DRAFT

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
^{o}C	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

Executive Summary

This document is the Staff Report that summarizes the Numeric Target and Pollutant Source Analysis and describes the Load Allocations, Implementation Plan, and Adaptive Management 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 6224 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 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. The Clean Water Act also requires states to establish total maximum daily loads (TMDLs) for such waters. The deep water transparency standard for Lake Tahoe is the average annual Secchi depth measured between 1967 and 1971, an annual average Secchi depth of 29.7 meters (97.4 feet).

The transparency standard for Lake Tahoe has not been met since its adoption. In 2007 the annual average Secchi depth was approximately 21.3 meters (70 feet), or 8.4 meters (27.6 feet) from the standard. Transparency loss is considered a water quality impairment from the input of nutrients and sediment. Consequently, Lake Tahoe is listed under Section 303(d) as impaired by input of nitrogen, phosphorus, and sediment. The goal of the Lake Tahoe TMDL is to set forth a plan to restore Lake Tahoe's historic transparency to 29.7 meters annual average Secchi depth.

The ongoing decline in Lake Tahoe's water quality 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 lake waters, accounting for roughly two thirds of the lake's impairment.

Source analysis for fine sediment and nutrients identified the various pollutant sources and estimated delivery of these pollutants to Lake Tahoe. Source categories include urban upland runoff, atmospheric deposition, forested upland runoff, stream channel erosion, and groundwater. The largest source of fine sediment particles to Lake Tahoe is stormwater runoff from urban areas, comprising 72 percent of the total fine sediment contribution. The urban uplands also present the largest opportunity to reduce fine sediment particle contributions to the lake. Phosphorus contributions to the lake from runoff are associated with sediment. The largest source of nitrogen to the lake is atmospheric deposition, accounting for 55 percent of the nitrogen loading. Most atmospheric deposition of pollutants originates in the Lake Tahoe basin from motor vehicles, road dust and, to a lesser degree, wood burning.

To achieve the transparency standard, estimated basin-wide reductions for fine sediment particles, phosphorus, and nitrogen are 65 percent, 35 percent, and 10 percent, respectively. Achieving these final load reductions may take 60 years or more.

A 20-year interim transparency goal, known as the Clarity Challenge, was set. The Clarity Challenge establishes a reasonable goal for the 20-year planning horizon, which lines up with updates to the 20-year TRPA Regional Plan and the US Forest Service-Lake Tahoe Basin Management Unit Forest Plan Revision. The Clarity Challenge proposes basin-wide pollutant load reductions to be achieved within 15 years, followed by five years of monitoring to confirm that about 24 meters of Secchi depth transparency has been reached. Successful implementation requires a 32 percent reduction of fine sediment particles, a 14 percent reduction in phosphorus, and a 4 percent reduction in nitrogen. Achieving the interim transparency depth within the first 20 years of TMDL implementation will be sufficient evidence the long-term transparency loss trend has been reversed.

The Lake Tahoe TMDL's Pollutant Reduction Opportunity Report (PRO) 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 PRO estimated potential pollutant load reductions and associated costs at a basin-wide scale for implementation at several levels of effort. This is the first comprehensive estimate of possible load reductions based on differing levels of effort applied to the major pollutant sources. This information formed the basis for the development of an integrated strategy to protect water quality.

The Integrated Water Quality Management Strategy Report combines selected pollutant controls from each of the four primary sources of fine sediment and nutrients to develop several candidate integrated strategies. These strategies provided the basis for engaging project implementers and public stakeholders during an extensive public input process. Input and comments from this series of communications helped to guide the development of a Recommended Strategy to meet the Clarity Challenge goal. The Recommended Strategy focuses on the reduction of fine sediment particles because it is the pollutant that contributes the most to the impairment of Lake Tahoe

The Recommended Strategy incorporates the best available science and extensive stakeholder input to describe a Basin-wide strategy to inform the Lake Tahoe TMDL implementation plan. The Recommended Strategy is a non-prescriptive approach that distributes pollutant reduction needed from each pollutant source category to achieve the Clarity Challenge. Of the 32 percent required reduction in the overall fine sediment particle loading to meet the Clarity Challenge, 24.5 percent can come from the urban uplands, 4.6 percent from atmospheric deposition, 1.8 percent from the stream channel erosion source, and 1 percent from the forested uplands. These basin-wide reductions translate to source category specific fine sediment particle reductions of 34 percent of the urban upland load, 30 percent of the atmospheric load, 53 percent of the loading from stream channel erosion, and 12 percent of the forest uplands load. The Recommended Strategy also includes actions to reduce nitrogen and phosphorus loading.

Stormwater from urban uplands is considered a point source on the California side of the Lake Tahoe basin. The City of South Lake Tahoe, El Dorado County, Placer County, Caltrans, and the Nevada Department of Transportation are regulated with National Pollutant Discharge Elimination System permits and will be assigned jurisdiction specific waste load allocations.

To attain the Lake Tahoe TMDL Clarity Challenge, specific implementation actions need to be taken. Implementation actions are designed to encourage and build upon on-going pollutant reduction programs. The focus of these actions is the urban uplands, which contribute the majority of fine sediment particles to the lake. For urban jurisdictions, pollutant reduction targets will be detailed in NPDES permits, Memoranda Of Implementation, or other regulatory measures.

Monitoring is necessary to determine if implementation actions are resulting in the predicted outcome to achieve of water quality standards. Comprehensive monitoring efforts will be coordinated by regional agency stakeholders to measure water quality impacts at multiple scales.

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 Regional Water Board will conduct during the 20 year implementation timeframe of the Lake Tahoe TMDL. Adaptive management will address ongoing changes from climate change, catastrophic wildfires, and other significant events. At 5 years from the TMDL effective date, resource managers will evaluate load allocations and the TMDL implementation approach and update as needed.

This TMDL Report and the adoption and approval process are fully compliant with the California Environmental Quality Act (CEQA). The adoption of the Lake Tahoe TMDL will not have a significant adverse impact on the environment

PLACEHOLDER: ECONOMICS SECTION ELUCIDATED IN CEQA ANALYSIS
PLACEHOLDER: PUBLIC PARTICIPATION AND OUTREACH

1 Introduction

Lake Tahoe is a unique environmental treasure located in the Sierra Nevada mountains 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.

Lake Tahoe's famed transparency and clarity have shown a significant decline since regular monitoring began in the 1960's. Clarity and transparency 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 (TMDL's) to address their impairments. This TMDL has been developed to address Lake Tahoe's optical impairment and restore its transparency and clarity to the levels recorded when regular monitoring began to protect the aesthetic beneficial uses of the lake.

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, while clarity is the depth light can penetrate the water column.

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 clarity, their sources, and the plan to achieve existing water quality objectives. Three pollutants — fine sediment particles, nitrogen, and phosphorus — are responsible for the clarity and 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.

1.2 Involved Entities

The California Regional Water Quality Control Board, Lahontan Region (Water Board), and the Nevada Department 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) requirements and 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.Pathway2007.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. Consequently, the Lake Tahoe TMDL effort is the most comprehensive evaluation of Lake Tahoe's clarity 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

This Lake Tahoe TMDL summarizes information from three distinct supplementary documents: The Lake Tahoe TMDL Technical Report, the Pollutant Reduction Opportunity Report, and the Integrated Water Quality Management Strategy Report. These three supplementary documents support the scientific and technical conclusions in the Lake Tahoe TMDL.

The Lake Tahoe TMDL Technical Report - June 2009 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 and editing, parts of the TMDL Technical Report were updated in June 2009.

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 basin-wide recommended strategy.

Previously, the TMDL program referenced the pollutant of concern as fine sediment particles less than 20 micrometers (µm) in size. The September 2007 draft Lake Tahoe TMDL Technical Report, the Pollutant Reduction Opportunity Report, and the Integrated Water Quality Management Strategy Report all describe fine sediment particles as those less than 20 µm. These references are in error. 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 were correctly based on a fine sediment particle definition of < 16 µm. The error has been corrected in the June 2009 version of the 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 English 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 4,003 feet (1,220 meters) above lake level, steep slopes, and erosive granitic soils. Volcanic rocks and soils are also present in some areas.

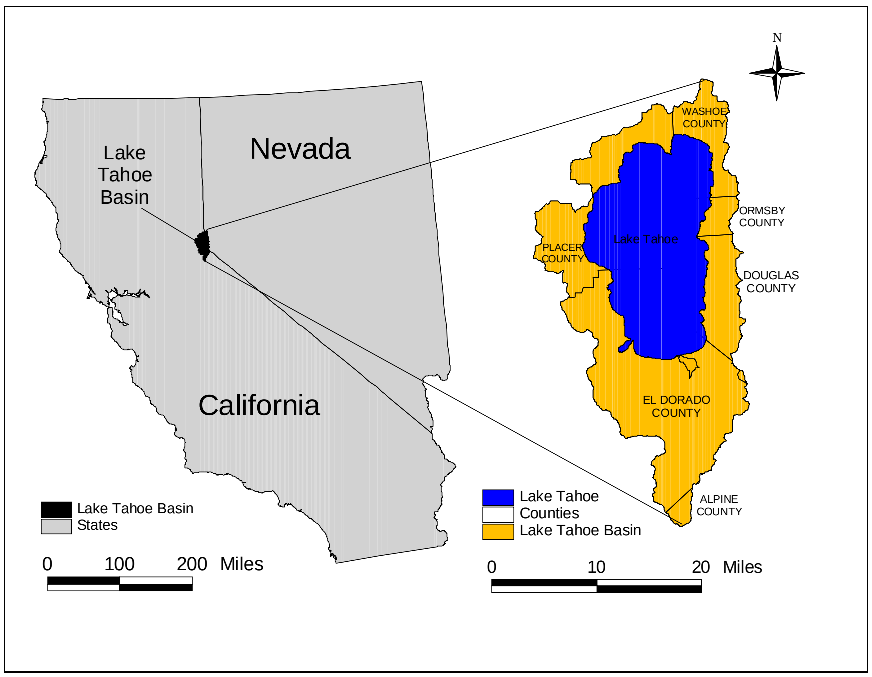

Figure 2-1. Location of the Lake Tahoe basin.

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 generally low-nutrient granitic soils, with more nutrient-rich volcanic soils 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 (1870's – 1910's), livestock grazing (1900's – 1950's), urbanization of the lakeshore and lowest-lying parts of the basin beginning in the 1950's (USDA 2000), and public acquisition and protection of thousands of acres of sensitive lands since the mid-1960's. 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.

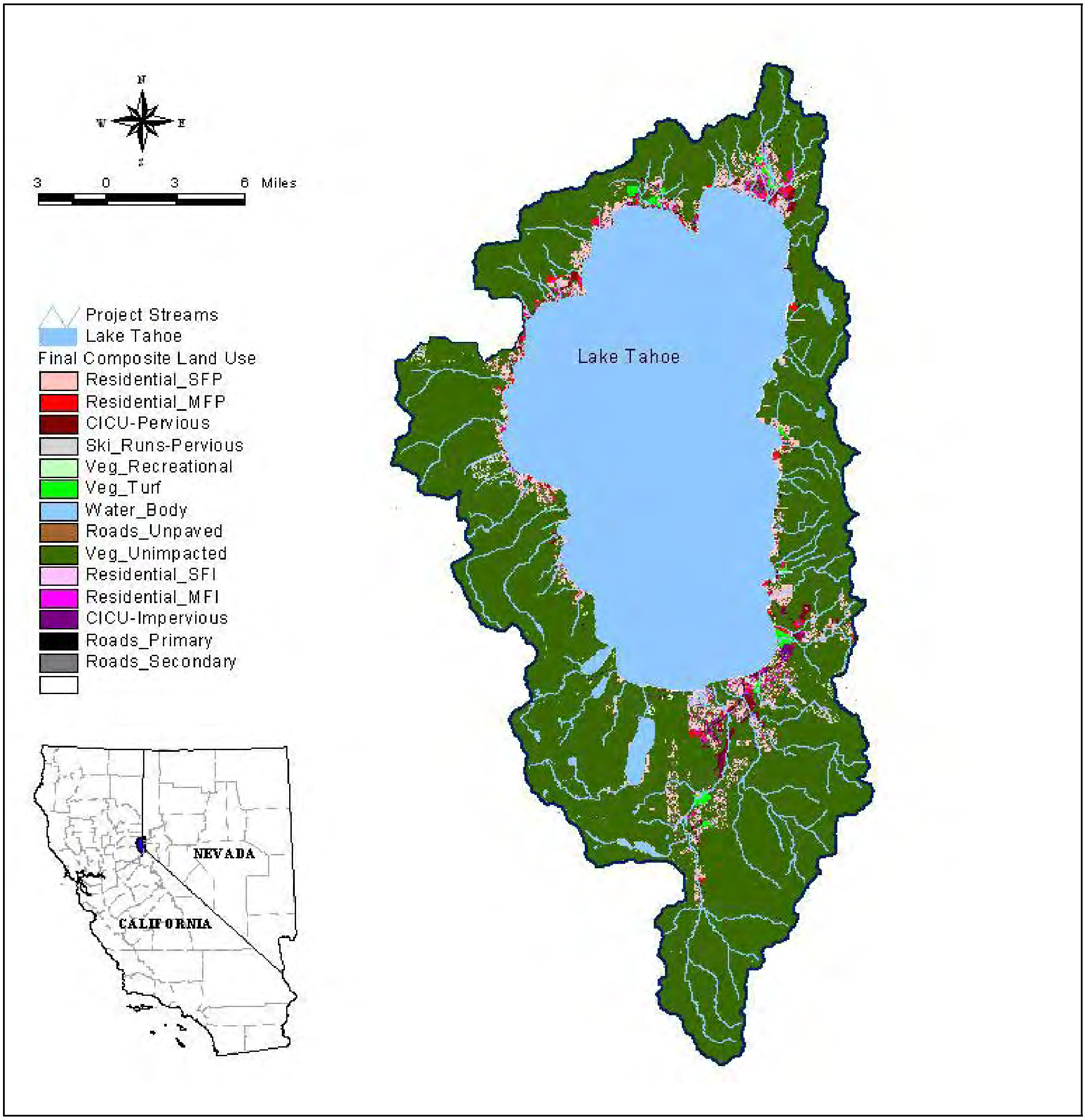

Figure 2-2. Land-uses in the Lake Tahoe basin (Tetra Tech unpublished).

Most urban development exists along the lake’s shoreline, with the largest concentrations at South Lake Tahoe in the southeast, 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 and 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 like 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 mountains 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 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 has 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, and material in the water. Material in the water can include inorganic particles (like sediment, minerals, and nutrients) and organic particles (like floating algae and other phytoplankton, and leaves). 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 photometer to measure the vertical extinction of light per meter of water.

3.1 Particles Absorb and Scatter Light

Inorganic and organic particles in water both absorb and scatter light, while water molecules only scatter light (Figure 3-1). The absorption and scattering of light affects the rate light intensity decreases with depth. Therefore, more particles contribute to additional absorption and scattering of light, which means a greater rate of light attenuation with depth.

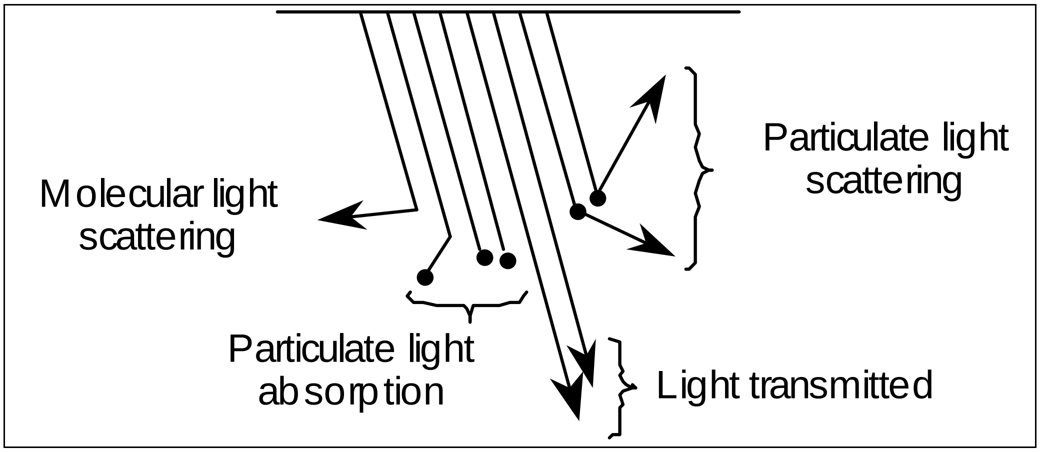

Figure 3-1. Conceptual model of the pathway of light in water (Swift 2004).

Secchi depth has long been known to be controlled by both absorption and scattering of light by particles. This can be seen in recent Secchi depth data collected in Lake Tahoe (Figure 3-2). These data show the significant relationship between the measured number of particles in Lake Tahoe and the corresponding Secchi depth (Swift 2004).

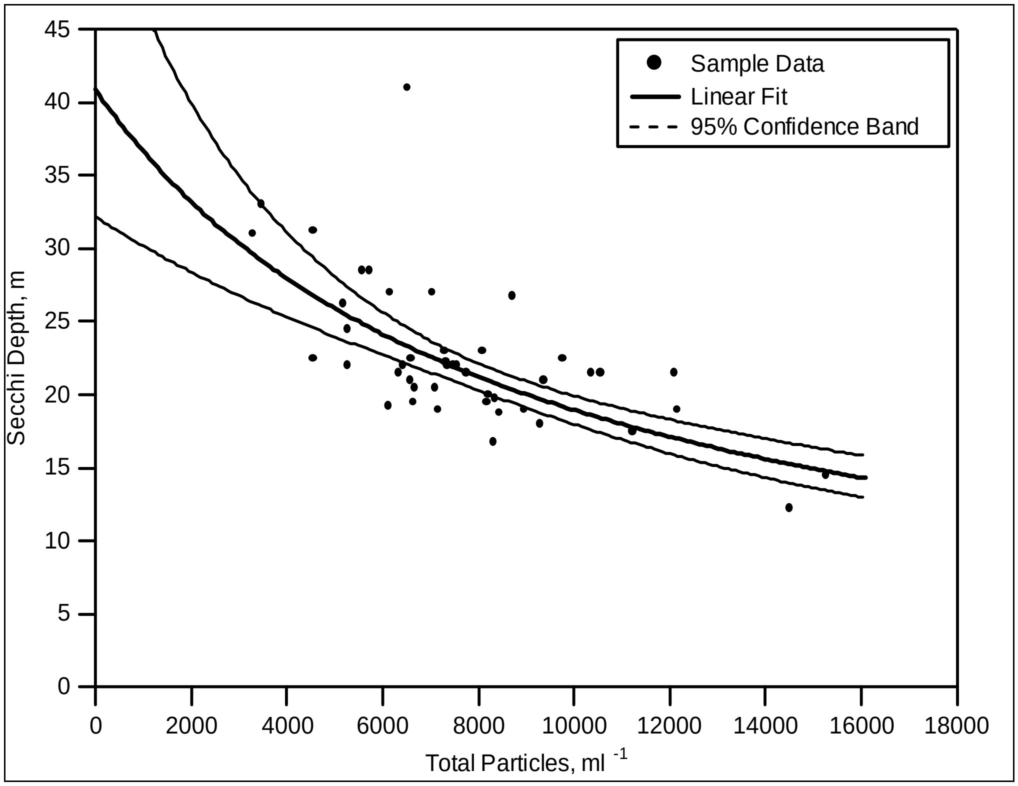

Figure 3-2. Relationship between in-lake particle number and Secchi depth (Swift 2004).

