter and separated by a membrane that allowed the passage of dissolved phosphorus but not particulate phosphorus into the algal culture. New text has been added to the Technical Report (Section 3.4.2) with this information.

PB-49: While the range from Dillon and Reid is large, this citation was put in to provide perspective and not to justify the Hackley et al. value. The text was revised in the Technical Report in Section 3.4.2 to remove the reference that the two studies results are in agreement.

little careless. Also, if the budgets were developed in 1998 and revised in 2000, why were they not published until 2003? Given that Jassby et al. noted the concern about fine particles as a pollution source for the lake in 1999, the argument that the budgets focused on nutrients because they were thought to be the principal cause of clarity loss are a little strained.

4-4	3fb	Actually, it is 72%, which is closer to three-fourths.
4-7	1	It would be helpful if the report would show results demonstrating that ground water in fact is "nutrient-rich," as this line states. Alternatively, it would be fine if the text would refer the reader to any table or figure elsewhere in the report where such documentation is given.
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4-90	5	I think the authors mean "latter" not "later." Nonetheless (line 8) is one word, not three.
4-109		One wonders why the streambed samples that were analyzed for TP were not analyzed for TN at the same time. The same digestion procedure can be used for both N and P, and the amount of additional labor would have been minor.
4-121	¶ 1	The reasoning in this paragraph to ignore organic particles is questionable. Certainly the authors would agree that phytoplankton and detritus produced from phytoplankton and other microbial activity in the water does have an important effect on water clarity even though the particles are nearly entirely organic. I cannot see any reason why organic particles from the atmosphere would not affect lake transparency.
5-13		The standard deviations for most sites exceed the mean values for both particle sizes, in some cases substantially so. This indicates that the data are highly skewed. The text should acknowledge this and describe what was done to overcome this problem.
5-14	¶ 2	Use of four-place precision (318.3) for the multiplication factor is a rather extreme example of going overboard in creating a false sense of precision in the analysis. There is no way that the authors can imply that the factor is known to that level of precision and accuracy. Rounding to one place (300) would describe better the accuracy with which they can estimate the factor.

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Response

PB-50: All waterbodies need some amount of nitrogen and phosphorus loading to sustain production. If this level is exceeded it can be considered a pollutant. No attempt was made here to imply that all nutrient loads are pollutants. Language regarding fine sediment was modified for consistency in the Technical Report in the beginning of Chapter 4. As stated the nutrient budgets were developed in 1998-2000 at the same time that Jassby et al. (1999) hypothesized that the role of fine particles could be significant. It was not until Swift's work in 2004 that this was actually substantiated.

PB-51: The text has been changed in the Technical Report to give reference that the urban uplands contribution is close to three fourths of all the fine sediment particles to Lake Tahoe in the beginning of Chapter 4.

PB-52: The text was modified in the Technical Report (Section 4.1) to remove the term "nutrient-rich" for the groundwater and reference to Table 4-4 was given where the data is located.

PB-53: The word "principals" has been replaced with "principles" in the Technical Report (Section 4.1.3).

PB-54: The word "have" has been inserted into the text in the Technical Report (Section 4.1.3).

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Response

PB-55: The word "ambient" was misused; the word has been replaced with "background" in the Technical Report, Section 4.1.3 and in Table 4-4.

PB-56: The word "later" was changed to "latter" and "none the less" has been changed to "nonetheless" in the Technical Report (Section 4.3.6).

PB-57: Prior to the samples being analyzed for total nitrogen, there was a problem with the QA/QC protocol (specifically the holding times). At that point there was uncertainty regarding the appropriateness of conducting the total nitrogen analysis, and thus is was not conducted. The uncertainty regarding the estimate for stream channel total nitrogen was discussed in the Technical Report, Section 4.4.3 under the heading - Estimates of Nutrient Loading Associated with Streambank Erosion.

PB-58: Based on the work of Swift (2004) and Swift et al. (2006) organic particles influence lake transparency but to a much less extent than fine sediment particles. This is also supported by modeling runs that suggest that annual average Secchi depth would be close to 31 meters if all urban fine sediment particles were removed (including atmospheric deposition). This, in concert with the lower level of confidence in our atmospheric particle deposition of organic particles to the whole lake, a conservative approach was taken. More research could help clarify this point. The text has been updated in the Technical Report, Section 4.5.2 to address this comment.

PB-59: As the urban particle concentration data demonstrates there is considerable variability both between locations and during the year at a single location. This latter variability is evident by the elevated standard deviations at each site; the standard deviation frequently exceeds the annual mean. This is not necessarily a sign of sampling or statistical uncertainty as it is a reflection of the degree of seasonal changes in concentration for stormwater samples. Particle concentrations in urban runoff vary significantly, especially in an environment where precipitation type (summer thunderstorm, snow melt, rain on ground, etc.) and amount (drizzle to ~1 inch in a few hours) also vary significantly over the year. This is the first time this type of data (particle size in urban runoff) was collected at Lake Tahoe – the objective was to evaluate annual loading and not event loading. New text has been added to the Technical Report (Section 5.1.4) to address this comment.

PB-60: The number of significant figures associated with this multiplication factor was not intended to be a reflection of the level of confidence in this value. Given that the objective was to estimate a basin-wide loading value, the location-to-location variability was accounted for by using the average value of all stations with data. Ongoing stormwater monitoring will provide additional information on this topic. Text was added to the Technical Report (Section 5.1.4) in response to this comment.

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Lake Tahoe Sediment and Nutrient TMDL

Response to Peer Review Comments

Menachem Elimelech

Peer Review Received: August 5, 2009

Review of

Lake Tahoe Total Maximum Daily Load Report

Menachem Elimelech
Department of Chemical Engineering
Yale University
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The Lake Tahoe Total Maximum Daily Load (TMDL) Report is a comprehensive document that identifies the contaminants responsible for the deterioration in transparency and clarity of the lake, the sources of these contaminants, and the plan to reduce the input of these contaminants to the lake in order to attain the water quality objectives and restore the lake clarity. It is concluded that the culprit for the deterioration in lake clarity is mainly the presence of suspended inorganic particles and, to a lesser extent, nutrients in the form of nitrogen and phosphorus.

The TMDL report has benefited tremendously from extensive research and monitoring data for Lake Tahoe that started nearly 40 years ago. Research associated with the development of the Lake Tahoe TMDL was designed to build on the extensive information available on the lake and its watershed. The components of the model used to develop the plan to restore the lake clarity are based on completed research projects from the past 10-20 years, most of which have been published in peer-reviewed journals. The published research adds to the credibility of the methodology used and the developed plan. Further, there are additional ongoing research projects that support the next phases of the Lake Tahoe TMDL.

The Lake Tahoe TMDL report is well presented. It clearly states the problem and objectives, provides the necessary background, presents the methodology used to arrive at the plan to attain the TMDL Clarity Challenge, and outlines the implementation steps that need to be taken. The Final Report also refers to the relevant reports and documents when needed. Overall, I find the report to be technically sound and of high quality.

Below are a few comments and suggestions that may help in refining the report at this stage as well as in the next phases of the Lake Tahoe TMDL. Furthermore, replies to the 8 specific issues that the reviewers were requested to address will follow.

Inverse Modeling

The Lake Clarity Model is a mathematical model comprising several sub-models and algorithms. The model can simulate the water quality in the lake (concentrations of particles and nutrients)

Response

Review of

Lake Tahoe Total Maximum Daily Load Report

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Inverse Modeling

The Lake Clarity Model is a mathematical model comprising several sub-models and algorithms. The model can simulate the water quality in the lake (concentrations of particles and nutrients) and link it to water clarity (or Secchi depths), which is essential to achieving the Clarity Challenge. This approach is termed forward modeling. The model has been used to determine the total maximum daily loads of particles and nutrients to the lake and the necessary reductions in the loadings of particles and nutrients from the various sources to attain the Clarity Challenge.

However, there is also a need for an inverse problem modeling as well as a parameter identification algorithm. A robust inverse problem model can be used to optimize performance and minimize costs in the TMDL management system as well as the monitoring program. Currently, the management and monitoring plans/models are conceptual and qualitative in nature, and thus will not yield the most cost-effective outcomes. The inverse problem approach has been used extensively in water quality management covering a wide range of problems. See for example the book by Ne-Zhen Sun (Inverse Problems in Groundwater Modeling, 1994, Kluwer Academic Publishers). Lastly, the inverse problem coupled with a robust parameter identification algorithm can help in finding the unknown physical parameters for the model based on limited experimental data.

Other recent references highlighting the inverse problem modeling with applications to water quality can be found in:

> Zou, R., Lung, W.S., Wu, J. "An adaptive neural network embedded genetic algorithm approach for inverse water quality modeling", *Water Resources Research*, 43 (2007, W08427.

> Shen, J., Jia, J.J., Sisson, G.M., "Inverse estimation of nonpoint sources of fecal coliform for establishing allowable load for Wye River, Maryland", *Water Research*, 40 (2006) 3333-3342.

<u>Role of Particle Aggregation</u>

One of the key steps in the Lake Clarity Model is to link the loadings of particulates and chemicals (nutrients) into Lake Tahoe to the Secchi depth and light attenuation which are measures of lake clarity. Since inorganic suspended particles govern the light attenuation behavior, it is imperative to be able to predict the number concentration and size distribution of particles at various water depths. Thus, even if the other modeling efforts can estimate adequately the inorganic particle loading to Lake Tahoe, the ability to predict the Secchi depth remains the key to the Lake Tahoe TMDL Clarity Challenge.

An important process governing the number and size distribution of particles in lakes (as well as marine environments) is particle aggregation. Examples for the important role of particle aggregation in aquatic systems can be found in the following references (and references therein):

> Weilenmann, U., O'Melia, CR, and Stumm, W. "Particle-Transport in Lakes - Models and Measurements", *Limnology and Oceanography*, 34 (2009) 1-18.

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2

Response

ME-1: The level of sophistication needed to analyze this using an inverse problem modeling approach and a parameter identification algorithm was outside the scope of this project. As part of the ongoing research at Lake Tahoe, the intent is that a quantitative linkage between management, monitoring, cost-effectiveness and environmental response will be developed and continually improved upon as new information becomes available. The Lake Tahoe TMDL Management System is being developed to ensure that milestones will be evaluated for all sources (quantitatively, not qualitatively) and if recommendations arise that result in a need to adapt and make changes to the TMDL implementation program, this will occur within the adaptive management framework.