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 particles in Lake Tahoe streams (Rabidoux 2005). The results of these studies indicate that the finer fraction of inorganic material (1 – 10 µm) has the greatest impact on light scattering (Figure 3-3) and hence clarity.

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.

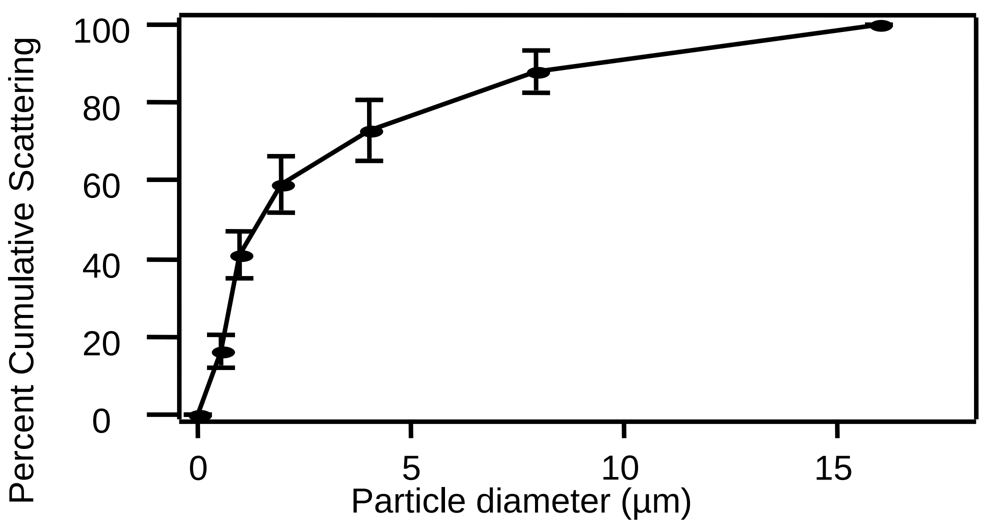

Figure 3-3. Influence of particle size on light scattering (modified from Swift et al. 2006).

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 3-4). 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.

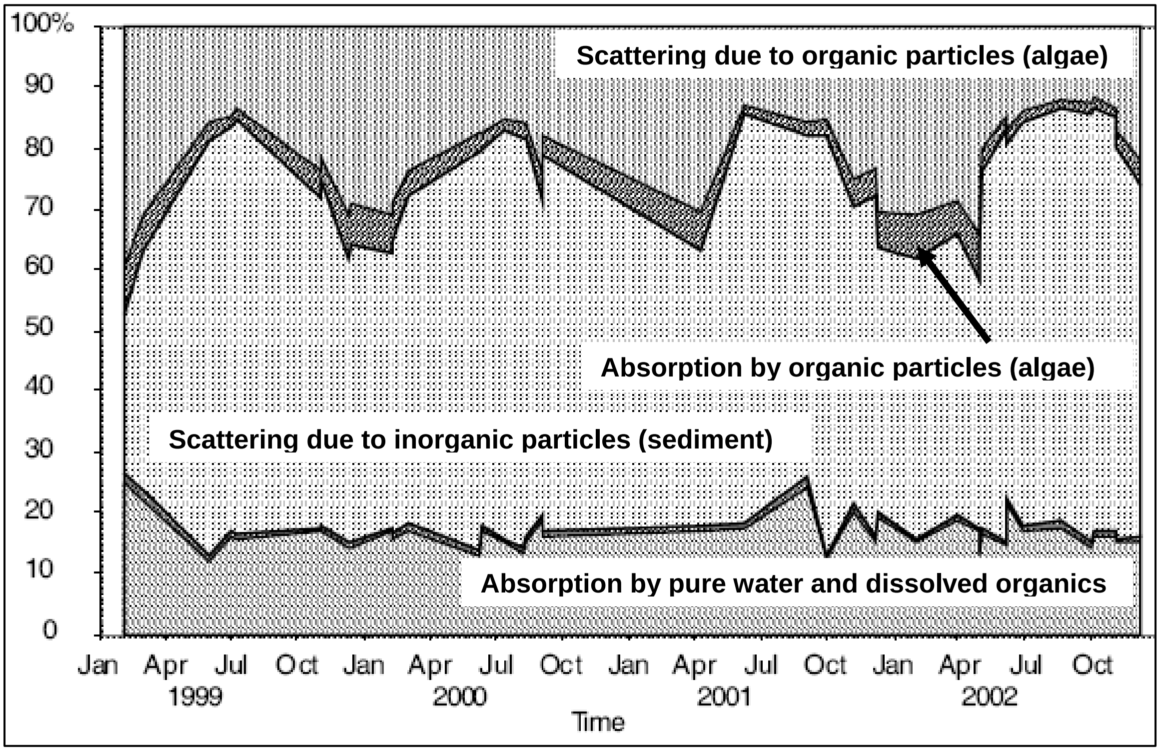

Figure 3-4. Results of an optical model showing the percentage of light absorption and scattering caused by different types of particles, at different times of the year (modified from Swift et al. 2006).

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

Primary productivity is the rate at which organisms (like phytoplankton) convert inorganic materials and sunlight into food, through the process of photosynthesis. A high primary productivity means organisms can more quickly produce food for themselves, which means more energy for metabolic activity and growth.

Primary productivity of phytoplankton in Lake Tahoe has increased steadily and significantly, by about 725 percent over pre-disturbance conditions (before 1850). As noted, this increase is a contributing factor to lake transparency decline. Before 1850, researchers estimate phytoplankton primary productivity was 28 g C/m^2/year (Heyvaert 1998). By 1959, primary productivity, as measured in lake water, had increased by about 30 percent over pre-disturbance conditions to slightly less than 40 g C/m^2/year (Goldman 1974). By 2005, measured primary productivity had increased approximately 500 percent over 1959 conditions, to 203 g C/m^2/year (UC Davis – TERC 2008). Although conditions vary year-to-year, primary productivity data show a highly significant upward trend that continues at a rate of approximately 5 percent per year (Figure 3-5).

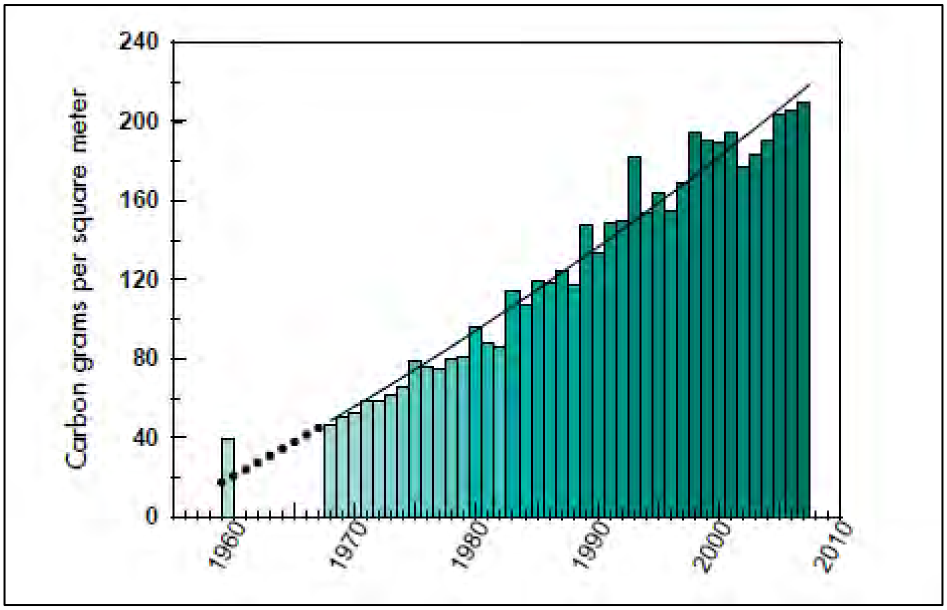

Figure 3-5. Annual average primary productivity in Lake Tahoe from approximately 25-30 measurements per year (UC Davis – TERC 2008).

Composition Changes in the Phytoplankton Community

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.

Similar Nutrient Concentrations across Lake Tahoe

Nitrogen and phosphorus conditions are similar at two sampling stations at Lake Tahoe (the UC Davis – TERC index and mid-lake stations). Specifically, the annual mean concentrations of nitrate and THP are similar in the euphotic zone (the depth of the water in the lake that is exposed to sufficient sunlight for photosynthesis) at both stations. From 1985 through 1993, nitrate at the index station was 4.9 ± 0.8 µg/L and slightly higher than the average concentration of 4.5 ± 1.0 µg/L at the mid-lake station (average of mean annual concentrations). THP was virtually identical at these two stations, with the average mean annual concentration equal to 3.0 µg/L at the index station and 2.9 µg/L for mid-lake.

Long-term Nitrogen and Phosphorus Trends

In the mid-1980's Lake Tahoe began to experience an increase in nitrogen entering the lake. This shift is due to accumulated anthropogenic 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).

Significant vertical mixing can also occur during the summer months (Pamlarsson and Schladow 2000). 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.

Another important mixing 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 mixes in 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 clarity. Cold, dense stream flow and associated pollutant loads will mix deeper in the lake while warmer flows will mix 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

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

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.

3.6 Nearshore Water Quality

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."

Like the deeper, open-waters 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.

The nearshore area is affected by surface loading either as direct discharge, tributary inflow, and groundwater loading. Indeed, watershed runoff must first pass through this area on route to the deeper waters. Water quality is historically measured in the nearshore as 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). Secchi depth cannot be used to measure nearshore clarity because the water is not deep enough here. Another indicator of near shore water quality is the abundance and distribution of periphyton, or attached filamentous algae. Attached algae grow excessively when extra nitrogen and phosphorus are present.

In addition, since 1995, Eurasian watermilfoil (*Myriophyllum spicatum*), the rooted aquatic plant, has experienced a dramatic spread in the nearshore region relative to historic conditions (Anderson 2006). 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

Much of the nearshore is characterized by low turbidity (e.g. < 0.15 Nephelometric Turbidity Units (NTU)). Measured nearshore turbidity levels that are chronically above these background levels most frequently occur near urbanized areas during periods of surface water discharge.

Turbidity measurements exceeding background levels have been observed in the south shore region of the Lake (Taylor et al. 2003). Specifically, the mouth of the Upper Truckee River was often characterized as having relatively high turbidity (sometimes greater than 3 NTU) while the Al Tahoe intervening zone, Bijou Creek, Tahoe Keys Marina and Ski Run Marina showed moderate levels of turbidity (typical values near or slightly above 1 NTU).

The highest turbidity measurements coincided with spring snowmelt and runoff, which also had the highest ratios of mineral to algal particle content. Summer thunderstorms had a lesser but still discernable effect on turbidity.

3.6.2 Attached Algae

For the largely shore-bound population, the first visible evidence of Lake Tahoe's eutrophication was the increased growth of attached algae along the shoreline in the 1960's (Goldman 1974). 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, thus significantly impacting the aesthetic beneficial use of the shorezone.

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.

4 Problem Statement

Studies over the past forty years have concluded that many factors related to the increasing resident and tourist population have interacted to degrade the quality of the Lake Tahoe basin's water, air, and land including soil erosion, air pollution, road construction and maintenance, and loss of natural landscapes that detain and infiltrate runoff (Goldman 1998, Reuter et al. 2003). Cumulatively these factors have impacted Lake Tahoe's famed transparency and clarity.

California has a strict 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). In 2002, because of clarity loss, Lake Tahoe was placed on Nevada's Section 303(d) list of impaired waterbodies (NDEP 2002). This chapter describes the changes in transparency and clarity, as well as on ecological communities within the lake.

4.1 Transparency and Clarity

Continuous long-term evaluation of water quality in Lake Tahoe between 1968 and 2007 has documented a decline of water transparency (commonly referred to as clarity) from an annual average of 31.2 meters to 21.4 meters, respectively (Jassby et al. 1999, 2003, UC Davis - TERC 2008). Transparency is expressed as Secchi depth and is the depth to which an observer can see a 25 cm diameter white disk lowered into the water from the surface. This long-term loss of transparency is both statistically significant ($p < 0.001$) and visually apparent (Figure 4-1).

> **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.

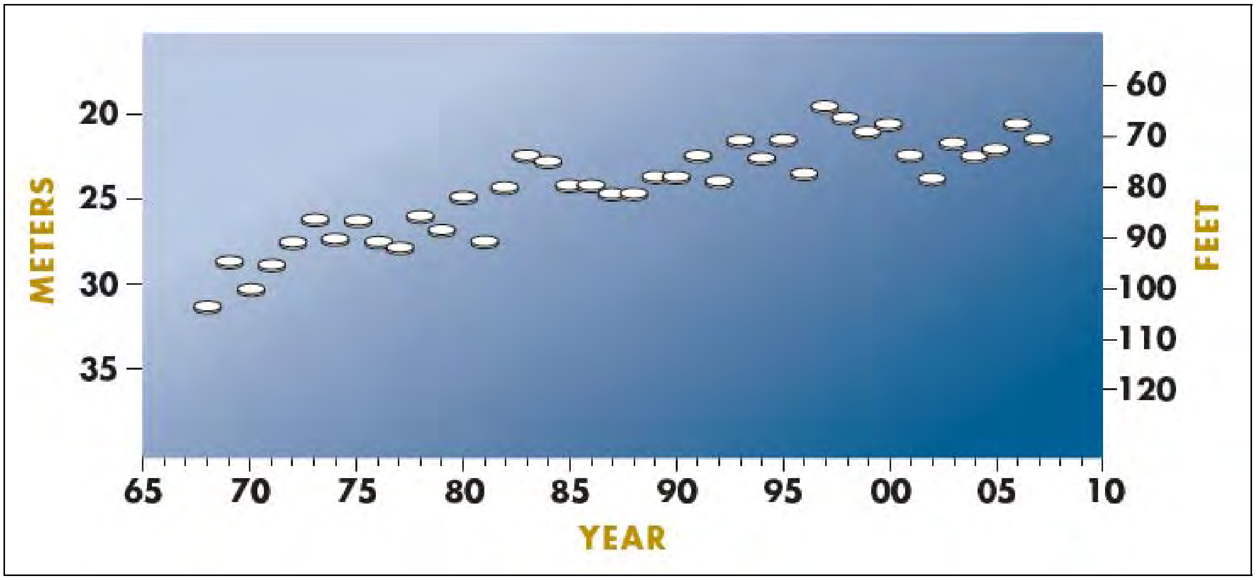

Figure 4-1. Average Annual Secchi Depth measurements (UC Davis – TERC unpublished).

In addition to a shallower Secchi depth (transparency), Lake Tahoe also now has a shallower depth for the vertical extinction of light (clarity). This means that light cannot penetrate as deep into the water. The light penetration zone (euphotic zone), has been as deep as about 100 meters at Lake Tahoe (Swift 2004), but over the past decade has largely ranged from 50 – 70 meters.

> **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.

Based on the most recent Secchi depth data for 2007 and applying a more sophisticated statistical approach known as a *generalized additive model*, it was recently reported that between 2001 and 2007 there was an apparent slowing in the rate of clarity loss (UC Davis-TERC 2008). Researchers caution that the rate of clarity loss could change; the seven 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 21.4 meters (70.2 feet) as measured in 2007 is 8 meters (27 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 2007 (Table 4-1).

Table 4-1. Annual Average Secchi Depth values for the period of record (UC Davis – TERC unpublished).

Year	Secchi Depth (m)	Year	Secchi Depth (m)
1968	31.22	1988	24.66
1969	28.57	1989	23.64
1970	30.21	1990	23.64
1971	28.74	1991	22.43
1972	27.41	1992	23.89
1973	26.08	1993	21.47
1974	27.21	1994	22.57
1975	26.11	1995	21.47
1976	27.38	1996	23.45
1977	27.75	1997	19.53
1978	25.95	1998	20.14
1979	26.72	1999	21.04
1980	24.82	2000	20.53
1981	27.39	2001	22.44
1982	24.31	2002	23.78
1983	22.38	2003	21.62
1984	22.79	2004	22.42
1985	24.20	2005	22.05
1986	24.08	2006	20.63
1987	24.65	2007	21.37

4.2 Ecological Communities

Reduced transparency and clarity have caused significant changes in the euphotic zone and the ecological communities found there. The deep chlorophyll maximum, a stratified segment of the euphotic zone where maximum algal concentrations occur, has shifted upward from 60 – 90 meters in the early 1970's to 40 – 70 meters more recently (Swift 2004). Changes in nutrient inputs to the lake have resulted in a significant change of the phytoplankton community from complete dominance by diatoms to the current condition where multiple algal groups share equally in phytoplankton composition (Hunter et al. 1990, Hunter 2004).

Food webs are also changing in bottom sediment (benthic) as well as deep open water (pelagic) communities (Vander Zanden et al. 2003, Chandra et al. 2005). Changes also are documented in communities of deep-water aquatic rooted plants, used as spawning and rearing habitat by lake trout (Beauchamp et al. 1992). These studies add further evidence that increased inputs of nutrients and fine sediment particles to Lake Tahoe have produced significant changes in the chemical, physical and biological condition of the lake.

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 antidegradation 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 nondegradation provisions.

5.2 States of California and Nevada

The state of California protects water quality through the California Water Code implemented by the State Water Resources Control Board (State Water Board) and nine California Regional Water Quality Control Boards (Regional Water Boards). The California Regional Water Quality Control Board, Lahontan Region (Lahontan 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 Water Board sets statewide policy to implement 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 groundwaters 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 and federal laws, the most important of which are the federal Clean Water Act 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. The Department of Conservation and Natural Resources is responsible for developing and implementing comprehensive plans to reduce or eliminate water pollution, consistent with federal legislation. Within the agency, the Nevada Division of Environmental Protection (NDEP) is the branch that implements the water quality protection programs, 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 (which includes clarity) as a quality to be protected through designation of the following beneficial uses: "non-contact water recreation" (in California) and "recreation not involving contact with water" (in Nevada). Accordingly, the two states also established numeric water quality objectives to protect the beneficial use of non-contact recreation. Applicable water quality objectives for the protection of the aesthetic beneficial uses include indicators of water column optical properties, nutrient concentrations, and various biological indicators (Table 5-1). In accordance with Article V of the Tahoe Regional Planning Compact, if one state has a more stringent objective than the other, the more stringent objective takes precedence (TRPA 1980).