Burd A.B., Jackson G.A., “Particle Aggregation”, *Annual Review of Marine Science*, 1 (2009) 65-90.

It is not clear from the Lake Tahoe TMDL report (and related reports) if and how the process of particle aggregation has been incorporated in the Lake Clarity Model. It is likely that the impact of aggregation may not be as significant if the number concentration of particles is relatively low and if the collision (sticking) efficiency is low. The latter is dependent on the water chemistry, namely the total ionic strength, concentration of divalent cations (mostly calcium), and dissolved natural organic matter (NOM). The collision efficiency cannot be predicted from theory but must be determined from experimental measurements Note also that particle aggregation results in fractal aggregates having settling behavior that cannot predicted by the simple Stokes Law.

Beneficial Health Effects to Beaches

The largest source of inorganic particles to Lake Tahoe comes from storm water runoff from urban areas. To achieve the Clarity Challenge, significant reductions in particle loading from urban areas are proposed. This measure will not only improve the lake clarity but will also have beneficial health effects by minimizing potential microbial pathogen loads to recreational beaches along Lake Tahoe. In recent years it has been recognized that microbial contamination of beaches form urban and agricultural runoff is responsible for numerous illnesses. This may be a potential problem for Lake Tahoe and, as such, funding and research programs tackling both lake clarity and microbial contamination of beaches should be promoted. This will lead to more effective use of state and federal funds. Recent papers highlighting the problem of microbial contamination of recreational water include:

Heaney, C.D. et al. “Contact with Beach Sand among Beach Goers and Risk of Illness”, *American Journal of Epidemiology*, 170 (2009) 164-172.

Wong, M. et al. “Evaluation of public health risks at recreational beaches in Lake Michigan via detection of enteric viruses and a human-specific bacteriological marker”, *Water Research*, 43 (2009) 1137-1149.

Boehm, A.B. et al. “A sea change ahead for recreational water quality criteria”, *Journal of Water and Health*, 7 (2009) 9-20.

Potential Detrimental Effects on Lake Water Quality

Suspended particles in lakes play an important role in the transport of heavy and trace metals to the sediments. Heavy and trace metals adsorb to suspended particles which aggregate and settle to the sediment. Thus, lakes with greater concentrations of suspended particles may have lower concentration of dissolved metals in the water. Examples of references describing this phenomenon include:

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Response

ME-2: Particle aggregation is an important consideration in Lake Tahoe and was included in the Lake Clarity Model (see technical support document on model structure, development and algorithms by Sahoo et al. (2006 and 2009). Particle settling rate was tested in the sensitivity analysis (Technical Report Section 6.3.1) and was found to affect Secchi depth. Sahoo et al. (2006) discussed that particle aggregation depends on (1) particle concentration, (2) collision rate, and (3) sticking efficiency (coagulation rate). The Lake Clarity Model used the algorithms reported by O'Melia (1985) and supported by Casamitjana and Schaldow (1993). As noted in Table 6-5 of the Technical Report, coagulation rates found in the literature typically range from 0.001-0.1. A value of 0.015 was used in the Lake Clarity Model. Since the model showed a higher degree of sensitivity to this parameter, it was considered most appropriate to determine its value by direct calibration based on the actual measured and predicted Secchi depth values. It was outside the scope of this work to conduct collision efficiency and coagulation research. Since 'sticking efficiency' in aqueous solutions, and especially under low concentrations, is very complex, we considered the calibration approach (based within the literature values) to be a reasonable approach.

Sigg, L., Sturm, M., Kistler, D. "Vertical Transport of Heavy-Metals by Settling Particles in Lake Zurich", *Limnology and Oceanography*, 32 (1987) 112-130.

Sigg, L. et al. Cycles of Trace-Elements (Copper and Zinc) in a Eutrophic Lake - Role of Speciation and Sedimentation, In: Aquatic Chemistry - Interfacial and Interspecies Processes. Advances in Chemistry Series, Vol. 244, pages 177-194, 1995.

I wonder if the concentration of heavy and trace metals in Lake Tahoe has ever been correlated to the concentration of suspended particles in the water column. This will give an indication if the proposed reduction in the particle loading will have an effect on the concentration of metals in the lake water.

Finally, it was also requested to determine whether the following eight specific issues are based on sound scientific knowledge, methods, and practices.

1. Determination of fine sediment particles (<16 micrometers) as the primary cause of clarity impairment based on interpretation of scientific studies, available data, and the Lake Clarity Model.

I concur with the analysis and scientific methods leading to this conclusion. This has also been published in the peer-reviewed literature as outlined in the report.

2. Identification of the six sources of pollution affecting lake clarity of which urban upland areas was found to be the primary source of fine sediment particles causing Lake Tahoe's clarity loss.

I concur with the analysis and scientific methods leading to this conclusion. This conclusion was based on extensive data collected over the past 40 years. Some of this data has also been published in the peer-reviewed literature as outlined in the report.

3. Determination that the Lake Tahoe Watershed Model was an appropriate model to estimate upland pollutant source loads.

I am not familiar with this model and thus I cannot provide an assessment of this question. For this question you should rely on a reviewer with expertise in watershed modeling.

4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

I cannot provide an assessment of this question. For this question you should rely on a reviewer with expertise in groundwater hydrology, more specifically someone with knowledge on groundwater – surface water interactions.

5. Pollutant loading rates from atmospheric deposition directly to the lake surface were quantified and in-basin sources were found to be the dominant source of both nitrogen and fine

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4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

I cannot provide an assessment of this question. For this question you should rely on a reviewer with expertise in groundwater hydrology, more specifically someone with knowledge on groundwater – surface water interactions.

5. Pollutant loading rates from atmospheric deposition directly to the lake surface were quantified and in-basin sources were found to be the dominant source of both nitrogen and fine

4

Response

ME-3: While heavy and trace metals can be correlated with suspended particles as suggested, heavy and trace metals have not been linked to water quality problems that interfere with the beneficial uses of Lake Tahoe (i.e. Lake Tahoe is not 303 (d) listed for metals). This TMDL focuses on deep water transparency, or Secchi depth. No scientific studies have been conducted to correlate suspended sediment concentration to heavy or trace metals in Lake Tahoe.

particulate matter. Direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

I concur with the conclusion that atmospheric deposition directly to the lake is the dominant source of nitrogen; this was also documented in the peer-reviewed literature. Atmospheric deposition is not the main source of fine suspended particles; the main source of fine particles is the urban upland.

6. Pollutant Reduction Opportunity (PRO) analysis identifies fine sediment particle and nutrient reduction options that can be quantified. The PRO findings offer basin-wide pollutant load reduction estimates and costs for a range of implementation alternatives for reduction loads from urban uplands, forest uplands, stream channel erosion, and atmospheric deposition sources.

It is a reasonable conclusion that the largest, most cost effective opportunities for fine sediment particle load reductions are from the urban upland source. The PRO analysis is interesting and appears to be reasonable; however, the approach used was semi-quantitative in nature. Hence, it may not represent the most optimal solution to the problem in terms of cost and effectiveness. Perhaps the use of more quantitative approaches involving optimization techniques and control theories that are common in the chemical engineering process industry would have resulted in a more optimal solution.

7. Lake Clarity Model was the most appropriate for predicting the lake response to changes in pollutant loads.

I concur that the Lake Clarity Model was appropriate to predict how Lake Tahoe's Secchi depths will respond to changing particle loading. The major components of the model have been published in the peer-reviewed literature as outlined in the report. However, as indicated in my general comments above, it is not clear if and how the aggregation of particles was incorporated in the model.

8. Allocation of allowable fine sediment particle and nutrient loads is based on the relative magnitude of each pollutant source's contribution and the estimated ability to reduce fine sediment particle and nutrient loads

This statement seems reasonable, but see my reservation indicated in item (6) above.

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This statement seems reasonable, but see my reservation indicated in item (6) above.

5

Response

ME-4: The Pollutant Reduction Opportunity project represents the most quantitative analysis of basin-wide load reduction potential performed to date. The project only analyzed quantifiable load reduction options and used available performance and cost effectiveness data to evaluate site-scale load reduction and cost estimates. A meta-heuristic optimization technique was applied to evaluate the benefits, costs, and selection trade-offs among basin-wide pollutant sources. This technique was applied in a Microsoft Excel environment and was developed by Tetra Tech to facilitate aggregation of pollutant controls, load reductions, and costs. The tool uses a lookup table and linear scaling to adjust estimated load reductions and costs of applying differing levels of implementation measures on the landscape. This tool provided the TMDL team the opportunity to compare different options across pollutant source categories and objectively evaluate a number of implementation scenarios to determine the most efficient and cost effective approach to achieving needed load reductions. The analysis included an optimization effort to identify the most cost effective load reduction opportunities and develop implementation options for stakeholder review. The TMDL implementation plan reflects a quantitative, optimized approach for reducing fine sediment particle and nutrient loads at Lake Tahoe.

ME-5: Same as response ME-2 above.

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Lake Tahoe Sediment and Nutrient TMDL

Response to Peer Review Comments

John M. Melack

Peer Review Received: August 15, 2009

Review of Lake Tahoe Total Maximum Daily Load

John M. Melack
Acting Dean and Professor
Bren School of Environmental Science and Management
University of California, Santa Barbara

The following material was read as the basis of the review of the Lake Tahoe Total Maximum Daily Load:

- Draft (June 2009) Lake Tahoe Total Maximum Daily Load
- Technical Report (June 2009) Lake Tahoe Total Maximum Daily Load
- Lake Tahoe TMDL Pollutant Reduction Opportunity Report (March 2008)
- Integrated Water Quality Management Strategy Project Report (March 2008)
- Appendices:
    - Urban and Groundwater Appendix A: PSC Performance Review
    - Forest Uplands Appendix B: Fire Literature Review
    - Appendix A: Stream Channel Erosion Nutrient Framework Analysis
    - Appendix B: Stream Channel Erosion Pollutant Control Options
    - Appendix C: Stream Channel Erosion Bank Stability Modeling
    - Appendix D: Stream Channel Erosion Load Reduction Analysis
- Appendix A: Packaging and Assessment Tool Description
- Appendix B: Information Supporting Chapter 3
- Appendix C: Supporting Tables and Figures
- CARB (2006)
- Tetra Tech (2007)

NB: Over the years I have read many of the papers published on Lake Tahoe, have heard numerous presentations at professional meetings by researchers from the area, and have visited the Lake Tahoe basin in all seasons.

In addition, several key journal articles were examined as part of the TMDL review; if specific publications are cited, they were read.