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

Parameter	California[a]	Nevada[b]
Total Soluble Inorganic Nitrogen (mg/L)	NA[C]	Annual Average ≤ 0.025
Algal Growth Potential	The mean annual algal growth potential at any point in the lake 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.	The mean annual algal growth 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 ≤ 100	Jun – Sep Average ≤ 100
	Maximum ≤ 500	Single Value ≤ 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

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 open 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 Lahontan Water Board has adopted a Secchi depth transparency objective and the NDEP is evaluating the need for a similar objective.

The vertical extinction of light (clarity) is a measure of how far light can penetrate the water column, and thus is also a measure for deep open 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.

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 open 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 State Water Board and USEPA designated Lake Tahoe an Outstanding National Resource Water which requires the highest level of protection under the nondegradation objective. Consequently, no permanent or long-term reduction in water quality is allowable in Lake Tahoe (40 Code of Federal Regulations section 131.12(a)(3)).

The Lahontan Water 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.*

Nevada has designated Lake Tahoe as Water of Extraordinary Ecological or Aesthetic Value (Nevada Administrative Code 445A.1905.). Lake Tahoe is the only water body in the State of Nevada to receive this designation.

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[1].

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

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[1] 109.6 feet

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 it Regional Plan, Code of Ordinances, and Environmental Threshold Carrying Capacities (thresholds). Changes to the thresholds are needed to incorporate updated science and changes in law, address climate change relative to the Region's carbon footprint and address the risk of catastrophic wildfire.

In August 2007, the TRPA commenced its official public scoping of the environmental document for the update package. An Environmental Impact Statement (EIS) with alternatives is being prepared and TRPA is planning to bring the Regional Plan update package and the EIS to its Governing Board for action in December 2009, following a public comment and response period.

In the proposed update package, TRPA has committed to change its WQ-2 threshold to be consistent with the transparency standard as stated in the Lahontan Basin Plan. Specifically, TRPA proposes to use the annual average Secchi depth of 29.7 meters as its updated threshold standard.

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, Lahontan Basin Plan, NDEP Statutes, and the USFS Forest Plan. In addition to reviewing the water quality standards and thresholds, the Water Quality Technical 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.*

Having a single desired condition for off-shore Lake Tahoe clarity has enabled all the stakeholders to focus efforts on determining how best to restore the famed clarity. The Water Quality Technical Working Group also proposed associated indicators and standards to support the desired condition. The proposed indicators and standards are all aligned with the numeric target for 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 Lahontan 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 against degradation. Each of the three entities adopted its own water quality objectives to protect Lake Tahoe's aesthetic beneficial use, but not all the objectives are the same. This TMDL evaluated the various water quality objectives and selected the most appropriate and protective numeric target for the lake's deep water transparency and clarity.

The Lake Tahoe TMDL focuses solely on the deep water transparency and does not address shallow, nearshore conditions of the lake. The numeric target is defined as 29.7 meters average annual Secchi depth.

6.1 Transparency and Clarity Objectives

The Water Board has both transparency and clarity water quality objectives, while NDEP relies solely on a clarity objective. To determine the most appropriate numeric target (clarity or transparency), the relationship between transparency and clarity objectives was evaluated.

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 Lahontan Water Board transparency standard 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 Tahoe 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 Water Board transparency objective does not specify a Secchi depth measurement method. (Sawyer 2009).

Deep water *clarity* is measured as the vertical extinction coefficient (VEC) of light in the water column. The VEC is a measurement of the fraction of light held back per meter of water from particle absorption and scattering of the light. The Lahontan Water Board and NDEP 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.*

During the years 1967 – 1971, Secchi depth transparency measurements were in the range of 28.5 – 32.5 meters. During the same period, a total of 71 measured VEC values varied from 0.045 – 0.073 per meter, while three VEC measurements were recorded at ≥ 0.08 per meter (Swift 2004). From 1971 to 2002, VEC measurements have generally fluctuated from approximately 0.04 – 0.11 per meter, with no apparent trend. Yet, average annual Secchi depth transparency has continued to decrease from the period measured in 1967-1971. Therefore, the deep water transparency standard based on Secchi depth recorded from 1967-1971 is more protective than the clarity objective based on VEC.

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. The TRPA objective uses a winter average Secchi depth objective because measured light transmission is at its maximum during this season (Jassby et al. 1999). The TRPA winter objective does not reflect the entire year, so it is not protective of the transparency during the other three seasons, particularly during the spring months when snowmelt results in the greatest pollutant loads being delivered to the lake. Summer is typically when most people experience the visual quality of Lake Tahoe's deep water transparency. Consequently, the annual average Secchi depth is protective of all lake conditions and accounts for seasonal variability.

6.2 Historic Transparency Data

The Lahontan Water Board's transparency 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 and Watershed modeling 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 being based on the TRG data (UC Davis – TERC unpublished data).

Seasonal Variation of Transparency 1967-1971

The Lahontan Water Board transparency standard references a comparison of seasonal and annual mean Secchi depth values. The 1967-1971 recorded Secchi depths vary widely (UC Davis – TERC unpublished data).

The pollutant source analyses, Lake Clarity Modeling work, and load reduction estimates all evaluated annual average fine sediment particle, phosphorus and nitrogen loading conditions. Further, the seasonal variability in Secchi depth measurements is complicated by several factors unrelated to seasonal pollutant loading. Due to the limited amount of seasonal stormwater data available, the challenges associated with estimating load reductions on a seasonal basis, and the complexity of Lake Tahoe's thermal and hydro dynamic properties, the numeric target for the Lake Tahoe TMDL relies on the average annual value and not seasonal average values.

Though seasonal average is not part of the Lake Tahoe TMDL numeric target, it is useful to understand the factors influencing seasonal variation in Secchi depth measurements. Seasonal variation can be seen throughout the entire dataset.
In summer and early fall, transparency gradually increases for two reasons. First, the snow pack is smaller (mostly melted) so fewer sediment particles enter the lake from incoming waters. Second, beginning in June, thermal stratification within the lake intensifies, causing algae and other phytoplankton to stay at lower, colder depths.

In winter, water becomes less transparent because lake water is mixing (i.e., the thermocline erodes). Lake mixing occurs because surface water becomes colder due to cooler air temperatures, wind, and other climatic factors. Because the temperature difference between layers is less distinct, algae, other phytoplankton and other light-attenuating particles can travel upward, closer to the lake surface. Mixing brings suspended fine sediment particles closer to the surface, further decreasing transparency.

6.3 Clarity Challenge

The Lake Tahoe TMDL program has set an interim transparency goal called the Clarity Challenge. The Clarity Challenge represents a reasonable yet 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.

The Clarity Challenge establishes basin-wide fine sediment particle and nutrient load reductions adequate to achieve 23.5 to 24 meter Secchi depth measurements. Lake Clarity Model results suggest that five years of data are needed to clearly show a shift in the Secchi depth trend (Reuter, personal communication 2007). As such, the Clarity Challenge establishes load reduction targets to be achieved within the first 15 years of implementation to allow for five years of Secchi depth trend analysis with the 20-year plan horizon.

If met, the Clarity Challenge will mark a clear turning point from the decline in transparency and will 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 2009).

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. Fine inorganic particles have a significant impact on Lake Tahoe's clarity (e.g. Jassby et al. 1999, Perez-Losada 2001, Swift 2004, and Swift et al. 2006). 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 – 6 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**	**NA****
Shoreline Erosion		**2**	**2**	**1**
TOTAL		**397**	**46**	**481**

**NA=not applicable since it was assumed that groundwater does not transport fine sediment particles

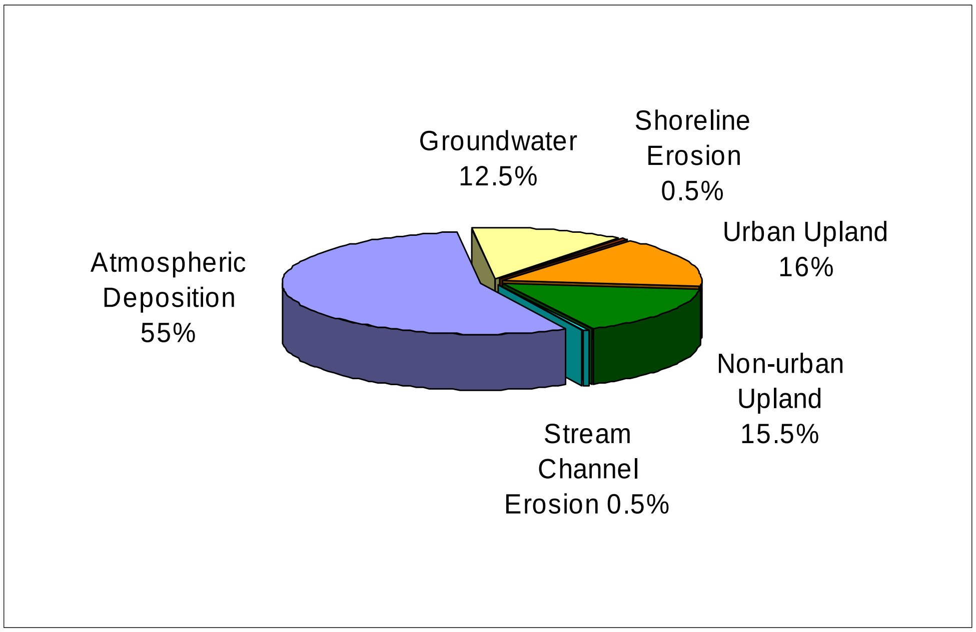

Figure 7-1. Percent Total Nitrogen Contribution per Source Category.

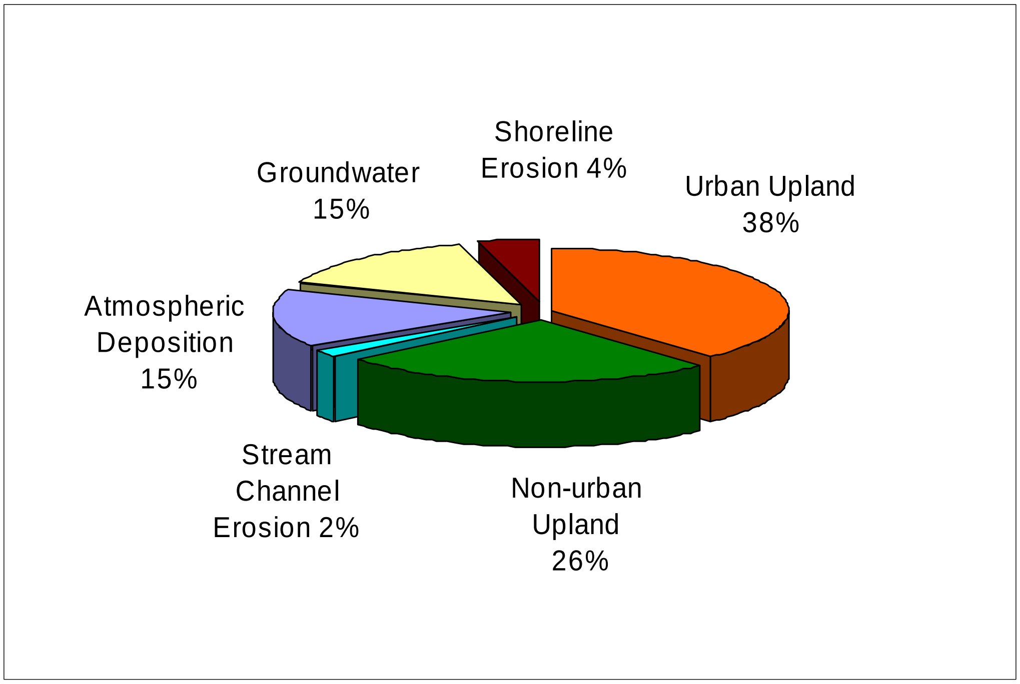

Figure 7-2. Percent Total Phosphorus Contribution per Source Category.

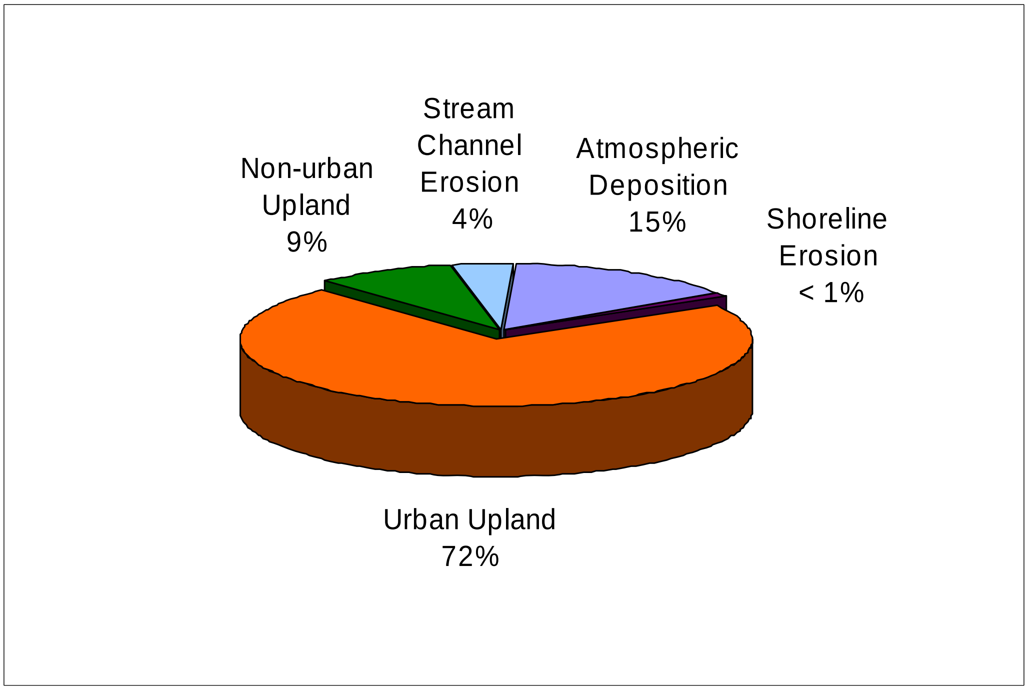

Figure 7-3. Percent Fine Sediment Particle (< 16 micrometer) Contribution per Source Category.

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 ambient 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 2002) 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 TMDL team 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 (< 63 µm) loadings in metric tons per year from streambank erosion and the relative contribution of each of the Basin's 63 streams. 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; (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 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 sumulated 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 was 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 2009). 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 provide by the Lake Tahoe Watershed Model, Tetra Tech, Inc. estimate 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 2009).

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. Road dust is the primary source of inorganic fine sediment particles and phosphorus, while wood burning primarily generates airborne organic fine sediment particles. Swift et al. (2006) determined that inorganic particles are the dominant factor in clarity loss since those particles contribute greater than 55 to 60 percent of the clarity loss while organic particles contribute up to 25 percent of the clarity loss.

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 (2009) 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 clarity 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).

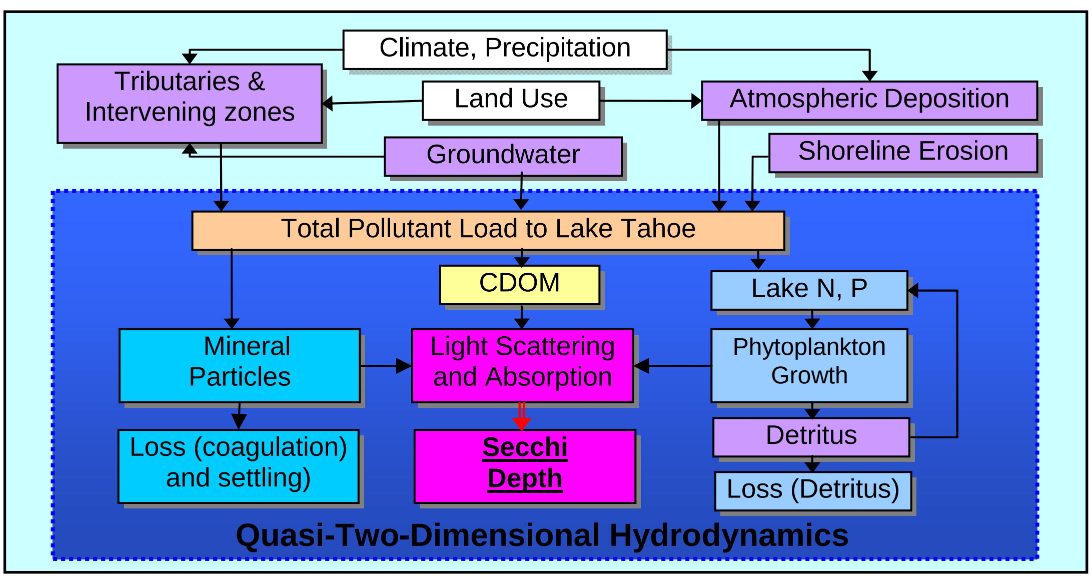

Figure 8-1. Conceptual Lake Clarity Model.

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, 2008).

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 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, phytoplankton and zooplankton and phytoplankton primary productivity.

Pollutant Loading – The pollutants of concern affecting Secchi depth transparency in Lake Tahoe are fine sediment particles, phosphorus and nitrogen. Pollutant loading from the primary sources is summarized below in Table 8-1.

Table 8-1. Annual Pollutant Loading Estimates.

Source Category		Total Nitrogen (metric tons/year)	Total Phosphorus (metric tons/year)	Number of Fine Sediment Particles ($x10^{18}$/year)
Upland	**Urban**	63	18	348
	Non-Urban	62	12	41
Atmospheric Deposition		218	7	75
Stream Channel Erosion		2	<1	17
Groundwater		50	7	NA
Shoreline Erosion		2	2	1
TOTAL		397	46	481

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 8-2 shows simulated and measured annual Secchi depths to be in good agreement.

Table 8-2. Comparison of annual average Secchi depths.

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 well 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 water quality standard (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 includedd the effect of Best Management Practices n 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.

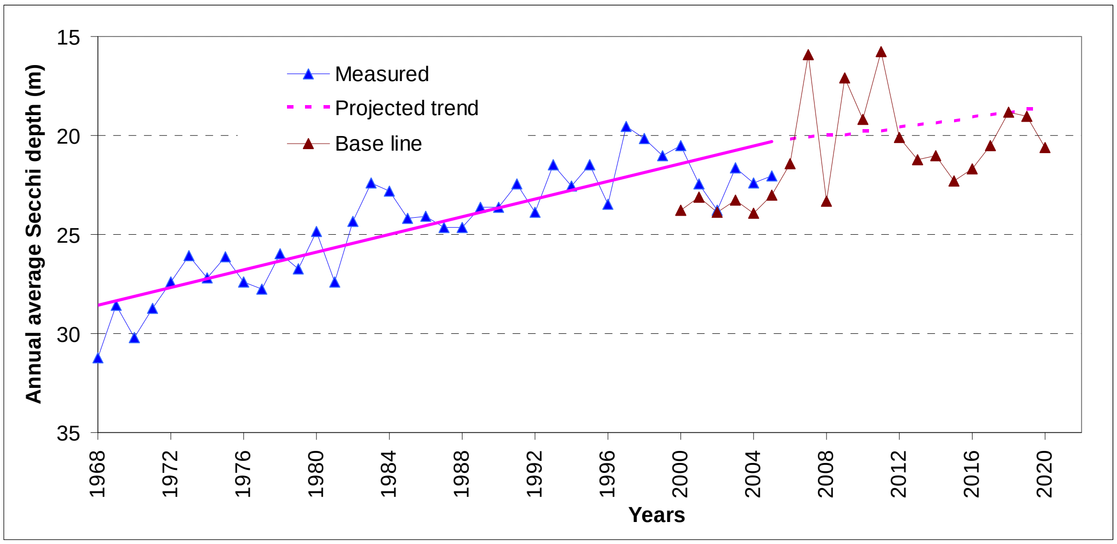

Figure 8-2. Measured and modeled Secchi depths for 2000-2020 (Solid line represents line of best fit while dashed line represents the line of best fit for the simulated results). The close agreement during the period between 2000-2005 between field data and modeled output highlight utility of the Lake Clarity Model.

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 transparency standard, 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 do not include all Lake Clarity Model runs performed as part of the TMDL analysis, but rather offer a representative sampling of model findings gleaned 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. Table 8-3 provides the simulated average annual Secchi depths for the years 2011 to 2020 for the abstract load reduction combinations.

These results suggested that reaching the 29.7 meter Secchi depth annual average standard 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 8-3. 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.

Reduction (%)	Average Secchi Depth (m) 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 (2.06)	20.1 (2.06)	20.1 (2.06)	20.1 (2.06)	20.1 (2.06)
25	20.4 (2.06)	20.5 (1.83)	21.3 (2.18)	23.2 (2.46)	23.2 (2.16)
50	21.0 (2.28)	21.6 (2.07)	21.4 (2.40)	26.2 (2.30)	27.0 (2.17)
75	22.0 (2.46)	21.8 (2.41)	21.7 (2.29)	28.6 (2.55)	35.3 (2.82)

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 8-4 lists the fine sediment particle and nutrient load reductions needed to achieve both the Clarity Challenge and transparency standard based on the load reduction opportunity analysis. The Pollutant Reduction Opportunity Report (Lahontan and NDEP 2008a) contains detailed information from the evaluation process.

Table 8-4. Basin-wide pollutant reductions needed to meet Clarity Challenge and transparency standard.

Pollutant	Interim Secchi Depth 24.0 m "Clarity Challenge"	Target Secchi Depth 29. 7 m Transparency Standard
Fine Sediment Particles (< 16 µm)	32 %	65 %
Phosphorus	14 %	35 %
Nitrogen	4 %	10 %

9 Pollutant Load Reduction Opportunities

After estimating annual loads from the major pollutant sources, the Lake Tahoe TMDL program began identifying pollutant load reduction opportunities. To meet this need, the Water Board received funding from the United States Environmental Protection Agency to help estimate pollutant load reduction options and associated costs. The Water Board contracted with Tetra Tech, Inc. to develop an "Integrated Water Quality Management Strategy" – a comprehensive implementation approach to achieve the Clarity Challenge and the water quality standard.

The Pollutant Reduction Opportunity Analysis was used as the foundation for developing a series of comprehensive "integrated implementation strategies." The TMDL program solicited stakeholder input on the integrated strategies and developed a Recommended Strategy that provides the basis for the Lake Tahoe TMDL pollutant load allocation approach and the TMDL Implementation Plan. The following summarizes the Pollutant Reduction Opportunity analysis and the Recommended Strategy. Following chapters detail Pollutant Load Allocations and the Implementation Plan.

9.1 Pollutant Reduction Opportunity Project

To evaluate load reduction opportunities, the project was organized around four Source Category Groups (SCGs) representing the major pollutant sources: atmospheric, urban and groundwater, forested uplands, and stream channel. An interagency Source Category Integration Committee (SCIC) coordinated the SCGs. The Water Board and NDEP used the SCG findings to develop the Lake Tahoe TMDL implementation Recommended Strategy. The Recommended Strategy combines the most cost effective, reasonable implementation opportunities into a comprehensive implementation package that achieves the load reduction necessary to meet the Clarity Challenge.

The following sections discuss the organization and composition of the SCIC and SCG groups, describe the approach taken to estimate load reduction opportunities, present the results, and describe the Recommended Strategy. Additional information and detail regarding the Integrated Water Quality Management Strategy project and the SCG work can be found in the *Lake Tahoe TMDL Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a) and the *Integrated Water Quality Management Strategy Final Report* (Lahontan and NDEP 2008b).

9.1.1 Source Category Groups

The Water Board and NDEP assembled regional and national experts into Source Category Groups (SCGs) to investigate Pollutant Control Options (PCOs) for each major source of pollutants entering Lake Tahoe.

The SCGs were led by respected experts with distinguished careers within each field of study. The SCG Leaders coordinated the technical investigations and were responsible for the products and findings of the SCG. Each SCG was further composed of members who provided background research, reviewed internal products, and assisted with the final report. The SCGs were kept small and focused to produce results within several months. Results from urban and groundwater are presented together because of the extensive interactions between these source categories.

SCG Leaders

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

Urban runoff and groundwater—Ed Wallace, P.E., with Northwest Hydraulics Consultants has completed more than 40 urban runoff treatment projects in Lake Tahoe.

Dr. Nicole Beck, with 2ND Nature, LLC, led the groundwater studies.

Forest upland—Michael Hogan, with IERS, Inc., has more than 15 years of experience working on erosion control efforts in the Tahoe region.

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

9.1.2 Source Category Integration Committee

A Source Category Integration Committee (SCIC) and the Tetra Tech Project Team provided direction, review and cross-SCG coordination. The SCIC included staff from the Lahontan Water Board, NDEP, and TRPA; a Pathway Coordination Team representative (agency management level staff); and the Lake Tahoe TMDL Science Advisor. All SCIC members have also been involved with the development and implementation of water quality control projects in the Lake Tahoe basin.

9.1.3 General Approach

Each SCG was tasked to estimate potential pollutant reductions and associated implementation costs at a basin-wide scale. This work involved three general steps.

9.1.4 Step 1: Pollutant Control Option Evaluation

These analyses began with evaluations of PCOs that could be applied to the landscape. Each SCG compiled a list of potential PCOs on the basis of professional experience, local knowledge, and input from the SCIC, Pathway Technical Working Groups, the Pathway Forum, and other sources. The list of PCOs was screened on the basis of the SCG's ability to quantify the load reduction and expected effectiveness of a specific PCO within the Lake Tahoe basin. Example PCOs include infiltration practices for urban stormwater, stream bank stabilization to address stream channel erosion, revegetation practices for disturbed forested areas, and construction site dust suppressants to address atmospheric particle deposition.

9.1.5 Step 2: Site-scale Analysis

Each SCG analyzed the full area within the Lake Tahoe basin to estimate the (1) potential for pollutant load reductions and (2) associated implementation cost of applying the identified PCOs on a representative site scale. During this step, the SCGs defined the representative site areas (Settings) and the packages of PCOs that could be applied to each site. Settings for the Atmospheric SCG, for example, emphasized the distance from the lake to account for pollutant transport processes while the Urban and Groundwater SCG settings accounted for variations in slope and impervious coverage.

Pollutant Reduction Opportunity Analysis Key Definitions

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

Settings
Settings are representative areas of the Lake Tahoe Basin that can include similar physical characteristics, PCO applicability, or loading effects. For example, the urban SCG used slope and impervious cover to define representative settings.

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

Further, the SCGs combined viable PCOs into *Treatment Tiers* (Tiers) designed to provide a spectrum of potential effort level and load reduction potential for each Setting.

9.1.6 Step 3: Basin-wide Extrapolation

Each SCG used an array of different techniques to analyze PCO effectiveness and costs of applying the various Treatment Tiers to the entire Lake Tahoe basin. Each SCG conducted a thorough review to identify available information. The most appropriate information was incorporated into spreadsheet and database models that allowed the SCG to simulate or estimate the load reductions and costs of applying each Treatment Tier to each Setting. In most cases, geographic information systems (GIS) analysis was used to extrapolate to basin-wide estimates. Additional tools and models used during this step ranged widely, and compose much of the content within the *Lake Tahoe TMDL Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a).

9.1.7 Processing SCG Results

In some cases information provided by the SCGs required additional processing to ensure consistent and comparable results. These calculations were performed by the SCIC and Tetra Tech Project Team. For instance, because the Lake Tahoe Clarity Model shows that the number of fine sediment particles less than 16 micrometers in diameter, rather than the mass of fine sediment particles, affects Secchi depth readings, all mass-based results were translated to particle numbers using a converter developed by U.C. Davis (see the Lake Tahoe TMDL Technical Report (Lahontan and NDEP 2009) for details of the particle converter method). Several calculations were also performed to estimate the basin-wide implementation costs.

9.2 Source Category Considerations

This section summarizes each SCG's treatment tier descriptions, key considerations, and notable findings which were used to identify load reduction opportunities and estimate implementation costs. For more detailed information regarding the analytical process for each SCG, please refer to the *Lake Tahoe TMDL Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a).

9.2.1 Urban and Groundwater Sources

Since the primary source of groundwater pollution lies within the urban landscape, and because groundwater pollution control measures overlap with urban stormwater management actions, groundwater sources were assumed to be part of urban sources. Urban pollutant controls are categorized into three treatment tiers, with some example PCOs for each tier:

- **Best Current Practices (Tier 1)** – Detention and retention basins, stormwater vaults, road shoulder stabilization, vacuum sweeping heavily sanded roads, limited impervious coverage removal and 50 percent completion of private property best management practices (BMPs)
- **Advanced, Intensive Practices** (**Tier 2)** – Wetland and passive filtration basins, media filters in stormwater vaults, deicing compounds or advanced abrasive (sand) recovery, intensive maintenance of stormwater infrastructure, 100 percent completion of private property BMPs
- **Innovative Technology** (**Tier 3)** – Active pumping and filtration systems for stormwater applied to urban areas with concentrated impervious coverage (such as "commercial core" areas) and Tier 2 treatment applied

to urban areas with dispersed impervious coverage (such as many residential areas)

Urban and Groundwater SCG Notes

1. Tier 3 has the greatest estimated pollutant load reduction capability and is more cost effective than Tier 2. Tier 3 has the potential to reduce sediment particle loads of approximately 4% more than Tier 2 controls and implementation throughout the basin costs approximately 13% less. Additionally, as the density of urban development increases Tier 3 appears to become more cost effective. Measures that reduce pollutant concentrations as well as reduce runoff volume (e.g. private property BMPs) are a very important component of this tier.
2. The investment in a Tier 2 level of O&M activities is a significant cost that is at least 10 times greater than the current resources devoted to water quality O&M in the Lake Tahoe basin. While, O&M cost estimates are preliminary and must be verified and compared to existing stormwater utility programs, an increase in O&M activity will be needed to increase pollutant reductions.
3. The estimates of potential load reduction for the centralized pumping and treatment controls that make up part of Tier 3 are based on limited compared with other urban Treatment Tiers. Numerous assumptions that were made about the design and effectiveness of centralized treatment systems further add to the uncertainty associated with these load reduction estimates. Consequently

9.2.2 Atmospheric Sources

Atmospheric pollutant controls are classified into two tiers based on treatment intensity. The *Increased Intensity* treatment tier is generally applied more intensively or extensively than current efforts. This group of pollutant controls was referred to as *Tier 2* in the *Lake Tahoe TMDL Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a) and includes:

- Every other week street sweeping with vacuum equipment that captures 10 micron particles
- Pave dirt roads at access points
- Speed limits on unpaved roads
- Gravel 50 percent of unpaved roads, including forest roads
- Require adequate soil moisture during earth-moving operations
- Use dust suppressants on exposed soil at road-building projects
- 20 percent reduction in residential wood burning emissions

The second treatment tier, called ***High Intensity,*** is applied more intensively and pollutant load reduction effectiveness is higher. In the *Lake Tahoe TMDL Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a) this group of pollutant controls was referred to as *Tier 3*, and it includes:

- Weekly street sweeping with vacuum equipment that captures 10 micron particles
- Pave all unpaved roads
- Limit speeds on unpaved roads
- Require adequate soil moisture during earth-moving operations
- Use dust suppressants on roadway and construction projects
- 50 percent reduction in residential wood burning emissions

Atmospheric SCG Notes

1. In some instances, atmospheric PCOs overlap with urban and forest PCOs. As a result, integrated PCO strategies that employ both atmospheric and urban or forest controls will include some double counting of costs. Examples of such overlap include:
    - Paved roads where the atmospheric group estimated the total costs of street sweeping and the urban and groundwater group estimated the cost of street sweeping/vacuuming.
    - Unpaved roads where atmospheric dust control strategies could potentially overlap forested uplands particulate runoff controls.
2. There is a significant cost difference between mobile source PCOs that target nitrogen and stationary controls that typically target fine sediment and phosphorus. In general, basin-wide costs to control nitrogen from mobile sources are two orders of magnitude higher than comparable costs to control fine sediment and phosphorus from stationary dust sources. The SCG analysis was able to focus on non-mobile sources or mobile sources separately.

9.2.3 Forest Upland Sources

Forest upland pollutant controls are often specific to particular land uses (e.g., unpaved roads, campgrounds or ski runs) but can generally be divided into two categories.

Standard BMP treatments are planned by federal and state land management agencies for roads, trails and fuels reduction projects. Examples of these treatments include the following:

- Full, unpaved roadway BMPs (waterbars, armored ditches, rut stabilization) and annual maintenance
- Hydro-seeding and tackifier for ski runs
- Forest treatments implemented with ground-based crews and equipment and required BMPs

Advanced treatments designed to achieve a range of effects from better hydrologic function to complete restoration that will mimic natural conditions as time progresses. Examples of these treatments can include those found under standard BMP treatments, plus:

- Mulching and revegetating with seeding or transplanted seedlings on ski runs
- Road re-contouring, tilling, organic soil amendments, mulch, and revegetation with seedlings and seeding
- Urban sediment capture BMP for paved roadways (e.g., stormwater vaults, settling basins)
- Full restoration of legacy roads and trails

Forest Upland SCG Notes

1. Unpaved roads represent a small fraction of forested upland land-uses in the basin. However, annual per acre fine sediment loading rates from unpaved roads are roughly double that from ski trails and 20–40 times greater than loading rates from undeveloped forested areas.
2. Obliteration of *legacy areas*—such as old logging roads, trails, abandoned landings, and other erosion ‘hot spots’—has the greatest potential to efficiently reduce loading from forested areas, especially if conducted in combination with planned thinning and fuels reduction treatments.
3. Since wildfire is not a regular or predictable feature that can be entered into the calculations with any degree of certainty, this analysis did not consider wildfire or controlled-burn effects on subwatershed hydrologic dynamics and subsequent stream loading. The effect of fire on runoff, sediment, and nutrient yield in the basin is a topic that requires additional research and focused analyses beyond those considered here. The framework developed here could be applied to future fire analysis and continued investigation into the water quality effects of fire should be considered a top priority.
4. Results show little nitrogen removal by forested upland controls because regression equations used in the model applied could not be adjusted to match existing datasets.
5. There is a general need to define terms and establish clear, quantitative success criteria for different treatments and PCOs within the basin.

9.2.4 Stream Channel Sources

The evaluation of potential load reductions and costs involved with stream channel sources defined two kinds of restoration or treatment tiers. ***Unconstrained restoration*** of the stream includes a set of treatments that modify plan form, increases length and sinuosity, increases connectivity between flow in the channel and the floodplain, and decrease slope such that a restored condition is eventually reached. These treatments are designed to achieve load reductions as well as other ecosystem objectives such as riparian habitat enhancement, flood control and recreation value. The second kind of restoration, ***bank protection****,* is a basic set of channel armoring and minor bank slope reductions that increase hydraulic resistance and reduce bank failure. The current and planned future projects under consideration in the Lake Tahoe basin generally involve a ***mixed approach*** of unconstrained restoration where land use and other variables allow and simple bank protection on constrained stream reaches.

Stream Channel SCG Notes

1. The total load reductions available from reducing stream channel erosion are relatively small compared to the other sources. However, stream restoration is cost effective and provides significant riparian/ecosystem benefits. Stream channel erosion load reduction estimates only account for the reduction in streambank erosion and do not include treatment of upland loads during flood events. Future research is targeted to quantify the potential load reductions from stream restoration by increasing floodplain connectivity and over-bank flows. Once the additional benefits can be quantified, stream restoration cost effectiveness will likely increase significantly as compared to PCOs for the other sources.
2. The uncertainty about PCO effectiveness for bank protection is more likely to overestimate load reductions and underestimate costs since bank protection maintenance needs are not included in cost estimates.

9.3 Recommended Strategy

The Recommended Strategy for achieving load reductions builds on the Pollutant Reduction Opportunity analysis and incorporates detailed scientific investigation and extensive stakeholder input. The Recommended Strategy describes a basin-wide, non-prescriptive strategy to guide the TMDL load allocation process and develop an implementation plan to achieve the Clarity Challenge and meet established water quality objectives. The Recommended Strategy describes a reasonable distribution of potential reductions from each source category. The Recommended Strategy combines pollutant controls from all four major pollutant source categories of pollutant sources while emphasizing the largest load reduction opportunities. Load reductions associated with operation and maintenance of various pollutant controls, particularly for the urban source, are an integral part of the Recommended Strategy.

The Recommended Strategy was developed through an iterative process of design and adjustment which included scientists and engineers, stakeholders, and TMDL staff and consultants participated. There were three cycles in the process with each referred to in terms of its objectives:

1. Identify, screen and analyze pollutant controls

2. Formulate integrated strategies
3. Develop and refine the Recommended Strategy

In each cycle, four activities took place:

- Working with consultant support, the TMDL Team developed an interim product to engage reviewers in substantive discussion.
- Stakeholders commented on the interim product.
- The TMDL Team adjusted the interim product to address comments—resulting in a new interim product.
- SCGs answered additional stakeholder questions.

Through the three cycles, each SCG revised the products which were packaged together into the Recommended Strategy.