Supporting material was read less intently than primary TMDL text, in part, because the text was less focused on the key issues and many of the tables and figures were not sufficiently well described or were difficult to read given their size.

General comments

The process of developing the Lake Tahoe TMDL and the product is scientifically sound and credible. By building on a long period of research with many peer-reviewed publications and by conducting focused studies to augment and synthesize prior information, the TMDL is well supported. Modeling plays a significant part in the determination of the TMDL and is based on established approaches; the models are examined with appropriate sensitivity analyses.

One weakness in the Draft TMDL report is the lack of convincing evidence for the criteria used as the basis for the TMDL. Though Swift's thesis may contain the necessary

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Response

level of analysis of underwater optical conditions and their relation to Secchi transparency, particles and phytoplankton, the Draft TMDL does not. Similarly, the case that N and P are the key nutrients influencing changes in phytoplankton abundance is not well documented.

The inclusion of the nearshore waters and bottom in the scope of a follow-on TMDL is recommended given the documented reductions in habitat quality nearshore, the region that most people experience.

Specific issues

Were sound scientific knowledge, methods and practices applied to the following determinations and actions in the TMDL?

1. Determination of fine sediment particles (<20 micrometers) as the primary cause of clarity impairment based on interpretation of scientific studies, available data, and the Lake Clarity Model.

The Ph.D. thesis by Swift (2004) as published in Swift et al. (2006) provides a theoretically and empirically sound basis for the 'determination of fine sediment particles (<20 micrometers) as the primary cause of clarity impairment'. More precisely, Swift's results demonstrate that most of the light scattering occurs because of inorganic particles less than 10 micrometers in size and with a significant contribution to light attenuation by algal cells. Swift developed an additive semi-analytic model of water clarity to calculate apparent optical properties of diffuse attenuation and Secchi depth from inherent optical properties due to water, algal cells, suspended inorganic sediments and colored dissolved organic matter. His modeling approach is based on recognized optical theory and uses measured properties of particles and algae in Lake Tahoe. Though the TMDL cites several additional sources of supporting information in support of the determination, this evidence is in Master's theses that were not provided for review.

2. Identification of the six sources of pollution affecting lake clarity of which urban upland areas was found to be the primary source of fine sediment particles causing Lake Tahoe's clarity loss.

The six sources areas considered include urban areas, forested areas, groundwater, stream channel erosion, atmospheric deposition and shoreline erosion. Each was evaluated with detailed measurements and extrapolated to the whole lake using GIS techniques and/or modeling (see following sections for evaluation of these models). In each case, the approach used, the analyses done and the conclusions reached are well supported and scientifically sound. A critical aspect of such calculations is that the uncertainty in the estimates be discussed, and this was done reasonably well. The results from these analyses clearly identify urban uplands as the dominant source of fine particles.

3. Determination that the Lake Tahoe Watershed Model was an appropriate

level of analysis of underwater optical conditions and their relation to Secchi transparency, particles and phytoplankton, the Draft TMDL does not. Similarly, the case that N and P are the key nutrients influencing changes in phytoplankton abundance is not well documented.

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Response

JM-1: Additional text has been added to the Technical Report, Section 3.4.2 on the optical conditions and information about phytoplankton (new Figure 3-14), changes in the deep chlorophyll maximum (new Figure 3-15), and the depth of mixing (Figure 3-16).

JM-2: For a TMDL to be conducted on a water body, it must first be listed on the 303(d) list as impaired, and then the TMDL will address the pollutants that have caused the impairment. Though the existing nearshore standards are not listed as being impaired, these standards do not address the changing nearshore conditions and are not appropriate indicators. The nearshore region of Lake Tahoe currently has research projects underway to assist in determining new and appropriate standards that will allow for assessing the condition and if impairments are occurring.

model to estimate upland pollutant source loads.

Several models are available with which to calculate inputs of pollutants for uplands, and the selection of the USEPA's LSPC modeling system as the basis for the Lake Tahoe Watershed Model is a reasonable choice. This modeling system includes simulations of watershed hydrology, erosion and processes influencing water quality and in-stream transport processes. The material available in the Technical Report (June 2009; Lake Tahoe Total Maximum Daily Load) is sufficient to judge the veracity of the model. To fully evaluate the version of LSPC being applied to Lake Tahoe required examining Tetra Tech (2007).

The estimation of sediment loads and parameterization of nutrient and TSS by land use, including an intensive stormwater study, represent a substantial effort with mixed results as illustrated in Tables 4-26 to 4-28 and Figures 4-27 to 4-29. While typical of comparisons between modeled and measured values for variables such as TSS, TN or TP, the scatter indicates the difficulty in modeling these items. The mean annual loading of TSS and N and P fractions calculated by LSPC falls within the standard deviations of the measured values in most of the 10 streams monitored. Based on the Lake Clarity Model inorganic particles less than 10 micrometer in size have the most influence on clarity, yet the fine sediment calculated by the Watershed Model is material less than 63 micrometers in size. This issue is dealt with in Chapter 5.

A few questions about the application of the model arise:

1. No in-stream transformations or biological interactions were simulated. While appropriate during maximum snow melt or major runoff events, during baseflow conditions it may not be appropriate.
2. What resolution DEM was used to delineate watersheds, subwatersheds and slopes?
3. How well validated is the National Hydrology Dataset for stream lengths in the Tahoe basin?
4. How were the rainfall and snowfall amounts distributed spatially from the eight SNOTEL sites?
5. Riverson et al. (2005) is cited as the basis for the selection of an evapotranspiration (ET) calculation, but this appears to be a presentation at a conference and is not available. ET and sublimation from snow are important aspects of the hydrological balance, and it would strengthen the report to provide more information about how these processes were determined.
6. Land –use is a key component of a watershed model, and several data sets apparently vetted by knowledgeable personnel were used. It would be helpful to have an overall assessment of the veracity of the land-use classification and the areas assigned to each class. When remote sensed data are used, such as the IKONOS data, formal procedures are usually applied to evaluate the validity of the product; however, Minor and Cabik (2004) is not available for review.
7. Metrics, such as the Sutcliff-Nash metric, are usually applied to evaluate model predictions, but these metrics are provided. Offering plots (e.g., Figures 4-18 and 4-19) with measured and predicted lines is not sufficient. The 'error statistics' in Table 4-15

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Response

JM-3: LSPC is set-up to model in-stream transformations, but given the relatively fast time of concentration (i.e. time of travel from headwaters to mouth is only on the order of hours) the additional effort - and required assumptions - to represent these transformations was not considered to be significant during periods of elevated flow. While the statement is correct that biological interactions could be of consideration during the summer period of very low baseflow, loading during that period is minor. Nutrient fractions were determined using observed data at the mouth and upstream transformations had been made by that location in the channel. Additional text was added to the Technical Report, Section 4.3.5 under the heading *Water Quality* with the information above.

JM-4: Initially, more delineated watersheds were provided by Lahontan and TRPA (597 subwatersheds) - these were hydrologically merged into the fewer modeled subbasins. The merging process aimed to preserve important orographic changes in the delineation (i.e. merge areas with similar slope and elevations) while trying to minimize the number of subwatersheds. A 10-meter resolution Digital Elevation Model (DEM) was used to estimate average subwatershed elevations and to derive the average slope by land-use. Further details on land-use representation and watershed delineation are provided in Section 3.4 of Tetra Tech (2007).

JM-5: For stream segment delineation, the Lake Tahoe Watershed Model used the stream polylines, and calculated the lengths using the appropriate GIS layer(s). The main channel of each subwatershed was used to represent the primary water pathway. The National Hydrology Dataset was not used for this analysis.

JM-6: Precipitation and temperature were assigned to subwatersheds based on spatial proximity to the meteorology (MET) station. High-temporal-resolution weather observations for a long period of record are rarely available at a small enough scale to completely reflect the degree of spatial variability seen on mountainous landscapes. However, with the exception of the NRCS SNOTEL and NCDC weather stations, other MET sites in the Lake Tahoe Basin did not provide the level of resolution needed for the Lake Tahoe Watershed Model. Given the low percent error in total volume when the model output was validated using the LTIMP stream discharge data and the high level of agreement between the modeled annual water budget and those estimated over many years, the spatial distribution of precipitation based on the SNOTEL data appears reliable. The model's snow simulation module internally determines when precipitation is snowfall based on temperature. To distribute the rainfall and snowfall amounts spatially from the eight SNOTEL sites, a temperature lapse rate is applied to correct for elevation changes between the observed gage and the average watershed elevation of each subwatershed.

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Response

JM-7: Evapotranspiration and sublimation are important aspects of the hydrological balance. This was recognized in both the Technical Report and in Tetra Tech (2007). This was considered important enough by the modeling team that three approaches were taken to test which was most appropriate for conditions in the Lake Tahoe basin. These included Penman (1945), Hamon (1961) and Jensen-Haise (1963). The Penman method (1948) was deemed most suitable for Lake Tahoe (Riverson et al. 2005). Riverson et al. (2005) found that the annual observed evapotranspiration at Tahoe City was between 35.5 and 42.5 inches per year for reference crop (crop factor of 1.0) and evergreen forest (crop factor of 1.2), respectively. Total modeled evapotranspiration at Ward Creek is within the expected range at 37.5 inches per year. New text was added to the Technical Report, Section 4.3.3 under the heading *Evapotranspiration Calculations*.

JM-8: The land-use layer is a composite dataset based on the individual datasets that were known to have undergone their own quality assurance process. The additional effort to build this composite layer provided a more accurate spatial characterization of land-use than any other data source previously available. Spatial comparisons between the composite layer and an alternative UC Davis land-use layer are presented in Tetra Tech (2007). From a large set of GIS layers that varied in resolution and quality, a plan of action evolved through the data review process. A number of the most critical GIS layers became available only after this project had already begun. With input from staff at land-use management agencies (US Forest Service, TRPA, California Tahoe Conservancy, and Nevada Division of State Lands), the Water Board and NDEP determined a manageable and representative set of land-use categories and identified relevant spatial information available for representing each category. Over the course of this development process, certain categories and layers were included or excluded on the basis of ground-truth comparisons, data duplication/exclusion, and site-specific information about the significance of the impact. For example, the initial list of land-uses was modified to exclude grazing (a practice that has almost disappeared from the basin and whose historical or legacy impacts are not currently significant for water quality) and further refined the open space recreational category into turf and non-turf vegetated areas (e.g., golf courses versus campgrounds). New layers were developed when existing data was inadequate (e.g. zones of forest fires, forest harvest, ski runs). A detailed one-square-meter resolution Hard Impervious Cover (HIC) layer was developed using remote sensing techniques from IKONOS™ satellite imagery (Minor and Cablk 2004). Text was added to the Technical Report in Section 4.3.4 under the heading *Land-use Representation*.