9.3.1 Recommended Strategy Load Reduction Summary

The Recommended Strategy focuses on pollutant controls for fine sediment particles because these particles have the largest influence on water clarity in Lake Tahoe (Lahontan and NDEP 2009). This section and the following source-specific discussions present the Recommended Strategy by describing suggested actions for each of the major pollutant source categories to reduce fine sediment particle loads. While the Recommended Strategy focuses on fine sediment particles, the associated PCOs also account for nitrogen and phosphorus reductions and these nutrient reductions were accounted for in the lake response model runs associated with evaluation of load capacity.

The Recommended Strategy describes actions to achieve the Clarity Challenge within a 15-year implementation timeframe. Additional fine sediment particle and nutrient load reductions will be needed to meet the clarity standard. Implementing the Recommended Strategy will reduce fine sediment particle loads to Lake Tahoe by a total estimate of 32 percent relative to the most current estimates of loading as defined in the Lake Tahoe pollutant budget.

While implementation of the controls established in the Recommended Strategy is projected to achieve fine sediment particle load reductions from all the source categories, only a small proportion of fine particles come from the forest or stream categories. Urban stormwater pollutant controls account for the majority of these reductions, providing approximately 25 percent of the 32 percent fine sediment particle reduction needed to meet the Clarity Challenge. Atmospheric controls focused on stationary dust sources are estimated to account for five percent of the basin-wide total fine sediment particle reduction. Forested upland and stream channel source controls are estimated to produce one percent and two percent of the basin-wide load reduction, respectively (Table 9-1).

Table 9-1. Source Load Reductions expected by implementing the Recommended Strategy. Reductions expressed as percent of the basin-wide fine sediment particle load.

Pollutant Source	Total Clarity Challenge Load Reduction
Forest Upland	1.0%
Stream Channel Erosion	1.8%
Atmospheric Deposition	4.6%
Urban Uplands	24.6%
Total	32%

9.3.2 Urban Runoff Focus

Urban runoff produces the majority of pollutant loading and provides the greatest estimated potential for pollutant control. Therefore, the Recommended Strategy focuses potential pollutant controls on advanced practices and innovative technology to control fine sediment particles and associated nutrients within the urban runoff source category. As note in Table 9-1, implementation of the Recommended Strategy will reduce the overall fine sediment particle load by 24.6 percent.

The Recommended Strategy includes application of identified pollutant controls based on configuration of impervious coverage and slope. The areas of concentrated impervious coverage, such as commercial land uses with extensive streets and rooftops, involve an intensive application of advanced pollutant control measures (i.e. higher treatment tiers). The land uses with dispersed impervious coverage such as residential land uses with a high degree of open space, require less advanced treatments. Enhanced operation and maintenance of roadways and associated pollutant controls are important elements in the 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 these numbers is in the *Integrated Water Quality Management Strategy Final Report* (Lahontan and NDEP 2008b).

9.3.3 Atmospheric Deposition Focus on Stationary Sources

Atmospheric deposition contributes a much smaller amount of the annual fine sediment particle load. Although atmospheric deposition is a lesser pollutant source, there are cost-effective treatments available to control stationary dust sources such as unpaved areas, dirt roads, dust from traction abrasives on paved surfaces, and residential wood burning. The Recommended Strategy for the atmospheric deposition source, therefore, emphasizes dust controls for paved and unpaved roads as well as parking lots and construction areas. It also includes modest controls on residential wood burning such as providing incentives for clean burning wood stoves. The TMDL program estimates measures to reduce pollutants from atmospheric deposition will reduce the basin-wide fine sediment particle load by 4.6 percent.

The Recommended Strategy does not include actions to reduce atmospheric nitrogen deposition. To achieve the Clarity Challenge, efforts must reduce fine sediment particles, so the initial implementation effort focuses on fine sediment particle reductions. Efforts to reduce atmospheric nitrogen deposition will initially have little effect on improving lake clarity as compared to reducing fine sediment particles. Altering transportation habits can both reduce nitrogen deposition into the air and reduce dust generation from roads, but these options are two orders of magnitude more expensive than dust controls, such as improved street sweeping.

9.3.4 Stream Channel Erosion and Stream Restoration

The Recommended Strategy includes stream restoration that combines unconstrained restoration with bank stabilization measures because these practices are cost-effective and provide multiple ecosystem benefits. Tahoe basin resource management agencies have well established multi-objective stream channel restoration programs, and acceptable restoration methods do not differ widely with regard to the basic concepts related to treatment options. The analysis focuses on fine sediment particles released from stream banks and beds, and does not directly quantify the other potential benefits available from stream or floodplain restoration. A properly functioning floodplain may represent a feasible approach for the capture of fine particles and uptake of nutrients from upland runoff that has flowed into the stream channel and has dispersed onto the floodplain or adjacent stream zone during high flow events.

The analysis for the Recommended Strategy is based on the top three fine sediment particle producing tributaries in the basin. These three streams are responsible for 96 percent of the stream channel erosion fine sediment particle load:

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

Several resource management agencies in the 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. Consequently, the recommendations for this source category support and depend upon current plans and approaches. Restoration activities on these three streams should reduce overall fine sediment particle loads by 1.8 percent.

9.3.5 Forest Upland Planned Activities

Forested lands have a low fine sediment particle yield (per acre). Interestingly, the pollutant budget for all sources to Lake Tahoe shows that the non-urban upland is a large source for total suspended sediment. However, the relative contribution of the fine sediment particles from the urban areas is much greater. Certain land uses within forested areas, such as unpaved roads, ski runs and burn areas provide important opportunities to achieve cost-effective load reductions of fine sediment particles.

Federal, state, and some of the larger local management agencies have active, well-defined multi-objective restoration programs with established funding. The TMDL program focuses on the clarity of Lake Tahoe and supports the multi-objective scope of many existing forest restoration programs. Some restoration programs target water quality improvements, while others efforts have other primary goals (habitat improvement, forest health, etc.) with ancillary fine sediment and nutrient control benefits. 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.

The Recommended Strategy includes load reductions from planned or expected activities of multi-objective forest restoration programs. These considerations assumed that all activities (including fuel reduction projects and timber harvests) in the forested uplands either reduce or do not increase the fine sediment loads. While wildfire, extreme weather, and other unforeseeable catastrophic events may significantly impact loading rates and the efficacy of load reduction actions, the frequency, extent, and intensity of such events is impossible to predict. The Recommended Strategy does not quantify the potential impacts of these events, and the response to catastrophic events will necessarily rely on the adaptive management process. Land management activities within the forested uplands are anticipated to reduce the basin-wide fine sediment particle load by approximately one percent.

9.4 Cost Associated with the Recommended Strategy

SCG experts estimated the 20-year capital and annual operations and maintenance (O&M) costs of implementing the Recommended Strategy on a control-by-control basis and then aggregated into totals for each major source category. Capital costs include all implementation costs such as planning, design, acquisition and replacement when the useful life of the controls is shorter than 20 years. These estimates provide only an initial approximation and do not contain sufficient detail for budgeting and project level planning.

Implementing the entire Recommended Strategy would require an estimated capital investment of approximately $1.5 billion over 15 years. All values are in

2007/2008 equivalent dollars. The majority of costs, $1.3 billion, are for urban runoff pollutant controls. Pollutant controls for other sources estimated are $120 million, $48 million and $40 million for forest runoff, atmospheric and stream channel pollutant controls, respectively. The relatively high investment in urban runoff controls reflects the importance of this source category in reducing fine sediment particle loads. Both capital and O&M costs are important because state and federal funding has historically been available for capital investments, while local jurisdictions have been responsible for O&M costs. Because runoff from the urban upland generates the vast majority of the fine sediment particle loads, it is reasonable to initially focus the bulk of the pollutant control effort on the urban landscape.

The Recommended Strategy assumes funding in the amount of $500 million is available and expendable in each 5-year implementation period. This assumption is challenging but not unrealistic because committed funding was reported as $1.123 billion during the first 8 years of the Lake Tahoe Environmental Improvement Program (EIP) from 1997 to 2005. Approximately half of this EIP funding was expended on projects for water quality purposes.

Additional detail regarding how each SCG estimated implementation costs can be found in the *Lake Tahoe TMDL Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2008a).

10 Load Allocations

The TMDL process requires allocating allowable pollutant loads to identified pollutant sources. This chapter describes how the TMDL program translated the load reductions projected by the Recommended Strategy into allowable fine sediment particle and nutrient load allocations.

10.1 Load Allocations and Waste Load Allocations

Allocations are defined as either load allocations (LAs) for non-point sources, or waste load allocations (WLAs) for point sources. Because the Water Board regulates urban stormwater on the California side of the Lake Tahoe basin under the National Pollutant Discharge Elimination System (NPDES) program, urban runoff discharges within the three California jurisdictions are considered point sources and subject to WLAs. Similarly, the California and Nevada Departments of Transportation are also regulated by the NPDES program and are thus subject to WLAs.

All other identified pollutant sources – forest upland runoff, stream channel erosion, atmospheric deposition, and urban runoff in the state of Nevada – are non-point sources subject to LAs.

10.2 Recommended Strategy Allocations

The distribution of allowable pollutant loads is based on the Recommended Strategy described in Chapter 9. Building on the comprehensive Pollutant Reduction Opportunity analysis, the Recommended Strategy outlines a reasonable approach for achieving needed fine sediment particle, nitrogen, and phosphorus load reductions to meet the Clarity Challenge. These load reduction rates have been linearly extrapolated to determine the load reductions necessary and the time needed to achieve the clarity standard.

10.3 Defining Jurisdiction-Specific Pollutant Load Estimates

Establishing estimates of how much of the baseline load is attributable to each of the urban jurisdictions is a two-step process. First, TMDL team consultants overlaid urban jurisdiction boundaries in a GIS over the sub-watershed and land use layers used to generate pollutant load estimates. Then the team aggregated the pollutant loading results according to the referenced jurisdictional boundaries.

Four data sets were used to develop the jurisdiction specific load estimates: (1) the pollutant source analysis results of the Lake Tahoe Watershed Model baseline run; (2) a GIS layer of jurisdictions; (3) the Watershed Model land use grid; and (4) the Lake Tahoe Watershed Model sub-basin boundaries.

It is important to note that pollutant loads generated on State and federally owned lands within local government's jurisdictions are not part of the local government load estimate. State and federal implementation partners are expected to reduce fine sediment and nutrient loads from both urban and forest land uses within their respective jurisdictions and federal and state agencies have programs and policies in place to ensure BMP implementation on urban trailheads, visitor parking areas, and beaches.

Table 10-1 presents the annual average loads of fine sediment particles by jurisdiction along with the associated percentage relative to the basin-wide total. The jurisdictions with the largest total fine sediment particles loads are CalTrans and the City of South Lake Tahoe. Similar tables for nitrogen and phosphorus can be found in the *Integrated Water Quality Management Project Report* (Lahontan and NDEP 2008b).

Table 10-1. Baseline Fine Sediment Particle Loads by Jurisdiction.

Jurisdiction	2004 Particle Load (particles x 10^{18} per year)	% of total urban runoff source load
CalTrans, CA	76.4	20%
City of South Lake Tahoe, CA	74.6	19%
Douglas County, NV	10.2	3%
El Dorado County, CA	37.6	10%
NDOT, NV	32.8	8%
Placer County, CA	56.9	15%
Washoe County, NV	48.8	13%

10.4 Determining Load Allocations for Urban Jurisdictions

To assess each jurisdiction's needed load reduction, the TMDL team categorized each of the twenty land uses from the Lake Tahoe Watershed Model effort as either urban or forested and determined the amount of pollutant load coming from each category of each jurisdiction.

The corresponding source category percent load reduction from the Recommended Strategy was applied to the urban and forested loads independently and summed to determine the total jurisdictional load reduction for each of the identified milestones. For example, if 20 percent of a county's load comes from forest land uses and 80 percent comes from urban land uses, the county would be expected to achieve a 12 percent load reduction from the loads generated by forest land uses and a 34 percent reduction from loads generated within the urban land uses to meet the Clarity Challenge milestone. This corresponds to an overall jurisdictional weighted load reduction of 30 percent.

The fine sediment particle load generated from Placer County's forested land is noticeably higher than the other counties as a result of a greater area of highly erosive forested land uses and the high level of precipitation and runoff in the northwest portion of the basin. Placer County is the only urban jurisdiction where the forest load notably reduces the load reduction requirement compared to a purely urban area. Consequently, Placer County needs to reduce its jurisdictional fine sediment particle load by 32 percent while other urban jurisdictions need to reduce by 34 percent to achieve the Clarity Challenge. These reductions are expressed as a percentage of each jurisdiction's 2004 baseline load.

10.5 Load Reduction Milestones

The Lahontan Water Board and NDEP developed milestones toward achieving the Clarity Challenge and, eventually, the Lake Tahoe TMDL's numeric target for Secchi depth. Using a Packaging and Analysis Tool (PAT), TMDL consultants evaluated costs and load reductions associated with implementing pollutant controls described by the Recommended Strategy. The PAT helps integrate cost and load reduction information from representative control actions for the major source categories and allows the program to account for gradual development and implementation of more innovative and effective treatment measures, particularly for addressing urban runoff pollution. For more information on the PAT and how it was used to develop Recommended Strategy milestones, please refer to the *Integrated Water Quality Management Project Report* (Lahontan and NDEP 2008b).

Implementation periods are the intervals between milestones in which a level of effort (represented by $500 million dollars) is placed on implementing the recommended pollutant controls. The Water Board and NDEP anticipate each milestone will represent five-year implementation phases. Based on a realistic, yet ambitious timeline, it was estimated that with the Recommended Strategy implementation the Clarity Challenge could be met by the end of the third milestone (i.e. after the first 15 year implementation period). Due to seasonal and inter-annual Secchi depth variability, Lake Clarity Model output indicates a five year response time will be needed to confirm the Clarity Challenge has been met.

As the Water Board and NDEP work with implementation agencies, the implementation periods and milestones may be adjusted to reflect achievable load reductions.

10.6 Standard Attainment Timeframe

The TMDL implementation analysis has emphasized achieving the interim Clarity Challenge target. This goal was established to provide a reasonably achievable target for a twenty-year planning horizon. Assuming load reduction efforts (i.e. investment) continue at a similar pace established for the Clarity Challenge implementation phase, the Lake Tahoe TMDL program estimates the clarity standard may be achieved within 65 years. Pollutant load reduction rates will likely slow. Note that load reduction rates for equivalent investment will likely decrease over time, as load reduction opportunities become scarcer and more challenging.

10.7 Load Allocation Tables

The following tables provide detailed pollutant load allocations for the major pollutant sources and specific allocations for the seven municipal jurisdictions.

Tables 10.1 through 10.3 describe how the necessary load reductions are allocated among the four major pollutant source categories. Tables 10.1-10.3 include (1) 2004 baseline loading for each source, including its percent contribution to the basin wide load; (2) allowable source loads and related percent reductions for two interim milestones; (3) allowable source loads and related percent reductions to achieve the Clarity Challenge; and (4) allowable source loads and related percent reductions to achieve the clarity standard.

Tables 10.4 through 10.7 describe how the urban load allocation is distributed among the seven municipal jurisdictions. Similar to the pollutant source allocations in Tables 10.1 through 10.3, columns are included for (1) 2004 baseline load for each jurisdiction; (2) allowable pollutant loads and associated percent reduction from the 2004 baseline for two interim milestones; (3) allowable pollutant loads and associated percent reduction to achieve the Clarity Challenge; and (4) allowable pollutant loads and associated percent reduction to meet the clarity standard.

Table 10-2. Fine Sediment Particle Load Allocations by Pollutant Source Category.

	Baseline Load		First Milestone		Second Milestone		Clarity Challenge		Standard Attainment	
	Basin-Wide Load (Particles/yr)	% of Basin-Wide Load	Basin-Wide Particle Load (Particles/yr)	Source Category % Reduction	Basin-Wide Particle Load (Particles/yr)	Source Category % Reduction	Basin-Wide Particle Load (Particles/yr)	Source Category % Reduction	Basin-Wide Particle Load (Particles/yr)	Source Category % Reduction
Forest Upland	4.1E+19	8.54%	3.87E+19	5.66%	3.74E+19	8.81%	3.62E+19	11.73%	3.28E+19	20.04%
Urban Upland	3.48E+20	72.47%	3.12E+20	10.29%	2.74E+20	21.22%	2.30E+20	33.86%	1.00E+20	71.23%
Atmosphere	7.45E+19	15.51%	6.87E+19	7.85%	6.31E+19	15.26%	5.24E+19	29.60%	3.35E+19	54.98%
Stream Channel	1.67E+19	3.48%	1.45E+19	13.16%	1.23E+19	26.32%	7.91E+18	52.64%	1.82E+18	89.09%

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

	Baseline Load		First Milestone		Second Milestone		Clarity Challenge		Standard Attainment	
	Basin-Wide Nitrogen Load (MT/yr)	% of Basin-Wide Load	Basin-Wide Nitrogen Load (MT/yr)	Source Category % Reduction	Basin-Wide Nitrogen Load (MT/yr)	Source Category % Reduction	Basin-Wide Nitrogen Load (MT/yr)	Source Category % Reduction	Basin-Wide Nitrogen Load (MT/yr)	Source Category % Reduction
Forest Upland	62	18%	61.93	0.11%	61.90	0.16%	61.84	0.25%	61.73	0.44%
Urban Upland	63	18%	58.26	7.53%	54.00	14.29%	50.80	19.37%	31.19	50.50%
Atmosphere	218	63%	217.45	0.25%	216.93	0.49%	215.93	0.95%	214.17	1.76%
Stream Channel	2	1%	2.00	0.00%	2.00	0.00%	2.00	0.00%	2.00	0.00%

Table 10-4. Total Phosphorus Load Allocations by Pollutant Source Category.

	Baseline Load		First Milestone		Second Milestone		Clarity Challenge		Standard Attainment	
	Basin-Wide Phosphorus Load (MT/yr)	% of Basin-Wide Load	Basin-Wide Phosphorus Load (MT/yr)	Source Category % Reduction	Basin-Wide Phosphorus Load (MT/yr)	Source Category % Reduction	Basin-Wide Phosphorus Load (MT/yr)	Source Category % Reduction	Basin-Wide Phosphorus Load (MT/yr)	Source Category % Reduction
Forest Upland	12	32%	11.92	0.68%	11.88	1.00%	11.82	1.49%	11.69	2.61%
Urban Upland	18	47%	16.73	7.04%	15.55	13.61%	14.30	20.56%	9.66	46.31%
Atmosphere	7	18%	6.39	8.67%	5.81	16.93%	4.70	32.84%	2.73	60.98%
Stream Channel	1	3%	0.92	7.58%	0.85	15.17%	0.70	30.33%	0.49	51.34%

Table 10-5. Urban Fine Sediment Particle Load Allocations by Jurisdiction.

	Baseline Load	First Milestone		Second Milestone		Clarity Challenge		Standard Attainment	
Jurisdiction	Particle Load (Particles/year)	Allowable Particle Load (Particles/year)	Percent Reduction from Baseline	Allowable Particle Load (Particles/year)	Percent Reduction from Baseline	Allowable Particle Load (Particles/year)	Percent Reduction from Baseline	Allowable Particle Load (Particles/year)	Percent Reduction from Baseline
CalTrans, CA*	7.64E+19	6.85E+19	10.3%	6.02E+19	21.2%	5.05E+19	33.9%	2.20E+19	71.2%
City of South Lake Tahoe, CA*	7.46E+19	6.69E+19	10.3%	5.88E+19	21.2%	4.93E+19	33.9%	2.15E+19	71.2%
El Dorado County, CA*	3.76E+19	3.37E+19	10.2%	2.97E+19	21.1%	2.49E+19	33.7%	1.10E+19	70.8%
Placer County, CA*	5.69E+19	5.12E+19	9.9%	4.54E+19	20.2%	3.87E+19	32.0%	1.88E+19	66.9%
NDOT, NV*	3.28E+19	2.94E+19	10.3%	2.59E+19	21.2%	2.17E+19	33.9%	9.44E+18	71.2%
Douglas County, NV	1.02E+19	9.15E+18	10.3%	8.04E+18	21.2%	6.75E+18	33.8%	2.95E+18	71.1%
Washoe County, NV	4.88E+19	4.38E+19	10.2%	3.85E+19	21.1%	3.24E+19	33.7%	1.43E+19	70.8%

Table 10-6. Urban Total Nitrogen Load Allocations by Jurisdiction.

	Baseline Load	First Milestone		Second Milestone		Clarity Challenge		Standard Attainment	
Jurisdiction	Baseline Nitrogen Load (MT/year)	Allowable Nitrogen Load (MT/year)	Percent Reduction from Baseline	Allowable Nitrogen Load (MT/year)	Percent Reduction from Baseline	Allowable Nitrogen Load (MT/year)	Percent Reduction from Baseline	Allowable Nitrogen Load (MT/year)	Percent Reduction from Baseline
CalTrans, CA*	5.22	4.83	7.5%	4.48	14.3%	4.21	19.4%	2.59	50.5%
City of South Lake Tahoe, CA*	16.27	15.05	7.5%	13.96	14.2%	13.14	19.2%	8.12	50.1%
El Dorado County, CA*	14.43	13.43	6.9%	12.53	13.2%	11.85	17.9%	7.71	46.6%
Placer County, CA*	16.39	15.30	6.6%	14.33	12.5%	13.60	17.0%	9.13	44.3%
NDOT, NV*	1.88	1.73	7.5%	1.61	14.3%	1.51	19.4%	0.93	50.5%
Douglas County, NV	3.98	3.69	7.2%	3.43	13.7%	3.24	18.6%	2.05	48.5%
Washoe County, NV	9.23	8.60	6.8%	8.03	13.0%	7.60	17.6%	4.99	45.9%

Table 10-7. Urban Total Phosphorus Load Allocations by Jurisdiction.

	Baseline Load	First Milestone		Second Milestone		Clarity Challenge		Standard Attainment	
Jurisdiction	Baseline Phosphorus Load (MT/year)	Allowable Phosphorus Load (MT/year)	Percent Reduction from Baseline	Allowable Phosphorus Load (MT/year)	Percent Reduction from Baseline	Allowable Phosphorus Load (MT/year)	Percent Reduction from Baseline	Allowable Phosphorus Load (MT/year)	Percent Reduction from Baseline
CalTrans, CA*	2.85	2.65	7.0%	2.47	13.6%	2.27	20.6%	1.53	46.3%
City of South Lake Tahoe, CA*	3.61	3.36	7.0%	3.12	13.6%	2.87	20.5%	1.95	46.1%
El Dorado County, CA*	2.85	2.66	6.7%	2.48	13.0%	2.30	19.6%	1.60	44.0%
Placer County, CA*	5.41	5.08	6.1%	4.77	11.7%	4.45	17.7%	3.25	39.8%
NDOT, NV*	1.15	1.07	7.0%	0.99	13.6%	0.91	20.6%	0.62	46.3%
Douglas County, NV	1.03	0.96	6.8%	0.90	13.1%	0.83	19.8%	0.57	44.5%
Washoe County, NV	2.48	2.32	6.6%	2.17	12.7%	2.00	19.2%	1.41	43.2%

* Jurisdiction subject to Waste Load Allocations

10.8 Expressing Allowable Pollutant Loads

The Lake Tahoe TMDL program conducted an analysis of expressing allowable pollutant load allocations as daily loads. The results of two different approaches, a flow range daily load analysis and temporally variable daily load analysis can be found in the *Integrated Water Quality Management Strategy Project Report* (Lahontan and NDEP 2008b).

Although the Lake Tahoe TMDL program completed the daily load analysis as required by the USEPA, the average annual load expression remains a more useful and appropriate management tool for the Lake Tahoe basin. The clarity target is an average annual standard. The most meaningful measure of Lake Tahoe's transparency is generated by averaging the seasonal Secchi depth data. The modeling tools used to predict load reduction opportunity effectiveness, as well as the lake's response, are all driven by annual average conditions. An emphasis on average annual fine sediment particle and nutrient loads also levels the hydrologic variability driven by seasonal and inter-annual variability in precipitation amounts and types. Finally, average annual estimates will provide a more consistent regulatory metric to assess whether implementation partners are meeting established load reduction goals.

11 Lake Tahoe TMDL Implementation Plan

The Lake Tahoe TMDL Implementation Plan is a summary of the non-prescriptive policies and representative actions the should be taken by various funding, regulatory, and implementing agencies to reduce fine sediment particle, phosphorus, and nitrogen loads to Lake Tahoe to meet established load reduction milestones, particularly the Clarity Challenge.

As described in previous chapters, the Lake Tahoe TMDL program evaluated a broad spectrum of load reduction opportunities and used the Pollutant Reduction Opportunity analysis to identify a number of comprehensive implementation strategies. Through stakeholder input and additional analysis, the implementation strategies were narrowed to a single Recommended Strategy. Consistent with the Recommended Strategy, this implementation plan has a twenty year time horizon that anticipates a basin-wide 32 percent fine sediment particle load reduction following the first fifteen years of plan implementation. Five additional years are included in the overall timeline to assess the water quality benefits of the expected load reductions and evaluate the need for program adjustment. Continued load reduction actions beyond the first implementation phase will be needed to ensure ongoing progress toward meeting the clarity standard.

Lake Tahoe TMDL program implementation requires extensive coordination and cooperation between Lake Tahoe's implementing, funding, and regulatory entities. The bulk of the fine sediment particle load and expected reductions are from the urban source. Programs and policies to manage urban stormwater runoff have been and will remain the focus of water quality protection in the Lake Tahoe region. National Pollutant Discharge Elimination System (NPDES) permits for the California municipalities and the California and Nevada Departments of Transportation, anticipated Memoranda of Agreement for Nevada municipalities, and the Tahoe Regional Planning Agency's (TRPA) ongoing Environmental Improvement Program implementation provide the regulatory framework for achieving Recommended Strategy load reductions.

Two complementary plans, the United States Forest Service Lake Tahoe Basin Management Unit (LTBMU) Forest Plan and the TRPA Regional Plan provide the policy framework for reducing loads from atmospheric deposition, forest uplands, and stream channel erosion.

The following implementation plan has been organized by the major pollutant sources and follows the Lake Tahoe TMDL Recommended Strategy. The chapter includes a discussion of responsible parties to provide an overview of the funding, regulatory, and implementation agencies and describes each agency's role in TMDL implementation. The responsible parties section is followed by source-specific overview sub-chapters that describe reasonably foreseeable pollutant control measures for each major pollutant source category along with a discussion of proposed performance assessment measures.

11.1 Responsible Parties

Federal Government

The United States Forest Service manages 80 percent of the land in the Lake Tahoe basin as a unique kind of National Forest known as the Lake Tahoe Basin Management Unit (LTBMU). Although the bulk of LTBMU land is undeveloped forested upland areas (including undeveloped urban lots), the LTBMU manages a variety of recreational facilities within the urbanized landscape. The LTBMU also manages lands adjacent to several critical tributary streams and the LTBMU's actions impact each of the four major pollutant source categories.

Management direction is provided by the LTBMU Land and Resource Management Plan (Forest Plan). The current plan, adopted in 1988, is under revision to update portions of the plan related to ecosystem restoration, recreation management, land use, and adaptive management. The Forest Plan update effort has been an integral part of the 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.

As the largest land owner in the Lake Tahoe basin, the LTBMU has a responsibility to address runoff problems caused by disturbed areas within the undeveloped forest uplands, treat runoff from developed facilities in the urbanized area, and prevent runoff from forested lands from impacting the urban landscape.

Although not directly responsible for land management, there are a number of other agencies that provide critical Federal government support through the Lake Tahoe Federal Interagency Partnership. This Partnership was established in 1997 through strong local, State, Administration and Congressional support and 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, US Postal Service, and US Department of Transportation. The Partnership supports TMDL implementation through direct funding of TMDL research, support of regional, local, and state government water quality improvement projects, and seeks to improve coordination and efficient management of federal programs, projects, and activities within the Lake Tahoe basin.

Regional Government

The Tahoe Regional Planning Agency (TRPA) is required by the Tahoe Regional Planning Compact to regulate activities within the Lake Tahoe basin that have the potential to substantially affect natural resources. To protect these resources, the compact directs the TRPA to establish and ensure attainment of environmental threshold carrying capacities (threshold standards and indicator) standards for water quality, air quality, noise, recreation, soil conservation, wildlife habitat, vegetation preservation, scenic quality, and fisheries.

The TRPA Regional Plan, initially approved in 1987, is an extensive document that sets the stage for development and environmental restoration in the Lake Tahoe Basin. The Regional Plan includes many sections – Code of Ordinances, Transportation and Air Quality Plan, Goals and Policies, Water Quality Management Plan, Plan Area Statements, and the Scenic Quality Improvement Plan. The Regional Plan also addresses monitoring and capital improvements. Many efforts are underway to support the development of an updated Regional Plan. Critical to this is the Environmental Threshold Carrying Capacities update. The nine threshold categories were adopted in 1982 and each threshold category contains a number of specific indicators and standards that are used to track, evaluate, and report the status of each Threshold over time. The Regional Plan guides all land use decisions in the basin and is the basis for all of TRPA's ordinances and environmental codes. Through the Pathway Forum and Place-Based Planning process, a high level of public involvement has been incorporated into the emerging Regional Plan Update for Lake Tahoe. The final product, expected by 2010, will be the blueprint to restore the Lake and improve the environmental health of the Basin.

TRPA regulatory and regional planning efforts are integral to TMDL implementation efforts. Proposed updates to the Regional Plan highlight the need to reduce fine sediment particle loads from re-suspended dust that reaches Lake Tahoe through atmospheric deposition, programmatic efforts to maintain forested roads and prevent additional loading from fuels management activities, and underscore the importance of stream environment zone restoration activities.

The Environmental Improvement Program (EIP), a commitment to repairing damage to water and air quality, forest health, fish and wildlife, recreation and scenic views through projects supported by federal, state, local and private sectors, provides the framework for implementation activities to reduce pollutant loads from all sources. The EIP program encompasses hundreds of capital improvement, research, program support, and operation and maintenance projects in the Tahoe basin, all designed to help restore Lake Tahoe's clarity and environment.

California State Government

State Water Resources Control Board and the Lahontan Water Board

The primary responsibility for water quality protection in California rests with the State Water Resources Control Board and the nine Regional Water Quality Control Boards. The Lahontan Regional Water Quality Control Board (Water Board) jurisdiction extends from the Oregon Boarder to the northern Mojave Desert and includes all of California east of the Sierra Nevada Crest, including the Lake Tahoe basin.

The Lahontan Water Board is one of two state partners responsible for Lake Tahoe TMDL development and implementation. The Water Quality Control Plan for the Lahontan Region (Basin Plan) identifies urban stormwater runoff as the primary controllable source of pollutants reaching Lake Tahoe. The Lake Tahoe TMDL research described in this document supports this finding. The Water Board regulates stormwater discharges through waste discharge requirements for individual dischargers, waivers of waste discharge requirements, and through National Pollutant Discharge Elimination System (NPDES) stormwater permits. The State Water Resources Control Board manages a statewide permit for industrial activities and for the California Department of Transportation, while the Lahontan Water Board has adopted region-specific NPDES permits for construction activity disturbing more than one acre of soil and for the three municipal jurisdictions on the California side of the Lake Tahoe basin.

While industrial and construction NPDES permitting programs help prevent additional loads from reaching Lake Tahoe, the primary source and load reduction opportunity lies with addressing roadway and municipal stormwater discharges. The Water Board enrolled the three municipal jurisdictions on the California side of the Lake Tahoe basin in the municipal NPDES storm water program in 1992. Although the jurisdictions do not have populations large enough to trigger automatic NPDES requirements, the Water Board determined that municipal NPDES permits were needed due to the magnitude of the pollutant source and the sensitivity of the receiving water body.

Lahontan Water Board non-point source programs regulate surface discharges from the undeveloped landscape, including timber harvest and grazing activities. These programs will assist the Lake Tahoe TMDL program in meeting necessary load reductions from the forested uplands source category. Finally, Water Board programs and policies support stream restoration and stream environment zone rehabilitation efforts. Water Board staff routinely participate in multi-agency technical advisory groups to facilitate stream restoration projects and assist with necessary construction permitting processes.

<u>California Tahoe Conservancy</u>

The California Tahoe Conservancy (CTC) is an independent State agency within the 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, 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 has active 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, taking a lead role in Upper Truckee River and Ward Creek stream restoration efforts.

California Departments of Parks and Recreation
The California Department of Parks and Recreation manages more than 270 park units state wide, which contain a diverse collection of natural, cultural, and recreational resources found within California. State park units include underwater preserves and parks; redwood, rhododendron, and wildlife reserves; state beaches, recreation areas, wilderness areas, and reservoirs; state historic parks, historic homes, museums, visitor centers, cultural reserves, and preserves; as well as lighthouses, ghost towns, waterslides, golf courses, conference centers, and off-highway motor vehicle parks. Within the Lake Tahoe basin, the Sierra District of the California Department of Parks and Recreation manages nine park units covering over 8,600 acres of land. The Sierra District Resource Program is actively protecting, preserving, and managing many aspects of park resources, including forest 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.

California Department of Transportation
The California Department of Transportation (Caltrans) 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 are to (1) provide the safest transportation system in the nation for users and works, (2) maximize transportation system performance and accessibility, (3) efficiently deliver quality transportation projects and serves, (4) preserve and enhance California's resources and assets, and (5) promote quality service through an excellent workforce.

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) which regulated all stormwater discharges from Caltrans owned stormwater systems, maintenance facilities and construction activities. Future permit revision will likely require Caltrans to prepare and implement a Pollutant Load Reduction Strategy for the Lake Tahoe basin to target actions toward those highway outfall points that have the largest fine sediment particle loads.

Nevada State Government

Nevada Division of Environmental Protection
Within Nevada, the Nevada Division of Environmental Protection (NDEP) administers water and air quality protection programs under the Clean Water and Clean Air Acts. The Bureau of Water Quality Planning maintains the Lake Tahoe Watershed Program, which oversees and coordinates water quality protection activities and functions in the watershed, including water quality standards review and revision, non-point source TMDL development, non-point source pollution management, and water quality monitoring. In Nevada, non-point sources of pollution remain largely unregulated and the agency supports a locally led, voluntary approach to non-point source TMDL implementation. This voluntary approach relies on three primary mechanisms to

implementing non-point source controls: (1) Interagency coordination and collaboration to develop and implement watershed-based plans; (2) funding support of priority non-point source projects identified through the planning process; and (3) non-point source education and outreach. In the Lake Tahoe Basin, NDEP supports the more quasi-regulatory approach to non-point source implementation taken through TRPA's Regional Plan.

Similar to the Lahontan Water Board, NDEP's Bureau of Water Pollution Control regulates stormwater discharges through waste discharge requirements for individual dischargers and through NPDES stormwater permits for industrial activities and construction activities, as well as a statewide permit for the Nevada Department of Transportation.

NDEP also administers air programs for the purposes of air quality protection and compliance with Clean Air Act requirements. The mission of the Bureaus of Air Pollution Control and Air Quality Planning is to achieve and maintain air quality levels to protect human health and safety, prevent injury to plant and animal life, prevent damage to property, and preserve visibility and the scenic, esthetic and historic values of the State. This mission is accomplished through reasonable, fair and consistent implementation of state and federal air quality rules and regulations.

Nevada Division of State Lands

The Division of State Lands (DSL) leads the state of Nevada's programs to protect Lake Tahoe. The Nevada Tahoe Resource Team (NTRT) is an interagency team coordinated by DSL and dedicated to preserving and enhancing the natural environment in the Lake Tahoe basin. In addition to DSL 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 NTRT is responsible for implementing Nevada's share of the EIP, and is coordinating and implementing 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.

DSL administers a variety of other Tahoe programs, including the Nevada Lake Tahoe license plate program, and the excess coverage mitigation program and the management of approximately 500 urban parcels in the basin acquired through the 1986 Bond Act. DSL is also responsible for permitting activities affecting the bed of the Lake below elevation 6223'.

Nevada Department of Transportation

Similar to Caltrans, 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 impacted waterbodies 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. Therefore, with the approval of this document NDOT will gain the responsibility to retrofit jurisdictional roadways within the Lake Tahoe basin to reduce fine sediment particle and nutrient loads consistent with specified TMDL wastle load allocations.

Local Government

California Local Government

There are three municipal jurisdictions on the California side of the Lake Tahoe basin. There is one incorporated city, the City of South Lake Tahoe and portions of two California counties, El Dorado and Placer. Under the municipal stormwater NPDES permitting program (Board Order R6T-2005-0026, CAG616002), these three local government entities are held responsible for runoff water quality from within their jurisdictional boundaries (excepting federal and state owned lands). As such, these entities must provide collection, conveyance, and treatment facilities to reduce pollutant loads from urbanized areas. Federal NPDES storm water regulations require the California municipalities to develop and implement comprehensive Storm Water Management Plans that address urban runoff problems from commercial, industrial, residential, and construction sources along with providing treatment from 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 constituents and stakeholders about the importance of stormwater management.

Nevada Local Government

There are three counties, Washoe, Douglas, and Carson City Rural on the Nevada side of the Lake Tahoe basin. While the portions of Washoe and Douglas Counties that lie within the Lake Tahoe basin are predominantly developed, the portion of Carson City undeveloped forestlands. Incline Village within Washoe County is the largest urban area on the Nevada side of the Lake Tahoe basin. The community does not, however, meet the population density thresholds for mandatory Municipal NPDES permitting. Washoe County has assumed responsibility for planning, implementation and maintenance of water quality and erosion control projects. In Douglas County, water quality improvement project and storm water program planning, implementation and maintenance has historically been shared between County and the General Improvement Districts within the County.