JM-9: The Sutcliff-Nash metric was not used; however, this particular metric will be added to the validation work currently in process for the period 2004-2008 (Note - this updated validation is being done as part of a Southern Nevada Public Lands Management Act science grant that was funded after the TMDL modeling analysis was completed). The modeling report (Tetra Tech 2007) has more information on hydrology and water quality validation (Tables 4-2, 4-3, 4-4, 4-10 and 4-11). In addition, Table 4-41 in the Technical Report directly compares simulated loads versus loads estimated using LTIMP monitoring data. Confidence in the watershed model to simulate loads was based on these validation comparisons and not based on plots showing predicted and measured lines (data points). As stated in the Technical Report, the goal of the load modeling was not to simulate individual measurements.

help (though it is not clear if they are percentages or volumes), but are not really evaluated in the text.

8. Given the large amount of climate variability in the Tahoe basin, a four year calibration period seems short, especially since the model will be used to forecast conditions in the future as part of the overall TMDL.

4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

Groundwater movement and transport of materials is complex. It enters streams, where its influence is combined with other sources of runoff, and enters the lake directly. The USACE (2003) study (only summarized in the TMDL Technical Report) done as part of the TMDL work complements earlier investigations and used recognized, standard procedures, and provided spatially distributed estimates, which are relevant to mitigation options. The assumption of homogeneous aquifers and application of Darcy's Law is acknowledged as a simplification, and is asserted to provide reasonable estimates of groundwater flow. Since much more sophisticated, but data intensive, models, such as MODFLOW, exist and have been applied in other places, it would be valuable to have evidence offered to allow evaluation of the assertion. An indication of the considerable uncertainty in the estimates is noted in Table 4-5 where order of magnitude ranges from maximum to minimum values are listed. Given the acknowledged uncertainties, single values for basin-wide groundwater nutrient loading, as in Table 4-6, should not be listed. On page 4-15 under the subheading 'Ambient nutrient loading to Lake Tahoe from groundwater', it is stated that ambient groundwater represents approximately 46% and 34% of the P and N loading, while in Figures 4-1 and 4-2 groundwater is assigned 15% and 12.5% of the P and N loading. This apparent discrepancy should be clarified.

Estimates of groundwater nutrient loading should be described as reasonable estimates with wide error bars, hence the word accurate does not seem appropriate.

5. Pollutant loading rates from atmospheric deposition directly to the lake surface were quantified, and in-basin sources were found to be the dominant source of both nitrogen and fine particulate matter. Direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

Considerable effort was expended to quantify both wet and dry atmospheric deposition to the lake using established methods of measurement and calculation. The data on P deposition were quite difficult to obtain and special care was taken with the analytical methods. Dry deposition is a problematic measurement, and the two approaches used are complementary and have different sources of error. LTADS collected material from the air and then calculated deposition based on meteorological data and deposition velocities. LTIMP deployed bulk and wet/dry collectors; these bucket collectors are known to not represent true particle deposition. Snow sampling is also subject to errors if collected in buckets; this issue is not addressed. The transport models based on meteorological and

help (though it is not clear if they are percentages or volumes), but are not really evaluated in the text.

8. Given the large amount of climate variability in the Tahoe basin, a four year calibration period seems short, especially since the model will be used to forecast conditions in the future as part of the overall TMDL.

4. Determination that estimates of groundwater nutrient loading rates are reasonable and accurate.

Groundwater movement and transport of materials is complex. It enters streams, where its influence is combined with other sources of runoff, and enters the lake directly. The USACE (2003) study (only summarized in the TMDL Technical Report) done as part of the TMDL work complements earlier investigations and used recognized, standard procedures, and provided spatially distributed estimates, which are relevant to mitigation options. The assumption of homogeneous aquifers and application of Darcy's Law is acknowledged as a simplification, and is asserted to provide reasonable estimates of groundwater flow. Since much more sophisticated, but data intensive, models, such as MODFLOW, exist and have been applied in other places, it would be valuable to have evidence offered to allow evaluation of the assertion. An indication of the considerable uncertainty in the estimates is noted in Table 4-5 where order of magnitude ranges from maximum to minimum values are listed. Given the acknowledged uncertainties, single values for basin-wide groundwater nutrient loading, as in Table 4-6, should not be listed. On page 4-15 under the subheading 'Ambient nutrient loading to Lake Tahoe from groundwater', it is stated that ambient groundwater represents approximately 46% and 34% of the P and N loading, while in Figures 4-1 and 4-2 groundwater is assigned 15% and 12.5% of the P and N loading. This apparent discrepancy should be clarified.

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Response

JM-10: The calibration and validation periods used for the Lake Tahoe Watershed Model spanned the eight most recent years from WY1997 through WY2004 (10/1/1996 - 9/30/2004). Figure 4-19 in the Technical Report shows an example of four of the eight years calibrated and is not meant to imply that only four years was the calibration period. This eight year period of record included a wide range of annual precipitation values including the second highest (very wet) since measurements began in 1910 and two in the bottom 10 percent of all the values collected since 1910 (very dry).

JM-11: The accuracy of the groundwater discharge and nutrient loading estimates is a function of the input parameter data quality. The available data for parameters related to groundwater flow were considered sufficient enough for Fenske (ACOE 2003) to apply MODFLOW to the south shore region of Lake Tahoe. His report appears as Appendix B in the ACOE *Groundwater Evaluation Report* that was done for the TMDL. However, data to support a more sophisticated model, such as MODFLOW, does not exist for the entire Lake Tahoe basin. As a result, the groundwater scientists with the ACOE decided to rely on the simplicity of using Darcy's Law, i.e. when data is lacking the approach taken was <u>not</u> to rely on complex models. There was a wide range between the minimum and maximum values, which is why the ACOE provided a 'most reasonable' estimate. The high degree of similarity between the ACOE study and a previous study done by the USGS (Thodal 1997) for the entire Lake Tahoe basin increased confidence in these estimates. The single values given in Table 4-6 are intended for the sole purpose of comparing the Thodal (1997) and ACOE (2003) results based on mean estimated values. Table 4-5 includes the specific values for minimum, maximum and actual estimated loading for each nutrient constituent and flow for each of the modeled regions (i.e. Table 4-5 is intended to provide the reader with an estimate of variability). The ACOE used the term ambient to describe background conditions. The change in nomenclature has been made from ambient to background in the text in Section 4.1.4 of the Technical Report. The 46 percent and 34 percent values represent the relative contribution of background groundwater sources of phosphorus and nitrogen, respectively, to the total groundwater load (including background and urban sources). The values in Figures 4-1 and 4-2 represent the relative contribution of groundwater nitrogen and phosphorus to all the input sources (including atmospheric deposition, upland runoff, shoreline erosion and groundwater).

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Response

JM-12: Direct measurement of ambient air concentrations of phosphorus were problematic in the original LTADS monitoring. This was readily acknowledged by CARB, and as a consequence they solicited the assistance of Dr. Thomas Cahill and Dr. Steve Cliff at UC Davis. Cahill is an acknowledged international expert in air quality measurements. After considerable effort these researchers provided revised air phosphorus concentrations that were used to estimate phosphorus deposition. As discussed in the Technical Report (Section 4.5.4), two completely different approaches were taken to estimate nitrogen and phosphorus deposition to Lake Tahoe from the atmosphere. For nitrogen, only the deposition of the inorganic fraction had sufficient data for a direct comparison. The deposition rates for modeled versus direct measurement approaches for this component were remarkably similar at 116 metric tons per year and 76 to 101 metric tons per year. Phosphorus deposition as modeled by CARB, Cahill and Cliff, and directly measured using deposition buckets (UC Davis) were 3, 6 to 8 and 5 to 6 metric tons per year, respectively. Assuming the relative accuracy of the other phosphorus sources (see Table 4-66 in the Technical Report) the percent contribution from atmospheric deposition were 7, 15 and 12, respectively. Based on the difficultly that LTADS had with phosphorus deposition, the Technical Report reported the values estimated by Cahill; however, both the modeled and direct measurement approaches yielded a very similar relative contribution for phosphorus at 12 to 15 percent of all sources. Regardless of which of the three values are used, phosphorus loading from atmospheric deposition does not exceed approximately 15 percent. The 15 percent value for fine sediment particle load is acknowledged to have high uncertainty (see Section 4.6 of the Technical Report).

compositional measurements were used to account for atmospheric deposition in the basin that originated outside. It is surprising that error bars are not shown for results since the text notes uncertainty. However, the considerable sources of fine particles and N identified within the basin support the conclusion that in-basin sources dominant. The overall percentage of fine particle load from atmospheric deposition depends on the values of all the other sources, all of which have uncertainties; hence it is difficult to assign a level of certainty to the approximation that direct deposition of dust accounts for approximately 15% of the average annual fine sediment particle load.

6. Pollutant Reduction Opportunity (PRO) analysis identifies fine sediment particle and nutrient reduction options that can be quantified. The PRO findings offer basin-wide pollutant load reduction estimates and costs for a range of implementation alternatives for reduction loads from urban uplands, forest uplands, stream channel erosion, and atmospheric deposition sources.

The material presented in the PRO analysis appears to thoroughly consider options and provide abundant documentation of costs for many options. The reduction options and costs evaluated are not sufficiently well known to this reviewer to allow critical appraisal.

7. Lake Clarity Model was the most appropriate for predicting the lake response to changes in pollutant loads.

The 'Lake Clarity Model' combined an optical model (Swift et al. 2006) with a hydrodynamic model derived from the widely used DYRESM model (Imberger and Patterson 1981), an ecological model related to a model described in Schladow and Hamilton (1997) and particle fate model. As such it includes the key processes and has algorithms verified by use in other systems as well as Lake Tahoe. However, to argue that it is the 'most appropriate' model is not possible unless it is compared to alternative models. In particular, while the optical and hydrodynamic components are grounded in optics and hydrodynamics, the ecological model includes many simplified expressions and numerical values selected from the literature. Hence, application of the ecological model requires very careful sensitivity analysis and has considerable uncertainty.

The validity and accuracy of model output depends on inputs, and the hydrodynamic model is being driven by readily available data. Though considerable information on nutrients and plankton exist for Lake Tahoe, the inherent complexity of the biological system leads to missing information required for the ecological model, a further source of uncertainty. These differences are evident in Figures 6-2 to 6-6 in which the close match between modeled and measured temperature profiles contrasts with the less good matches for chlorophyll, nitrate and bioavailable phosphorus. While simulated and observed annual average Secchi depths are close (Table 6-6), seasonal variations of simulated and observed values diverge considerably (Figure 6-7) and reflect the difficulty of modeling the dynamic processes the combine to influence transparency.

8. Allocation of allowable fine sediment particle and nutrient loads is based on the relative magnitude of each pollutant source's contribution and the

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Response

JM-13: A review of the Technical Report and the Final Report reveals no suggestions that the Lake Clarity Model was the "most" appropriate model. The Lahontan website for the Lake Tahoe TMDL contains a list of selected peer reviewed journal articles where the full model has been used. Given the complexity of the lake biology/ecology, including a number of unknowns related to the microbial food web, trophic dynamics, bacteria and nutrient cycling, there is always room for improvement in the ecological portion of the model; this is largely true for nearly all lake models. Given the dependence of lake transparency on fide sediment particles, it is not believed that management decisions are being hindered by the ecological sub-model.

The ecological sub-model was simplified for two main reasons: (1) insufficient data existed to use in the model; and (2) nutrient cycling as it related to the physiological ecology of plankton and the aquatic food web is quite complex. Typically, most water quality models have difficulty in modeling these bio-ecological processes. Additionally, concentrations of chlorophyll and nutrients are very low in Lake Tahoe and small numeric deviations can appear large. For example, the total range of measured biologically available phosphorus in the water column typically occurs within the very narrow boundary of < 1 – 2.7 µ/L. The range of simulated concentrations was in a very similar range of < 1 – 2 µ/L. This is at the analytical limit of detection. Consequently, in a system with such low orthophosphate concentrations, it may be asking too much of this type of model to accurately simulate the very small and rapid changes in concentration. Also, the modeled nitrate values were able to demonstrate the typical nitricline. Chlorophyll concentrations like orthophosphate are very low in Lake Tahoe. The Lake Clarity Model simply can not distinguish between values that are close to detection limits. One aspect of the "inherent complexity" is that biological and chemical constituents generally exhibit spatial variability (or patchiness). Neither the sampling program nor the use of a one-dimensional model can capture this. However, since the model's intended use was to determine trends in lakewide annual averages, these shortcomings are negligible.

estimated ability to reduce fine sediment particle and nutrient loads.

The logic of this statement is correct, and the information supporting it is discussed elsewhere. However, a general concern is that allocations are not stated as ranges or as estimates with uncertainty specified.

Comments on text of Lake Tahoe Total Maximum Daily Load – June 2009 Draft

Executive Summary

Page ES-1 Lake Tahoe is a subalpine lake not an alpine lake, as is stated elsewhere in the material.

The basis for the transparency standard of a Secchi depth of 29.7m as the annual average for the period 1967 to 1971 seems overly precise and the selection of years for this standard is not well supported.

The percentage reductions assigned to particular sources are too precise and do not include uncertainties.

The 'adaptive management' to be used to address issues such as climate change or wildfires is not formally described and seems difficult to implement in the context of the TMDL process.

1. Introduction

The possibility that nutrients other than N and P may influence the growth of algae is not mentioned. In ultra-oligotrophic waters, such as those in Lake Tahoe, trace elements can be important.

2. Basin and Lake Characteristics

Since Lake Tahoe does not mix thoroughly each year, it would seem appropriate to calculate a residence time for the water that considered differing volumes.

Optical Properties

The introduction and conceptual model of underwater light should note the dissolved organic matter is a constituent contributing to underwater light attenuation.

What are the sizes of the particles represented in Figure 3-2?

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Response

JM-14: The load allocations are enforceable requirements and states as minimum values. The uncertainties involved in determining the absolute load reduction allocation, as discussed throughout the Technical Report and in the Margin of Safety (Section 14.3 of the Final Report), are not appropriate as enforceable regulatory targets.

JM-15: No change to the existing transparency standard is proposed. Rather, 29.7 meters is being specified as the annual average for the period of record stated in the standard.

JM-16: The percentages that describe expected pollutant load reductions within the Executive Summary do not explicitly describe the relative uncertainty associated with those values. There are a number of uncertainties associated with the load reduction percentage estimates, including but not limited to the uncertainty in baseline load calculations, unknown variability in best management practice effectiveness, and uncertainties in the relationship between loading rates and Lake Tahoe's transparency response. These uncertainties (and others) are addressed in the Margin of Safety portion of the TMDL (Chapter 14 of the Final Report). In response to the reviewer's position that the numbers, as presented, suggest a degree of accuracy that does not adequately reflect the reality of the uncertainty, the Final Report has been edited to round load reduction percentages to the nearest whole number.

JM-17: Chapter 12 in the Final Report has details on the adaptive management process that will be formally developed for this TMDL with funding allocated for the TMDL Management System.

JM-18: This TMDL addresses the three pollutants (nitrogen, phosphorus, and sediment) that resulted in Lake Tahoe being placed on the 303(d) list as an impaired water body. The trace metal iron has been found to stimulate algal growth in Lake Tahoe, presumably because of its importance to enzymes associated with nitrogen cycling. Since iron is inexorably linked to soils and watershed sediment, the control strategy is expected to reduce the potential impacts from iron inputs to Lake Tahoe as well.

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<u>Response</u>

JM-19: Hydraulic residence time was calculated using a textbook definition - time require for all the water in a lake to theoretically pass through its outflow. In the context of Chapter 2 of the Final Report and Chapter 3 of the Technical Report, the very long hydraulic residence time has significance in that pollutants that enter the lake will generally not be readily flushed from the lake. This means that loss of pollutants from Lake Tahoe will typically depend on in-lake physical, chemical and/or biological process and that loss from the outlet is not large. Because the lake does not mix to the bottom each year, the volume could be 'isolated'. However, given a 650-year hydraulic residence time, year-to-year differences resulting from the lack of assured complete mixing is not critical for the sections of the document where this is presented. It is important to note that the Lake Clarity Model takes the depth of mixing into account when simulating annual Secchi depth.

JM-20: The text was changed in the Technical Report, Section 3.4.1 and the Final Report, Section 3.1 to note that while absorption of light by colored dissolved organic matter (e.g. tannins and humic substances) was measurable in Lake Tahoe, it was a small contributor in comparison to the fine sediment particles for lake transparency decline.

JM-21: The size of particles represented in Figure 3-2 of the Final Report (and Figure 3-8 of the Technical Report) were particles <16 µm in diameter. This information was added to the appropriate figure captions.

Section 3.4.1: Primary productivity by phytoplankton does not directly cause transparency decline. It is the resulting accumulation of phytoplankton, not their rate of photosynthesis, that leads to less transparency.

4. Problem Statement

Since Secchi transparency is the key criterion, more information should be provided about the nature of the measurement and its relation to instrumental measurements of underwater light attenuation.

What is the definition of the euphotic zone used as the basis of the statement that light penetrates as deep as 100 m?

How many measurements per year are represented in Table 4.1? Though the annual average may be calculated to mm precision, the accuracy of the Secchi transparency measurement is at the cm level. The values in the Table should be rounded to the nearest cm.

5. Water Quality Standards

Page 5-6: To interpret the vertical extinction coefficient (VEC; which should be called the vertical attenuation coefficient), the wavelength range of the sensor used for the measurements must be specified.

6. Numeric Target

Pages 6-1 and 6-2: VEC is not properly defined, and it is a concern that there appears to be no trend in VEC from 1971 to 2002 while Secchi transparency has a declining trend.

Page 6-3: If the numeric target is based on the annual average Secchi transparency, the number of measurements and their seasonal distribution must be stated.

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Response

JM-22: A graph for chlorophyll biomass and accompanying text were added to both the Final Report (Figure 3-5, Section 3.4.1) and the Technical Report (Figure 3-14, Section 3.4.2). Additional text was added to these sections mentioned above to more accurately define primary productivity.

JM-23: Text was added to the Final Report, Section 4.1 to help explain the nature of the Secchi depth measurement. Section 6.1.1 of the Final Report contains an explanation of the vertical extinction coefficient - made by taking instrumental measurements of underwater light attenuation. It was concluded that with regard to the water body impairment, transparency was the focus of this TMDL since Secchi depth was more protective.

JM-24: The euphotic zone was taken as the approximate depth where algal photosynthesis and respiration are equal and primary productivity goes to zero. Text was added to the Final Report (Section 4.1) and the Technical Report (Section 1.4).

JM-25: Changes made as suggested to Table 4-1 and text was added to Section 4.1 on Secchi measurements in the Final Report (Table 1-3, Section 1.4.1 of the Technical Report).

JM-26: Language was added that specifies the wavelength range of the sensor (PAR, 400-700 nm) in Section 5.2 in the Final Report and Section 2.1.2 in the Technical Report. The term vertical extinction coefficient is used in limnology and is the language used in the Lahontan Basin Plan.

JM-27: While the pattern for the long-term VEC data is not as well defined as that for Secchi depth, some larger scale trends were seen. For example, during the period 1967-1976 the VEC was about 0.06 per meter. The average annual values were just less than 0.08 per meter during the ten year period from 1985-1995 and increased to 0.08-0.09 per meter between 1997 and 2002. The submersible sensor used to make measurement was considered questionable during 1977-1983, making it difficult to define the long-term trend with certainty. Since VEC also includes changes in water clarity below the Secchi depth - and is influenced by Lake Tahoe's deep chlorophyll maximum, a direct, side-by-side comparison between these two parameters may not occur. Text has been added to Section 6.1.1 of the Final Report and Section 2.2.1 of the Technical Report with the above information.

JM-28: Text was added to the Final Report, Section 6.2, and Section 1.4.1 of the Technical Report regarding the number of Secchi depth measurements taken during the period of 1967 – 1971 and during the entire period of record.

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19 Appendix C - TMDL Analysis Assumptions

Appendix C is a list of assumptions, which were compiled directly from the Lake Tahoe TMDL Technical Report, the Pollutant Reduction Opportunity Report, Integrated Water Quality Management Strategy Report, and the Lake Tahoe TMDL Report. The list does not include assumptions that were documented in 1) each of the scientific studies used in support of the TMDL development, and 2) appendices for the Pollutant Reduction Opportunity Report and the Integrated Water Quality Management Strategy Report.