11.2 Urban Upland and Groundwater

The majority of pollutant loading and load reduction potential come from urban runoff. The Recommended Strategy focuses on advanced practices and innovative technology to control fine sediment particles from the urban runoff source category. As described in the Recommended Strategy, traditional stormwater treatment methods are not adequate for treating the primary pollutant of concern (fine sediment particles) and urban municipalities will need to implement advanced stormwater treatment technologies and more intensive roadway operations and maintenance practices to meet load allocation targets.

Example Load Reduction Measures

1. Current best practices – treatment basins, stormwater vaults, road shoulder stabilization, limited street sweeping, and annual facilities maintenance with vacuum trucks.
2. Advanced, Intensive Practices – Constructed wetland and passive filtration basins, media filters in stormwater vaults, more frequent facilities inspection and maintenance actions.
3. Innovative Technologies – Active pumping and filtration systems for stormwater in urban areas with concentrated impervious coverage, including pumping water to upland areas for standard or advanced treatment and/or using drinking water and/or wastewater treatment-type technologies.
4. Use of alternative deicing and traction abrasive compounds and advanced technologies for determining the need and appropriate deicing and abrasive application rates.
5. Advanced abrasive recovery and intensive maintenance of stormwater infrastructure.
6. Advanced roadway facilities maintenance, including more frequent use of state-of-the-art vacuum sweeping equipment and alternative pavement surfaces.

Regulatory Approach

California regulates stormwater discharges from urban municipalities in the Tahoe basin under the federal NPDES program. On the Nevada side of the basin, the NDEP plans to manage urban runoff through Memoranda of Agreement with Douglas and Washoe Counties. Both the California and Nevada Departments of Transportation are regulated under a statewide NPDES storm water permits. These permits require compliance with TMDL requirements.

California

On the California side of the basin, the Water Board regulates runoff from the three municipal jurisdictions under a single Municipal NPDES stormwater permit (CAG16002). The current permit requires the City of South Lake Tahoe, El Dorado County, and Placer County to develop and implement comprehensive Storm Water Management Plans. These plans provide the framework for enhancing local government storm water programs to meet minimum federal NPDES permit requirements. The municipal NPDES permit has a five year update cycle and is scheduled for renewal in 2010. The Water Board anticipates incorporating Lake Tahoe TMDL waste load allocations and associated milestones into the 2010 permit along with references to various TMDL implementation tools. The Water Board will require the co-permittees to amend their Storm Water Management Plans to describe how each municipality will accomplish necessary annual pollutant load reductions. The statewide NPDES permit regulating discharges from the California Department of Transportation will also be amended to include similar planning and waste load allocation requirements.

Nevada

The NDEP expects to develop Memoranda of Agreement with Douglas and Washoe Counties to specify Lake Tahoe TMDL load reduction expectations. These Memoranda will likely include program descriptions, planning recommendations, load allocations, and load reduction milestone and tracking requirements similar to those expected for the California municipal NPDES permits. The existing NPDES permit regulating discharges from the Nevada Department of Transportation may be amended to include applicable waste load allocations.

Performance and Compliance Assessment

The Water Board and NDEP are working with a number of partners to develop implementation tools that will assist implementing agencies throughout the Lake Tahoe basin to estimate pollutant loads and track compliance with regulatory targets. These tools include a Pollutant Load Reduction Model project to provide nutrient and fine sediment load reduction estimates at a sub-watershed, or catchment, scale that will integrate water quality benefits from source control efforts, capital improvements, and operations and maintenance actions. The Water Board and NDEP are also working on the Lake Clarity Crediting Program to provide a system of related tools (such as the Pollutant Load Reduction Model) and methods to allow 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 to achieve needed load reductions with a blend of treatment approaches and cooperative efforts that span jurisdictional boundaries. The Lake Clarity Crediting Program will be used to track compliance with stormwater regulatory measures.

Followed Lake Tahoe TMDL adoption, the Water Board and NDEP will use load allocation milestones established by this TMDL to establish specific load reduction targets for NPDES permits and Memoranda of Agreement. To ensure implementing partners continue to achieve load reductions needed to meet the Clarity Challenge, the Water Board and NDEP will monitor load reduction progress by reviewing annual stormwater program reports and establishing new five year load reduction targets. New targets will reflect the success of the previous permit term and will maintain the overarching goal of meeting load reductions needed to achieve the Clarity Challenge goal as established by the TMDL allocation milestones.

Regulatory Measure Implementation Schedule – Urban Uplands

Action	Schedule	Responsible Party
Update California Municipal and Caltrans NPDES Permits to include waste load allocations and annual load reduction targets linked to the Lake Clarity Crediting Program	No later than one year from TMDL approval	Lahontan Water Board

Require California NPDES Permittees develop and implement Pollutant Load Reduction Strategies to target water quality improvement actions	Strategies to be submitted for Water Board Executive Officer acceptance no later than one year from TMDL approval	Lahontan Water Board
Draft Memoranda of Agreement to specify load allocations and load reduction targets for Nevada municipal jurisdictions	No later than one year from TMDL approval by the NDEP Administrator	NDEP
Incorporate Storm Water Management Plan and Lake Clarity Credit Program elements into the TRPA Regional Plan	No later than one year from TMDL approval	TRPA

11.3 Forest Upland

The Pollutant Reduction Opportunity analysis found there are a number of disturbed areas (e.g., unpaved roads, campgrounds and ski runs) where relatively high sediment particle yields and easy access make pollutant controls cost-effective (Lahontan and NDEP 2008a). The implementation approach for forested uplands focuses the most effort on easy-access, high pollutant yielding disturbed areas.

Pollutant controls can be categorized according to land uses (e.g., unpaved roads, campgrounds or ski runs) and actions taken on various land uses can further be divided into two categories. Standard BMP treatments are planned by federal and state land management agencies for their roads, trails and fuels reduction projects. More advanced treatments designed to achieve a range of effects from better hydrologic function to complete restoration that will mimic natural conditions as time progresses are also recommended.

<u>Example Load Reduction Measures</u>

1. Standard unpaved roadway BMPs (water bars, armored channels, shoulder stabilization).
2. Unpaved road and trail maintenance, including maintaining flow paths, and stabilizing or re-routing eroding segments.
3. Unpaved road and trail decommissioning and restoration.
4. Revegetate and stabilize ski runs and other disturbed recreational areas.
5. Implement standard BMPs for vegetation management activities.
6. Implement enhanced BMPs for vegetation management activities and restore soil infiltration capacity following fuels management project completion.

Regulatory Approach

The expected forest upland load reductions described by the Recommended Strategy will be accomplished through continued implementation of current forest management programs, policies, restoration activities, and vegetation management approaches. The

LTBMU, Nevada Division of State Lands, California Department of Parks and Recreation, and the CTC are the primary public forested land management agencies responsible for maintaining existing land management activities to ensure expected load reductions to meet the Clarity Challenge and other load reduction goals are achieved.

The Lake Tahoe TMDL program has worked with the LTBMU to include references to applicable TMDL implementation elements in the updated Forest Plan. The TMDL program expects the Forest Plan to commit to ongoing maintenance of LTBMU unpaved roadways and trails, inspections and maintenance of trailhead and parking lot BMPs, continued efforts to identify and restore landscape disturbances, and to responsibly implement vegetation management actions with appropriate BMPs.

The Water Board has adopted a Waiver of Waste Discharge Requirements consistent with agreements contained in a Memoranda of Understanding between the Water Board and the LTBMU that describes permitting and reporting requirements for projects such as site improvements, stream channel restoration work, trailhead parking retrofits, and roadway management actions. The Water Board desires to maintain this Waiver based on an updated Memorandum that includes more explicit reference to Lake Tahoe TMDL implementation expectations and reporting requirements to facilitate implementation tracking.

The California Department of Parks and Recreation and CTC have not entered into formal Memoranda of Understanding with the Water Board. Although these two land management agencies are committed to implementing projects and activities to reduce pollutant loads, the Water Board maintains the authority to issue Waste Discharge Requirements or Waivers of Waste Discharge Requirements as needed to be certain appropriate load reduction programs, policies, and activities continue as anticipated. Similarly, the Water Board may adopt Waste Discharge Requirements, or take other appropriate action to regulate LTBMU activities if the current Memoranda of Understanding do not adequately ensure needed load reduction actions are implemented.

The NDEP is considering adopting 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.

Performance Assessment

The TMDL program will track forest implementation partner activities to assess whether expected load reduction actions are being taken. The LTBMU is the largest land owner in the Lake Tahoe basin and the most significant of the forest management partners, thus the LTBMU has the largest responsibility to continue implementing the programs, policies, and projects outlined in the Recommended Strategy to accomplish needed load reductions. The Water Board will amend the LTBMU Memoranda of Understanding to include annual reporting of completed activities and projects along with proposed actions for the coming year. This information will be considered along with CTC and

California Department of Parks and Recreation annual accomplishments to determine if programs and activities remain consistent with the Recommended Strategy. If forest management agencies continue to complete projects and activities consistent with the Recommended Strategy, then the TMDL program will assume forest upland interim load reduction requirements will be met.

Regulatory Measure Implementation Schedule – Forest Uplands

Action	Schedule	Responsible Party
Update Forest Plan to reference applicable TMDL implementation actions	No later than one year from TMDL approval	LTBMU
Update Water Board-LTBMU Memoranda of Understanding to include implementation action planning and reporting requirements	No later than one year from TMDL approval	Lahontan Water Board
If needed, draft and issue Waste Discharge Requirements to forest implementing agencies or take other appropriate regulatory action to ensure TMDL implementation planning and reporting requirements are being completed	No later than two years from TMDL approval	Lahontan Water Board and NDEP

11.4 Atmospheric Deposition

Roughly fifteen percent of the basin-wide fine sediment particle load is transported and deposited on the lake surface through atmospheric deposition and cost-effective treatments are available by controlling stationary dust sources. The fine sediment load reduction available through enhanced maintenance and operation of non-mobile dust sources led to recommendations focusing on controls for both paved and unpaved roadways, as well as parking lots and construction sites. Current programs for reducing emissions from residential wood burning are also expected to provide some particle reduction from this source.

The Recommended Strategy and this implementation plan focus on non-mobile sources of fine sediment particles within the atmospheric source category because these sources provide the bulk of load reaching Lake Tahoe from this source and because mobile sources predominantly produce nitrogen, not fine sediment particles or phosphorus. Non-mobile sources of fugitive dust, such as paved and unpaved roads, are responsible for more than 88 percent of atmospheric fine sediment particle emissions in the Lake Tahoe Basin (Lahontan and NDEP 2007b). Stationary source controls for fine sediment particles and their associated phosphorus are also three orders of magnitude less expensive unit removed than mobile sources according to the *Pollutant Reduction Opportunity Report* (Lahontan and NDEP 2007b).

Example Load Reduction Measures

1. Frequent street sweeping with vacuum equipment that captures 10 micron particles.
2. Pave dirt roads at access points – actual stabilized ingress/egress or implementation of ordinances or policies requiring such action be taken by private property owners.
3. Posted speed limits on unpaved roads.
4. Stabilize unpaved roads, including forest roads, to reduce dust generation.
5. Require adequate soil moisture during earth-moving operations.
6. Use dust suppressants on exposed soil for road-building projects, including roads constructed for forest fuels management.
7. Reduce residential wood burning emissions through existing regulations and incentive programs.

Implementation Approach

The TRPA has the primary regulatory authority for air quality in the Lake Tahoe basin. TRPA has adopted environmental thresholds and indicators to monitor the amount of pollutants emitted by both mobile and stationary pollutant sources. TRPA has implemented regulatory programs to reduce air born pollutants discharged from wood burning stoves and reduce dust from active construction sites.

Since the majority of fine sediment particle load from the atmospheric source is generated by the urban roadways, it will is expected the required atmospheric load reductions and interim load allocations will be met by implementing regulatory measures to control stormwater pollutants from urban roadways under the urban upland source category. Similarly, actions taken to control runoff issues from unpaved roadways will also reduce dust from these areas.

11.5 Stream Channel Erosion

As an important element of TRPA's EIP, 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 achieving water quality improvements, implementation efforts for this source category are based on current plans and approaches. The analysis focuses only on fine sediment particles (and associated nutrients) released from stream bank and bed erosion. The load reduction estimates do not consider the other potential ecological benefits available from stream or wetland restoration. It is widely believed that restoring floodplain connectivity and improving natural geomorphic function will provide additional fine sediment particle and nutrient load reductions.

Example Load Reduction Measures

1. Unconstrained stream restoration (planform modification, increasing sinuosity, improving floodplain connectivity, etc.).

2. Bank protection (channel armoring, bank slope reduction, etc. to reduce bank failure).
3. Mixed approach of unconstrained restoration where possible and simple bank protection on constrained stream reaches.

Implementation Approach

The stream channel erosion analysis is based on restoration activities for 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 2007b). 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 planning for five different reaches of the Upper Truckee River was initiated in 2002. The CTC has completed a project at the mouth of the river to remove fill placed during development of the Tahoe Keys (Cove East 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 along the Lake Tahoe Airport in 2008 and plans to complete the restoration effort by 2010. 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 on the river below the Lake Tahoe Airport.

The LTBMU has taken the lead in planning and constructing restoration projects on Blackwood Creek. There have been three projects constructed within the past five years, including fish dam removal, Barker Pass culver removal and bridge construction, and floodplain rehabilitation. The LTBMU has additional plans for further channel and floodplain work to address historic disturbance. The CTC has 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 (February 2007) to evaluate the opportunities and constraints for 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.

The TMDL program expects needed load reductions and interim load allocation for the stream channel erosion source will be met once all the restoration projects and activities are completed for the three major tributaries. These restoration projects are anticipated to be completed within 20 years from the adoption of the TMDL.

11.6 Beyond the Clarity Challenge

After 15 years of Lake Tahoe TMDL implementation, the TMDL program will conduct a thorough evaluation of load reduction progress and develop the following phase of the implementation plan to continue load reduction efforts. The TMDL program evaluation will include an assessment of needed changes to the implementation strategy and a review of available load reduction estimation and tracking tools. This reassessment of the Lake Tahoe TMDL will seek to incorporate any new and relevant data and use that information to develop future load reduction milestones. The Lake Tahoe TMDL program is committed to a detailed planning exercise to adjust implementation policy as needed on a 15-year interval to ensure ongoing progress at restoring Lake Tahoe's transparency to historic levels.

12 Adaptive Management

An overall system is needed to manage the information generated from implementing the Lake Tahoe TMDL and monitoring implementation effectiveness. Responsible entities will implement load reduction strategies, track activities, estimate pollutant load reductions, and monitor effectiveness of actions. Concurrently, researchers will provide scientific updates on targeted research questions. This information must be evaluated, synthesized, and disseminated to the public so all stakeholders can participate in adaptively managing the information and its role in shaping future recommendations. The Lake Tahoe TMDL program plans to design a comprehensive Lake Tahoe TMDL Management System to accomplish these goals.

Environmental Incentives, LLC. prepared a Generalized Management System Design Manual (Sokulsky and Beierle 2007) that provides a framework for establishing a Lake Tahoe TMDL Management System. There are two processes within the proposed Management System: (1) a continual improvement cycle and (2) an adaptive management process. The continual improvement focuses on tracking and evaluating program and project implementation and regulatory compliance to understand the effectiveness of policy implementation. The adaptive management elements outline a process for reducing the uncertainty within the models and assumptions driving the TMDL load reduction requirements and load reduction crediting policies. These practices will enable the agencies to report quantifiable load reductions relative to project goals and adjust program expectations in response to measured improvements over time.

This chapter summarizes the development and components of the proposed Lake Tahoe TMDL 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 concept of adaptive management has been developed further in the Tahoe basin through the use of Southern Nevada Public Lands Management Act (SNPLMA) funds. These projects have resulted in four phases of the Adaptive Management Framework (AMF) developed for resource management agencies to apply to programs in the Tahoe basin. The AMF outlines the general components for performing adaptive management across all resource areas, such as vegetation, wildlife, and water quality. The Generalized Management System Design Manual (AMF Phase III funding) had specific recommendations to develop a management system for large programs that have had significant investment, namely: the Pathway Indicator Monitoring and Reporting Program, the Environmental Improvement Program, and the Lake Tahoe TMDL Program (Sokulsky and Beierle 2007).

To date, funding has provided the direct support to develop the Lake Tahoe Status and Trend Monitoring and Evaluation Program (AMF Phase IV funding) for select resource area desired conditions (Pathway Indicators) in the Lake Tahoe basin. Also the conceptual frameworks for the Environmental Improvement Program Management System and the Science Program Management System have been documented and will be pursuing future development. USEPA submitted a proposal for SNPLMA funding in November of 2008 to support development and implementation of the Lake Tahoe TMDL Management System. This proposal involves consultant and scientific coordination support for development and first year implementation of the Lake Tahoe TMDL Management System. With funding procured, this project will enable full implementation and adaptive management of the TMDL.

The Lahontan Water Board and the Nevada Division of Environmental Protection are committed to operating the management system throughout the implementation timeframe of the TMDL. This framework will enable adaptive management to occur in the context of the TMDL ensuring that important scientific findings and research results are included in management decisions relating to water quality policy in the Tahoe basin.

12.1.1 Management System Description

A management system defines the elements and process (boxes and arrows in Figure 12-1) in a plan created to achieve a desired goal using continual improvement and active adaptive management. A management system is also concerned with the people and relationships needed for operation of the plan. Aspects include (1) developing relationships between agencies, implementers, and stakeholders who need to work together to accomplish a goal, (2) defining the tasks and processes to enable all parties to work together in a targeted and predictable manner, (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, reporting, and working together. An organized set of operations to evaluate, track, and report pollutant load reductions from projects and actions in a science-based, quantitative manner at Lake Tahoe is critical for effective TMDL implementation. Additionally, this management system will structure communication between agency policy makers and researchers to identify areas of uncertainty and systematically incorporate scientific findings into management decisions. This project builds on the Generalized Management System designed by the Pathway agencies to utilize the conceptual format of the “Plan-Do-Check-Act Cycle” (Sokulsky and Beierle 2007).