Document	Page #	Paragraph	Sentence
Final	7-4	first	groundwater- Note that fine sediment is not believed to be transported via groundwater and will not be discussed further in this section
Final	7-4	fourth	groundwater- The USACE (2003) study assumed no water was added to or taken from the system and the aquifers are homogenous.
Final	7-9	last	atmospheric- CARB collected particle mass data in three size classes; PM2.5, PM8, and PM20. The smallest of the size classes was further divided in two to account for composition differences associated with particle size in the PM2.5 size class. The full set of seven-size classes required for input to the Lake Clarity Model was interpolated and extrapolated from these four-size measured classes.
Final	9-2	last	The Recommended Strategy assumes that pollutant controls will be applied differently based on configuration of impervious coverage and slope.
Final	11-12	first	The Water Board and NDEP anticipate that restoring floodplain connectivity and improving natural geomorphic function will provide additional fine sediment particle and nutrient load reductions.
Final	11-13	last	The Water Board and NDEP expect required load reductions for the stream channel erosion source will be met when all the restoration projects and activities are completed for the three major tributaries.
Final	13-10	last	The Lake Tahoe TMDL program anticipates the LTIMP water quality results will continue to be used as a comprehensive measure that integrates load reduction actions across all of the major pollutant sources.
			A 20 percent margin of safety was added to land-use Event Mean Concentration estimates. (Lahontan and NDEP 2010).
			The Lake Tahoe Watershed Model does not account for pollutant reduction as runoff flows overland from the developed and undeveloped intervening zones directly to the lake. This transport loss in the intervening zones requires hydrology modeling and estimates of urban losses that were too fine-scaled for the existing Lake Tahoe Watershed Model. However, estimates of this “transport loss” were accounted for by the Lake Tahoe Watershed Model in the urban subwatershed areas.
Final	14-5	Watershed Model assumptions	Estimates of nutrient runoff from fertilizer application on lawns do not account for infiltration loss of nitrogen and phosphorus. Had the estimates included infiltration, less nitrogen and phosphorus would be modeled to runoff from the vegetated turf land-use (Tetra Tech 2007).

Final	14-5	assumptions	Table 14-1. While assessing these opportunities, the Source Category Groups made a number of conservative assumptions that influenced the analysis of source reduction potential. Urban Uplands and Groundwater (UGSCG): Hydrologic Source Controls (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.* Bypassed flows are assumed to enter surface waters (Lake Tahoe) at influent concentrations. HSCs are flow-based pollutant control options that are designated to infiltrate urban storm water, thereby reducing flow volumes delivered downstream. HSCs are assumed to provide negligible water quality improvements to infiltrated waters.
Final	14-6	future growth	To establish the worst case scenario for build-out as it relates to pollutant loads, the Land-Use Model preferentially assigns each parcel to be either conserved or developed in a way that results in a scenario that is the most harmful to Lake Tahoe.
Tech	3-5	second	Land use divided in to 6 categories assuming these categories represent all land uses in the Basin
Tech	4-2 thru 4-3	last to first	The source loading estimates were applied to the Lake Clarity Model for evaluating the lake's response to the pollutant loading conditions. The urban and forest upland loading estimates were developed for the Lake Tahoe Watershed Model with the use of the Loading Simulation Program C++ (LSPC). The stream channel loading estimates were also applied to the Lake Tahoe Watershed Model to better represent stream channel loading. This allowed for the development of individual estimates of in-channel and upland pollutant sources. These combined estimates were then used as input to the Lake Clarity Model, while pollutant loading estimates from groundwater, atmospheric deposition, and shoreline erosion were used as direct inputs to the Lake Clarity Model.
Tech	4-12	last	USACE 2003-Groundwater-Because many of the regions did not have adequate monitoring networks at the time of the study, basin-wide average concentrations for specific land-use types were developed.
Tech	4-13	first	USACE 2003-Groundwater-Background conditions represent the concentration of nutrients that would be naturally occurring in the groundwater without the added impact of human development. It was assumed that these conditions were best represented by nutrient concentrations observed in undeveloped and undisturbed areas (vegetated and forested).
Tech	4-15	second	groundwater-The methods used to develop the discharge rates and ultimately nutrient loading are inherently uncertain. This uncertainty is discussed in more detail in the Thodal (1997) and USACE (2003) reports. While there may be the potential for error using the methods presented, the similarity between independent analysis supports the discharge estimates. On the basis of these findings, the mean of the Thodal (1997) and USACE (2003) studies were used as inputs to the Lake Clarity Model as part of the TMDL Linkage Analysis.

Tech	4-18	first	fertilizer-While the USACE (2003) Groundwater Evaluation report liberally assigned fertilizer use to a portion of the land area of all single-family homeowners in the Lake Tahoe basin, the values from the remaining land-use areas were considered by the USACE authors to be based on realistic rates.
Tech	4-21	second	shoreline-Since the aerial photographs literally only provide a ‘snapshot in time’, and based on the assumption that most shoreline change likely happens when the lake is at or near its legal limit, the research team devised a technique to estimate the position of the shore through time by correcting for different water levels based on the concept that on a stable, sloping shoreline the shore-water interface will migrate laterally in a predictable way depending on water level.
Tech	4-22	first	shoreline-In calculating the load of sediment and associated nutrients, the research team estimated the thickness of each eroded area using large-scale Bureau of Reclamation topographic maps dating from 1918 and 1919 and assumed a sediment bulk density of 1.5 grams per cubic centimeter.
Tech	4-29	first	uplands-Each delineated subwatershed in the Lake Tahoe Watershed Model is conceptually represented; a single stream is assumed to be a completely mixed, one-dimensional segment with a constant trapezoidal cross-section.
Tech	4-29 thru 4-30	last and first	uplands-Assuming representative trapezoidal geometry for all streams, mean stream depth and channel width were estimated, using regression curves that relate upstream drainage area to stream dimensions, and were compared with stream surveys at selected locations–
Tech	4-50	third	The Lake Tahoe Watershed Model is set up to model in-stream transformations, but given the relatively fast time of concentration (i.e. the time of travel from the headwaters to mouth of the tributaries is only on the order of hours) the additional effort - and required assumptions - to represent these transformations was not considered to be significant during periods of elevated flow. While biological transformations could be of consideration during the summer period of very low baseflow when residence time is higher, loading during that period is minor.
			upland-Reasonable baseflow and surface runoff volumes can be obtained using the HYSEP sliding-interval method, as defined by Sloto and Crouse (1996)
			upland-Reasonable baseflow and surface runoff volumes can be obtained using the HYSEP sliding-interval method, as defined by Sloto and Crouse (1996)
			upland-Since flow-versus-load regressions have errors that are normally distributed in log space, it is reasonable to use rating curves in conjunction with MVUEs to develop baseflow and surface runoff load relationships in linear space
			upland-TN and TP represent all transportable nitrogen and phosphorus from upstream sources
			upland-Baseflow pollutant load is primarily groundwater driven and storm-flow pollutant load is primarily surface runoff driven
Tech	4-54	Assumptions	upland-Baseflow associated samples are composed primarily of dissolved inorganic nutrients (dissolved nitrogen and dissolved phosphorus)

			upland-TN and TP baseflow samples represent total dissolved nutrients, which include both organic and inorganic forms
			upland-TSS, which is primarily associated with surface runoff, includes organic material that contains nutrients
			upland-Baseflow rating curves can be used in conjunction with total flow rating curves to back-calculate surface runoff nutrient loading
			upland-Surface runoff pollutant mass is composed of primarily particulate constituents
			upland-Particulate nutrient mass is primarily composed of organic material
			upland-Particulate-nutrient-mass to sediment-mass ratios represent sediment-associated nutrients
Tech	4-55	first	It was reasonable to assume that BF classification could be potentially assigned to any sample where the base-flow-to-total-flow ratio was greater than 50 percent. Therefore, this sample classification analysis was performed for each threshold value between 50 and 100 percent to see which threshold value resulted in the best correlation for both the BF and RO rating curves.
Tech	4-91	first	uplands-phosphorus & nitrogen- The load of total phosphorus (TP) from watershed sources was estimated by the Tahoe Watershed Model to be approximately 30 metric tons/year over the 1994-2004 calibration period (Table 4 38). Again, this agrees well with the overall value of 26 metric tons for TP reported using data collected prior to 1993 (Reuter et al. 2003). As noted above for TN, the latter estimate was not based on modeling, but rather on extrapolation of the LTIMP data to the whole basin.
Tech	4-110	last	stream channel-For the purpose of this evaluation, it was assumed that nitrogen loading from stream channel erosion was proportional to the ratio of stream load-phosphorus to stream load-nitrogen from upland runoff. This yielded a stream channel total nitrogen load of approximately 2 metric tons/year. While the uncertainty of this estimation is high, it only accounts for less than one percent of the total nitrogen budget from all sources. Therefore, the potential error associated with this estimate is negligible.
Tech	4-134	second	atmospheric deposition-The fall out of particles downwind of a local line or area source is modeled as logarithmic, based upon the observed fall off of fine particles at South Lake Tahoe (Barone et al. 1979). Fall out over the lake, however, was assumed to be less rapid due to the much lower surface roughness parameter (zo) over the water. In the total absence of these data, this parameter is set 3 to 5 times less than in forest conditions
Tech	4-134	fourth	atmospheric deposition-Assumptions associated with the calculation of deposition velocities (e.g., mean particle size within size fractions, limits on maximum deposition velocities) were varied over a range of feasible values to provide bounding estimates of the atmospheric deposition of nitrogen, phosphorus and particulate matter.
Tech	4-141	first	atmospheric deposition- only five years of estimates for annual particulate phosphorus are available

Tech	4-146	last	atmospheric deposition-Since the actual nutrient concentrations for each simulated storm used in the Lake Clarity Model could not be predicted, this was a reasonable approach to account for variation in wet deposition between years of varying precipitation. This approach also allows the introduction of wet deposition loading based on a more defined meteorological time scale (i.e. daily)
Tech	4-148	first	atmospheric deposition-CARB (2006) reported that the frequency of precipitation events is a better indicator of the wet deposition of atmospheric pollutants than the amount of precipitation. Thus, their analysis was based on the assumption that any precipitation, whether light or intense, will cleanse the air of pollutants.
Tech	5-15	second	Because the detailed data needed to develop regression equations to estimate particle fluxes exclusively for the urban land-uses was not available, a multiplication factor was developed and applied to the intervening zone, leading to the urban particle fluxes estimated using Rabidoux's equations. As mentioned earlier, for the particles flux from the non-urban portion of the intervening zones, it was assumed that Rabidoux's regression equations could be used. This assumption, while based on the best available data, does contribute to uncertainty.
Tech	5-17	second	Assuming a specific density of 2.56 g/cm^3 for soil (Troeh and Thompson 2005), this calculates into a weight per 1.5 µm fine sediment particle of:
Tech	5-28	last	The notion of a converter is based on a set of assumptions: (1) total suspended sediment in flow is dominated by inorganic soils, (2) the fine sediment particles (< 63 µm) can be characterized by having a density of 2.56 g/cm3, (3) the particles were spherical in shape, and (4) the distributions of the seven particle size classes between 0.5 – 64 µm used in the Lake Clarity Model followed the distributions presented in Table 5-13.
Tech	5-30	last	Estimated Land-use Specific Particle Loading - Applying the approach described above for particle size distribution as related to specific land-uses and employing the fine sediment to particle flux conversion, the following set of values was produced (Table 5-19). The importance particle loading from the urban regions is highlighted. The slight differences in particle numbers for the urban and non-urban land-uses (Comparison of Table 5-13 and Table 5-19) results from assumptions of the converter.
Tech	6-5	third	For intervening zones which include mostly urban areas the percentage of SRP, DOP and POP transformed to BAP were set to 95, 15, and 50, respectively. It was assumed that 100% of total dissolved inorganic nitrogen (NH_4 and NO_3) is bio-available.
Tech	6-10	Table 6-5	Table 6-5 summarizes the range of values taken as the limits for the model parameters; these are based on cited values in the literature. Whenever possible, the model parameters were calibrated within these ranges. However, the characteristics of every aquatic system are different. As discussed above, Lake Tahoe is a subalpine and oligotrophic lake that never freezes; therefore some of the parameters available in the literature may not be ideal. In cases where these types of model parameters do not contribute to a good match with the measured values (after many combinations with other parameters), a value higher or lower than the limits in Table 6-5 was assumed.

Tech	6-23	last	Groundwater contributes 12.8, 14.2 and 0 percent total nitrogen, total phosphorus and fine sediment loads, respectively, to Lake Tahoe. The estimated Secchi depth was examined assuming a ± 50 percent change in groundwater input conditions.
Tech	6-30	first	The year-to-year distribution of atmospheric load as dry deposition was not reported by CARB (2006). Based on the available data the daily load from wet and dry deposition was considered to be the same for all the years.
PRO	30	last	ES-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.
PRO	35	fourth	atmospheric-car emissions-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) 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; (2) 1.317 for all other sources based on the 2000 U.S. Census population estimates for the California and Nevada portions of the Basin
PRO	36	fifth	atmospheric-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/m2) for freeways, 0.035 g/m2 for major streets, 0.035 g/m2 for collector streets, and 0.32 g/m2 for local streets.
PRO	37	first	atmospheric-CARB assumes that each mile of unpaved road receives 10 vehicle passes each day.
PRO	49	last	atmospheric-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.
PRO	59	last	atmospheric-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.

PRO	59	last	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.
PRO	66-67	assumptions	atmospheric-Inherent in the estimates for on-road mobile sources are a number of assumptions (SHAW 2007), namely: (1) peak daily VMT in the Basin of 1,580,000 miles/day; (2) average trip length of 4.91 miles; (3) average vehicle occupancy of 1.82; (4) 57,000 vehicles per day driven by visitors arriving at he access points to the Basin; (5) average of 15 passengers per transit vehicle per hour; (6) shuttle bus service that is in operation 10 hours per day, 365 days a year; (7) total cost of shuttle bus service is $90/hr; (8) cost of new diesel electric hybrid bus is $300,000; (9) useful life of new buses is 10 years; (10) bus storage facility will accomodate 8.13 buses per acre; (11) park-and-ride lots will accomodate 125 automobiles per acre; (12) cost of bus storage facility and park-and-ride lots is $180,000 per acre; (13) useful life of bus storage facility and park-and-ride lots is 25 years
PRO	69	third	atmospheric-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.
PRO	70	Assumptions-1	The atmospheric deposition pollutant budget is assumed to be accurate.
PRO	70	Assumptions-2	The source activity for each atmospheric deposition source subcategories is assumed to be accurate.
PRO	70	Assumptions-3	The parameters used to estimate emissions (e.g., silt loading for paved roads, average vehicle weight) are assumed to be correct.
PRO	70	Assumptions-4	EPA's and CARB's emission factors are assumed to be correct.
PRO	70	Assumptions-5	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.
PRO	70	Assumptions-6	CARB's 2005 emission inventory for the California portion of the Basin is assumed to be representative of 2007 emissions.
PRO	70	Assumptions-7	The source profile test results providing the estimates of the content of elemental carbon and phosphorus are assumed to be accurate.
PRO	70	Assumptions-8	The published control efficiencies of different control measures are assumed to be accurate.
PRO	70	Assumptions-9	The list of control measures that are in force is assumed to be accurate.
PRO	71	Assumptions-10	The cost estimates for mobile sources obtained from Gordon Shaw of TRPA's Transportation Working Group are assumed to be accurate.

PRO	71	Assumptions-11	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.
PRO	71	Assumptions-12	The estimates of the transportable fraction of fugitive dust emissions as a function of distance from their source are assumed to be correct.
PRO	71	Assumptions-13	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.
PRO	71	Assumptions-14	The spatial distribution of pollutants within the Basin obtained from the TRPA is assumed to be accurate.
PRO	71	Assumptions-15	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.
PRO	71	Assumptions-16	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.
PRO	71	Assumptions-17	The load-reduction estimates are assumed to be proportional to emission-reduction estimates adjusted for the transportable fraction for different pollutants.
PRO	71	Assumptions-18	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.
PRO	71	Assumptions-19	The load-reduction estimates represent an average day on an annual basis without consideration for seasonal differences.
PRO	71	third	atmospheric-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.
PRO	71	last	atmospheric-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.
PRO	71	second	atmospheric-The SCG has focused on in-Basin controls to reduce inorganic nitrogen, while ignoring out-of-Basin sources.
PRO	82	last	uplands-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.

PRO	86	second	uplands- 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.
PRO	90	second	uplands-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)
PRO	91	first	uplands-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.
PRO	92	first bullet point	uplands UGSCG- 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.
PRO	93	first bullet point	uplands UGSCG- 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.
PRO	93	second bullet point	uplands UGSCG- 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).
PRO	93	third bullet point	uplands UGSCG- 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.

PRO	93	second	uplands UGSCG- 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.
PRO	93	second	uplands UGSCG- 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.
PRO	94	fourth	uplands- 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.
			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.
PRO	97	assumptions	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.

PRO	98	first	uplands- Table 3-5. 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.
PRO	98	second	uplands- Therefore, the design assumption for HSC-3 is storage of 1 inch of runoff per impervious acre.
PRO	98	last	uplands- Figure 3-2 illustrates the estimated PCO performance of each HSC according to the design assumptions described above.
PRO	99	second	uplands- 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.
PRO	103	first	uplands-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.
PRO	108	second	groundwater- 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).
PRO	108	third	groundwater-PSC-4 for Tier 2 assumes that each municipality will implement the complete potential action plans as outlined and prioritized by the ACOE (2003b).
PRO	112	first	groundwater-PSCs are assumed to reduce the nutrients and particles available for transport within urban storm water.

PRO	113	last	groundwater- 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.
PRO	113	last	groundwater- 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.
PRO	114	second	groundwater- 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 x 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).
PRO	116	second	groundwater- 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.
PRO	118	second	uplands- 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.
PRO	123	Assumptions	uplands- 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.
PRO	123	first	uplands- 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.
PRO	127	last	uplands- 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).
PRO	128	first bullet point	uplands- 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.

PRO	128	second bullet point	uplands- 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.
	134		Watershed and Storm Water Runoff: (1) 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; (2) 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; (3) 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.
PRO	134	UGSCG assumptions-stormwater	Collection System: (1) 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; (2) Infrastructure improvements for the collection system are at the spatial scale of application assumed for Tier 1 in a concentrated-moderate Setting; (3) The collection system draining to localized storage does not involve pumping.

	134		Localized Storage and Pumping: (1) 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; (2) Localize storage provides some capacity to improve capture for variable flows and settle coarse sediment to improve pump operations; (3) 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 .
	136		Regional Storage: (1) 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; (2) Regional storage is outside, but directly adjacent to the urban subwatersheds within a mile of urban development. Acquisition of undeveloped land is assumed.
	136		Treatment System-Targeted pollutants- 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.
	136		Treatment System-Selected system and estimated performance- 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.
	137		Outfall for Treated- Microfiltration Process Description- 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.
	138		Outfall for Treated- Estimated Performance- 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.
PRO	139	last	stormwater- Bypassed flows for SWT are assumed to discharge to surface waters at influent concentrations.

PRO	141	first	stormwater- The analysis methodology for a concentrated-steep Setting Tier 1 is shown in Figure 3-13. The Tier 1 routing is more complicated wthan the Tier 2 routing because the spatial scale of PCO implementation varies within a setting. This assumption is necessary because it represents existing practice.
PRO	144	last	stormwater- Table 3-21- 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.
PRO	145	second	stormwater- 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.
PRO	145	last	stormwater- 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).
PRO	146	first	stormwater- 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.
PRO	147	Table 3-22	stormwater- Table 3-22 provides a summary of the assumed infiltration rates for each PCO. PCO Assumed infiltration rate (in/hr) SWT-1A 0.2 SWT-1B 0.3 SWT-2A 0.05 SWT-2B 0.1
PRO	148	last	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.

PRO	153	first bullet point	uplands- 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.
PRO	155	first	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.
PRO	156	second	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.
PRO	156	last	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.
PRO	161	last	Tier 1- The assumed spatial scale of application (See Section 5) strongly influences pollutant load reductions achieved, as well as overall costs.
PRO	162	first	Tier 2- 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. (1) 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; (2) 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.
PRO	162	second	P&T Tier- 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.
PRO	174	third	forest- 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.

PRO	174	last	forest- 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).
PRO	177	second	forest- 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.
PRO	202-203	Assumptions	Forest- upaved road: (1) Annual maintenance will be performed on waterbars, rock-lined ditches and road surface (Tiers 1 and 2); (2) Treatments are based on highly disturbed soil conditions typical of unpaved roads. If soil is not highly disturbed, treatment costs would be lower; (3) Functional life of Tier 1 and 2 treatments is infinite, as long as regular maintenance is performed; (4) Functional life of Tier 3 treatments is infinite, as long as treatments are properly implemented and treated areas are not re-disturbed ski runs: (1) Annual maintenance will be performed on waterbars and ski run surface (Tiers 1 and 2); (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; (3) Functional life of Tier 3 treatments is infinite, as long as treatments are properly implemented and treated areas are not re-disturbed.

			undeveloped forested areas: (1) 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; (2) Assume tilling/ripping treatments will be done using mechanized equipment. If done by hand crews, costs will increase; (3) 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; (4) 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; (5) 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; (6) Functional life of all treatments is infinite, as long as treatments are properly implemented and treated areas are not re-disturbed; (7) 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- slope angle: 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: In estimating costs for Settings A and B, the FUSCG assumed that all ski runs and roads are in drastically disturbed condition; road access: In estimating treatment costs, the FUSCG assumed reasonable access to treatment areas for all Settings; the *true* cost of restoration: 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.
PRO	212	fourth	stream- 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.

PRO	225	second	stream- 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.
PRO	229	first	stream- 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.
PRO	237	second	stream- 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.
PRO	240	second	streams- 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.
PRO	245	second	stream- 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).
PRO	255	second bullet point	Ch. 6- 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.
PRO	255	fourth bullet point	CH. 6- In most cases, the SCGs presented average values that represent the wide ranges of many of their estimates.
PRO	256	second	CH. 6- 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.
IWQMS	16	last	This analysis assumes that all reductions for atmospheric, forest and stream channel sources are complete by the third milestone.

IWQMS	18-19	assumptions-1	The minimum application level for current best practices (Tier 1) controls on urban areas in the third period is 20 percent. This assumption is necessary because implementers have already completed or are planning projects that will achieve this level before innovative practices (Tier 2) or new technologies (Tier 3) are available.
IWQMS	18-19	assumptions-2	The maximum application level for pollutant controls to any given area is 80 percent. This reflects the understanding that implementation issues occur that cannot be determined at a Basin-wide planning scale. In particular, some areas might not be accessible, or pollutant reductions might not be achievable at certain sites. Site-specific challenges such as high groundwater, utility line interference, or bedrock intrusions could also make projects excessively costly in some areas.
IWQMS	18-19	assumptions-3	For the purposes of quantitative analysis, the periods were assumed to be 5 years. This assumption allows the load reductions necessary to reach the Clarity Challenge to be achieved in 15 years. However, the Recommended Strategy and the milestones do not need to be tied to any particular number of years.
IWQMS	18-19	assumptions-4	Funding in the amount of $500 million is available and expendable in each 5-year period. This assumption is considered challenging but reasonable because committed funding was reported as $1.123 billion during the first 8 years of the Lake Tahoe Environmental Improvement Program (EIP) (TRPA 2006, p. 2). Approximately 50 percent of this funding was expended on projects and research for water quality purposes (TRPA 2006, p. 7). Although the EIP's 8-year period is longer than the 5 years assumed for this analysis, the assumption is plausible given the implementation capacity that the Basin has gained during the first round of the EIP. This is the extent of the feasibility analysis that was considered for this assumption. The Recommended Strategy's cost estimates are above and beyond the previous funding of the EIP.
IWQMS	18-19	assumptions-5	Advancements in atmospheric pollutant control technology can be implemented more quickly than advancements in urban pollutant controls. Urban control advancements necessitate new technology that must be researched, demonstrated and pilot tested. Higher technology controls for atmospheric sources, such as fine sediment-effective sweepers used in concrete manufacturing plants, are currently available.
IWQMS	18-19	assumptions-6	The lag between the achievement of necessary load reductions and lake clarity response is assumed to be 10 years. The TMDL Technical Report includes an analysis using the Clarity Model that shows lake clarity achieving the clarity target within 15 years if all urban pollutant loads are reduced at a rate of 4.5 percent per year (Lahontan and NDEP 2007a, p. 5-56). At the outer limit, this implies that lake clarity lag could not be longer than 15 years. Another study of precipitation rates and their effect on Secchi depth measurements showed that the majority of clarity effects were noted within 2 years of precipitation extremes. Thus, it is reasonable to assume that the lake's clarity lag will be between 2 and 15 years.

IWQMS	18-19	assumptions-7	Technology limitations determine early ability to produce advanced practices and new technology (Tiers 2 and 3, respectively) projects in the urban source category. This understanding results in three assumptions for the milestone analysis: (1) Research into new technology and general applicability of advanced practices; (2) Limited application of advanced practices and pilot implementation of new technologies; (3) Widespread availability of advanced practices and innovative technology
IWQMS	67	first	The pollutant load reductions for the load target were calculated by linearly extrapolating the average load reduction rates through the fourth milestone to achieve the numeric target defined by using the Lake Clarity Model.
IWQMS	69	Approach 1-Assumptions	This analysis assumes that load reduction capability is primarily determined by the dominant loading source and that other loading sources within a jurisdiction will not significantly change the jurisdiction's ability to reduce overall loads. This assumption is valid in cases where forested land uses make up a small proportion of loading within a predominantly urban area. This assumption is less valid when urban land uses make up a small part of a forested area because there is a larger potential for urban areas to reduce fine sediment particles.
IWQMS	72	Approach 2-Assumptions	This analysis assumes that load reductions at the jurisdictional scale can be achieved in urban and forested land uses similar to the average reductions for urban and forest land uses developed in the Recommended Strategy. It does not differentiate between load reduction potential among the various urban and forest land use categories. It also does not consider any spatially variability in load patterns associated with climate and hydrologic variability around the basin.
IWQMS	75	Approach 3-Assumptions	This analysis assumes that load reductions at the jurisdictional scale can be achieved in urban and forested settings similar to the average reductions for those settings developed in the Recommended Strategy. It does not differentiate between load reduction potential within settings; however, it begins to factor in differences in load reduction potential between settings. Because similar settings are fairly well distributed around the basin, Approach III also does not explicitly consider any spatial variability in load patterns associated with climate and hydrologic variability around the basin.
IWQMS	77	Approach 4-Assumptions	This analysis assumes that pollutant controls will be implemented in every subbasin according to the Recommended Strategy application levels for Tiers 1, 2, and 3. While actual pollutant controls are likely to be implemented more intensively in certain subbasins and others will receive less treatment, this analysis approximates the load reductions possible from implementing pollutant controls throughout the watershed.
IWQMS	80	Approach 5-Assumptions	This approach assumes that the undeveloped load can be approximated in the watershed model by converting all areas to Vegetated, according to the five established erosion potential groups. This approach is also based on the assumption that anthropogenic loads of pollutants are controllable for all sources with the same effectiveness regardless of their spatial location in the watershed.

IWQMS	89	second	The EPA document Options for Expressing Daily Loads in TMDLs (EPA 2007) recommends guidelines for expressing daily loads in TMDLs from the following assumptions: (1) 1. Methods and information used to develop the daily load should be consistent with the approach used to develop the loading analysis; (2) 2. The analysis should avoid added analytical burden without providing added benefit; (3) 3. The daily load expression should incorporate terms that address acceptable variability in loading under the long-term loading allocation. Because many TMDLs are developed for precipitation driven parameters, one number will often not represent an adequate daily load value. Rather, a range of values might need to be presented to account for allowable differences in loading due to seasonal or flow-related conditions (e.g., daily maximum and daily median); (4) 4. The specific application (e.g., data used, values selected) should be based on knowledge and consideration of site-specific characteristics and priorities; (5) 5. The TMDL analysis on which the daily load expression is based fully meets the EPA requirements for approval, is appropriate for the specific pollutant and waterbody type, and results in attainment of water quality criteria.
IWQMS	A-7	Assumptions and Rationale	The SCG products for each setting and tier combination represent maximum application of the associated controls. These controls were quantity based, such that depending on the SCG and setting, controls are expressed in terms of amount of area treated, number of objects controlled, or length of segment treated. For this reason, it was both possible and appropriate to scale the LOA for these controls according to the applicable quantity. For each SCG, LOA was scaled linearly from 0 percent (baseline condition with no controls) to 100 percent (maximum application) for a given Tier and setting combination. Pollutant reduction was linearly scaled between baseline loads to reduced loads associated with each setting and tier combination. Associated management costs were scaled from zero cost for the baseline to 100 percent of the cost for full application to a given setting and tier combination.
IWQMS	A-7	Assumptions and Rationale	The setting is the smallest unit for management, for which there is a fixed manageable quantity. For example, given a specific Urban Upland setting, the fixed manageable quantity is area. Therefore, a 50 percent application level of Tier 1 means that the suite of controls associated with Tier 1 are applied to 50 percent of the total available area. If during the solution search routine, additional controls are found to be required for that specific setting in order to meet the defined objectives, it can be achieved by either (1) increasing the LOA for that particular Tier, (2) applying a different LOA of another Tier (i.e. Tier 2) which has a higher treatment potential, or applying combinations of LOA for more than one Tier (i.e. 50 percent Tier 1, and 20 percent Tier 2, for a total of 70 percent of the total area being treated).
IWQMS	A-8	Assumptions and Rationale	The maximum LOA for any given setting was assumed to be 80 percent. For practical reasons, it was thought unlikely that any given combination of tiers could be applied so as to treat 100 percent of a given setting. There will always be urban areas which cannot be treated due to restricted access or impracticability, remote forest settings which are naturally erodible and/or are not accessible by conventional means, private property air pollutant sources or vehicle emissions that cannot be managed for various reasons, or stream segments which cannot be easily stabilized and restored.

IWQMS	A-8	Assumptions and Rationale	There were certain assumptions associated with LOA constraints for the various packages. These include definition of the base package as well as selected minimum/maximum LOA constraints for some of the exploratory packages. These were introduced to limit the selection of some of the more sophisticated, but untested technologies. For example, lets assume that Tier 1 of a given SCG and setting is composed of common conventional practices, while Tier 2 includes some sophisticated and innovative practices. A scenario that focuses on traditional control technologies may restrict the selection of Tier 2 practices, in favor of Tier 1; whereas a scenario that focuses on innovative practices might constrain the selection of Tier 1, and allow more selection of Tier 2 practices.
IWQMS	A-9	second	Meta-heuristic optimization approaches are based on random number search techniques. Uncertainty increases with the prevalence of local minimums to which the solution technique might become trapped, and miss potentially better solutions within its search vicinity.