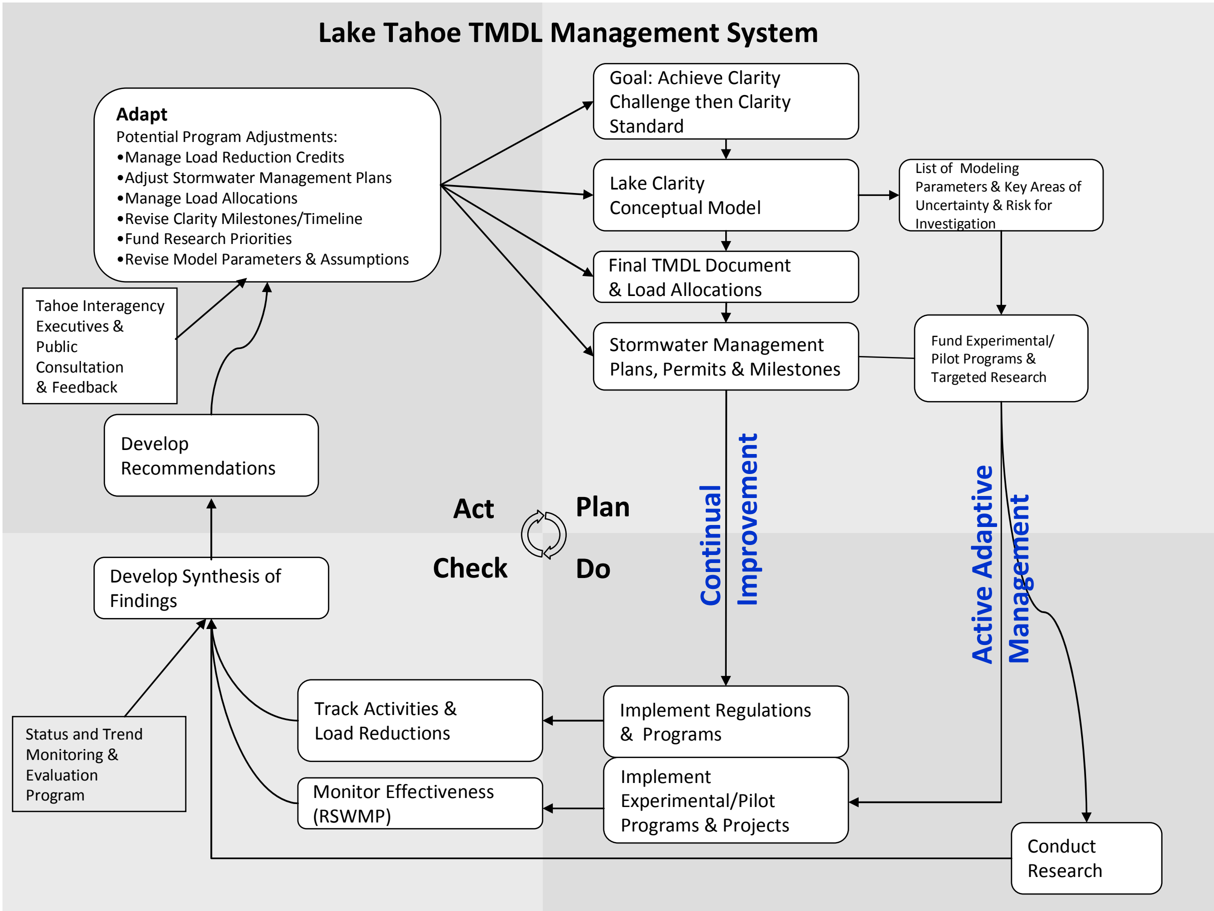

Figure 12-1. Lake Tahoe TMDL Management System diagram illustrating the continual improvement and active adaptive management cycles (adapted from Sokulsky and Beierle 2007).

The management system diagram depicts many required components needed for a functioning system to be operable. Individual components are listed and detailed in the end of this section. The “Plan” component of the diagram is the starting point with the goal (which is both the Clarity Challenge and the Clarity Standard), conceptual model identifying the linkages, the TMDL load allocations, and regulatory 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.

The “Do” component of the diagram in Figure 12-1 is part of the implementation of the TMDL. The active adaptive management component in this box and the “Check” component will have important implications into the future to ensure the wisest investment in the most effective and innovative projects critical to meet the load reduction goals. Research in this area is needed to inform how different projects and designs are able to reduce fine sediment particle and nutrient loads under a host of environmental conditions. Monitoring and validating predictive models and expected load reductions from experimental or pilot projects will advance the science and knowledge in the basin. This will ensure that the actions taken to meet load reductions are based on the best understanding of the fundamental principles and science of the environmental system to ensure success. The Synthesis of Findings report will allow all entities within the basin to have the same knowledge basis to continue to build on with innovative projects, research results, and recommendations for future investigations.

The “Act” component is where management decisions are based on the recommendations that stem from the Synthesis of Findings document that will be produced and distributed to the public and implementing partners. The feedback loop then continues to another cycle of events that continue to build on past efforts in an organized fashion to maximize efficiency in TMDL implementation and meeting the lake clarity goals.

Individual components of the Lake Tahoe TMDL Management System are elaborated upon below. They typically represent one part of a cycle that has important implications to the overall system. Some of the components below are currently under development and will be tailored for use in this management system.

Conceptual Model

An important element of a management system is a solid understanding of the cause and effect relationships within the environmental system in relation to the overall goal. The conceptual model is the visual linkage for how fine sediment and nutrient control actions for the different source categories will decrease the pollutant source loading to Lake Tahoe (see Appendix A for Lake Clarity Conceptual Model). The conceptual model links the different pollutant sources to the lake clarity response with various transport mechanisms. The conceptual model also identifies the most important drivers and actions that will allow resource managers to focus efforts on the actions that will be most influential towards load reductions. Annual pollutant loads reduced, in combination with in-lake physical, chemical, and biological processes, directly affect achievement of the lake clarity goal.

Track activities and Pollutant Load Reductions

The United States Army Corps of Engineers and the Lahontan Water Board are developing an Accounting and Tracking Tool to support the Lake Clarity Crediting Program. The Lake Clarity Crediting Program will provide a system of related tools (such as the Pollutant Load Reduction Model) and methods to allow 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 to achieve needed load reductions and will be used to track compliance with stormwater regulatory measures. The Accounting and Tracking Tool project began in spring of 2008 and is expected to be completed by summer of 2009. The Accounting and Tracking Tool will account for water clarity credits achieved and track load reduction estimates for all actions implemented to achieve fine sediment particle, phosphorus and nitrogen load reductions.

The Accounting and Tracking Tool will:

- Serve as a functional tool for TMDL and Lake Clarity Crediting Program managers
- Easily collect, store, and manage load reduction and credit value data
- Establish a robust database framework suitable for expansion to an online system

In addition to tracking load reductions and credits associated with urban actions, the Accounting and Tracking Tool will include data fields for fine sediment, phosphorus, and nitrogen load reductions from forest upland, stream channel erosion, and atmospheric deposition sources.

Monitor Effectiveness

The TMDL Monitoring Program will be a critical part of evaluating project and BMP effectiveness, project load reductions, and overall status and trends within certain subwatersheds and the basin as a whole. Chapter 13 of this document describes the proposed Lake Tahoe TMDL Monitoring Program.

Synthesis of Findings Report

Regulatory staff and researchers will collaboratively generate an annual Synthesis of Findings report. This will outline the load reduction accomplishments from the previous year. The report will provide an integrated understanding about the load reductions achieved, opportunities for innovation and efficiency, changes in lake clarity status, and new research findings. The synthesis will assemble and interpret new data and information that may become available each year. The overarching purpose of this product is to inform policy recommendations and information needed for the adaptive management process. The synthesis will be a tool to communicate with the public on progress towards meeting load allocation targets. Distributing information about implementation progress to stakeholders is intended to promote action and funding.

Additionally, a milestone evaluation report will be produced, every 5 years at a minimum by regulatory staff to show if the expected load reductions from the different source categories are being achieved. This evaluation report will provide important information for evaluating progress from implementation actions and may help to 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 (adaptive management).

Develop Recommendations

The recommendations for management decisions will come from the Synthesis of Findings 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, ensuring all input is considered in the recommendations.

Research Needs

A structured system for incorporating and managing TMDL research needs will guide future funding priorities for specific areas of investigation. A process will be needed to update load reduction estimation models with the latest research results regarding behavior of parameters, incorporate innovative practices if they prove to involve significant load reduction opportunities, and adjust policies in response to new findings. Research needs will include key areas of uncertainty related to TMDL development, modeling parameters, assumptions, and potential implications from climate change or other factors.

Experimental Pilot Projects

Targeted research and support of funding recommendations for experimental and pilot projects will be required to evaluate and quantify benefits from innovative practices and assist in decisions about which of the innovative practices warrant further investigation. Implementers and water quality managers will work collaboratively to implement the Recommended Strategy, which calls for advanced, alternative and innovative practices to meet the load reductions required. This action is often expensive and planning for it 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.

Adapt

As TMDL implementation progresses and new information and recommendations arise, adaptive management will be required to make program adjustments. Potential adaptations may include: revising load reduction credit estimates, updating model parameters and assumptions, revising implementation strategies, revising the clarity goal timeline, and selecting areas for additional adaptive management investigations.

The management system is designed to be the platform which allows management of the Lake Tahoe TMDL to be both flexible and effective. 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.

Lake Tahoe is vulnerable to a number of large scale events that can potentially impact the effectiveness of the Lake Tahoe TMDL Recommended Strategy and associated implementation plan.

The Lake Tahoe TMDL 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. The remainder of this chapter details with greater specificity of some of the large scale issues confronting the managers of the Lake Tahoe basin.

12.2 Climate Change

Climate change has the potential to affect pollutant generation and transport processes. This section examines expected climate change trends reported in peer reviewed articles and presents a climate change scenario developed for the Lake Tahoe Watershed Model. Due to the uncertainty of climate change predictions and related changes in pollutant loading and lake dynamics, the Lake Tahoe TMDL program does not assign pollutant load or waste load allocations to address potential impacts of climate change. The impacts of these changes on pollutant loading will be addressed through the continual improvement and active adaptive management processes. Measures that may be adopted through these management processes potentially 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 might create program adjustment needs.

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 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 updated 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 clarity.

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).

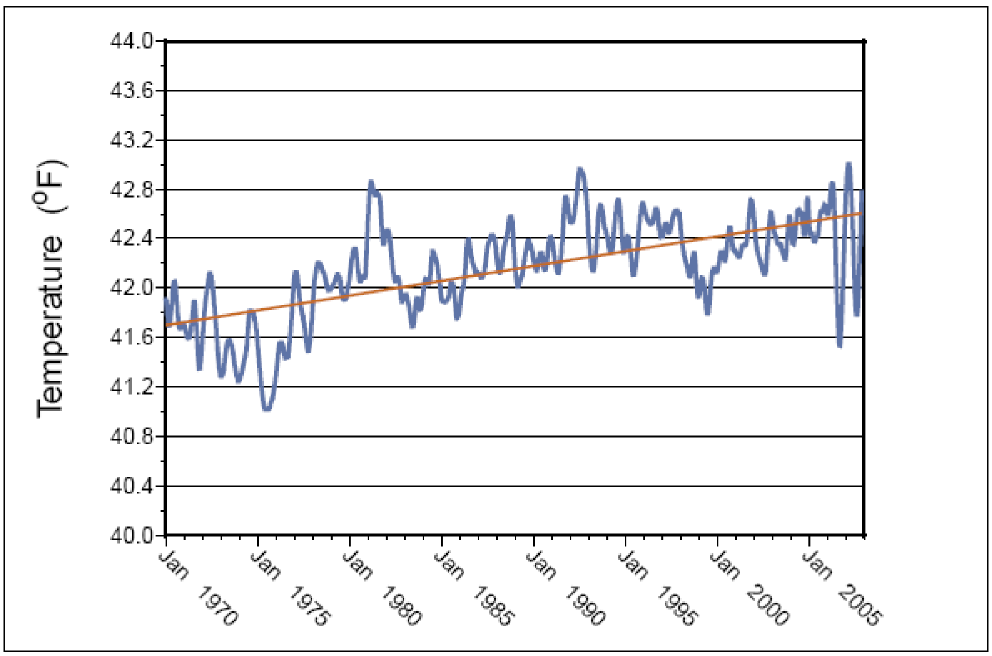

Figure 12-2. Volume-averaged Lake Tahoe water temperature (UC Davis – TERC 2008).

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 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).

Increased thermal stability and lake stratification may reduce the frequency of lake mixing, perhaps to just once every 20 years (Schladow et al. 2008). 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). 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 would likely cause a significant algal bloom, further impairing Tahoe's aesthetic beneficial uses.

Lake Tahoe Watershed Model Climate Change Analysis

Under direction from the Lake Tahoe TMDL program, Tetra Tech, Inc. conducted an exploratory scenario examining potential impacts associated with climate change (Tetra Tech 2007). The scenario did not utilize 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.

To develop the exploratory watershed model scenario examining potential impacts associated with climate change (Tetra Tech 2007), the USGS reviewed a number of peer reviewed papers and chose Dettinger (2005) and Cayan et al. (2006) as the starting point for applying a range of predicted precipitation and temperature changes to the Lake Tahoe Watershed Model.

Based on the predictions of the Dettinger and the Cayan papers, 11 climate change scenarios and a baseline scenario were applied to the 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% 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%, -10%, +0%, +15%. 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% decrease in precipitation, indicate a 61% 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 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 increase the amount of fuels reduction actions. The shift in snowmelt timing and the rise in temperature will result in earlier, longer, and hotter summers. The rise in temperature will 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 would 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.

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 water clarity objective. The foremost of these possibilities is wildfire in Tahoe's forests. In addition to the potential impacts of fire, Lake Tahoe is vulnerable to tributary flooding and seismological 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 highlight 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 their frequency, area burned, and intensity. Lahontan, NDEP, and their partner agencies, using the Lake Tahoe TMDL Management System, will evaluate and provide information to address the impacts of fires that may occur during the 20 year timeline of the TMDL Implementation Plan.

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). 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). Lahontan, NDEP, and partner agencies will address impacts to clarity through updates to reduction targets and implementation practices as determined through use of the Lake Tahoe TMDL Management System.

Case Study: The Gondola Fire and Eagle Rock Creek

The 673 acre Gondola fire of July 2002 can be examined for wildfire impacts in the Tahoe basin. Eagle Rock Creek flows through the Gondola fire burn area. The Eagle Rock Creek watershed is a 0.63 square mile subwatershed to Edgewood Creek. The fire burned 28 percent of the watershed, with eight percent of the watershed experiencing high severity burn conditions (Allander 2004).

The Lake Tahoe Watershed Model incorporates pollutant loading from the Gondola Fire. Eagle Rock Creek shows a post-fire increase in soluble reactive phosphorus (SRP), total inorganic nitrogen (TIN), and suspended sediment concentrations. 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. Conifer watersheds that burn at moderate to high severity can take seven to 14 years for sediment yields to return to normal (DeBano 1998, cited in Robichaud 2000). Further monitoring is needed to demonstrate the rate at which nutrient and sediment concentrations in Eagle Rock Creek return to pre-fire levels.

The Lake Tahoe TMDL used the Lake Tahoe Watershed Model to incorporate water quality impacts from the Gondola Fire, and model output was used to develop pollutant load estimates from the forested uplands source category.

Angora Fire

The Lake Tahoe TMDL program is supporting ongoing monitoring 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 one to two percent of the annual load from all sources (UC Davis – TERC 2008).The intervening year was an atypically dry water year with low flow, no strong summer thunderstorms, and only one significant rain on snow event. Monitoring efforts did record increased levels of nitrogen, turbidity, and suspended sediment during the January 2008 rain on snow event, a post fire first flush runoff event. The three periods of snowmelt in March and May 2008 included increases in total nitrogen concentration in Angora Creek. While event monitoring results indicate increases in sediment concentration, the fire was not a catastrophic source of sediment. Sediment and nutrient transport within Angora Creek was likely much less than what would be measured during a typical year (Reuter and Heyvaert memo 2008). Ongoing monitoring of Angora Creek, the Upper Truckee River, and urban runoff from within the burned area is needed to better understand the long term impact of this event.

Flooding

The analysis efforts of the Lake Tahoe Watershed and Lake Clarity Models included the rain on snow event of New Years 1997. On some tributaries within the basin, this event caused stream flows on the magnitude of a 100-year flood.

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, the substantial elevation increase of the snowline and an increase in rainstorm intensity will likely increase their frequency. The Lake Tahoe TMDL program intends to assess the impact of any future flood events when through the TMDL 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 (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 TMDL program will assess the resulting impacts in relation to load reduction milestones and make implementation plan adjustments as appropriate.

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 Tahoe TMDL team has prepared a monitoring program framework to meet this need. The team expects to further develop monitoring program components within the first year following TMDL adoption by USEPA, and full monitoring program operation is expected by the second year. 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 will 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 Phase Three, 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 clarity 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 our 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.

Although several parts of the Lake Tahoe TMDL monitoring program have been developed, the entire program has not been fully implemented. Some elements, such as in-lake monitoring, have been operating for many years, while other parts 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 NDEP, Lahontan Water Board, TRPA, US Forest Service Lake Tahoe Basin Management Unit, 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 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 based on the conceptual model framework outlined above and intended to inform the broader Lake Tahoe TMDL Management System.

13.2.1 Definition of Generalized Monitoring Categories

The Lake Tahoe Watershed Assessment provides a definition of monitoring that encompasses three different forms (Manley et al. 2000). 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, concerned with nonpoint source loads, 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. Effectiveness monitoring can also be used to help project engineers 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 scale 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, nitrogen, phosphorus and fine sediment particles entering the lake from the various major sources.

13.2.2 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 regulatory agencies, funding groups, planning agencies, science community, and local jurisdictions (implementers) 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 US Forest Service Lake Tahoe Basin Management Unit and the TRPA have agreed to fund the second phase and the work will begin in 2009 and be completed in 2010.

During the second phase, a list of priority analytic constituents and physical variables will be created to guide monitoring plan development. The past TMDL Stormwater Monitoring Study (Heyvaert et. al 2007) collected the following constituents: total nitrogen, total Kjeldahl nitrogen, nitrate, unionized 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 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 on 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 specific sources of urban stormwater pollutants. Needed for adaptive management to update and refine the event mean 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 to meet regulatory or other monitoring needs, it is anticipated that they will support this phase of RSWMP. The Water Board and NDEP will specify RSWMP participation or implementation of an equivalent monitoring program within NPDES municipal stormwater permits and Memoranda of Agreement.

13.2.3 Groundwater

As part of the Lake Tahoe Interagency Monitoring Program (LTIMP) the 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 Utilities District and other Tahoe Water Supply Agencies routinely monitor groundwater wells and submit detailed reports to the Lahontan 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 clarity are not transported to the lake through groundwater flow, and infiltration of pollutants into the shallow aquifer from BMPs is often included in project monitoring, there is no reason at this time to perform additional groundwater monitoring for the TMDL.

13.2.4 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) but, fine sediment particle deposition (< 16 µm) monitoring is not part of this monitoring program. However, atmospheric deposition is a significant source of pollutant loading to Lake Tahoe and 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 Mid-lake Buoy station located on the northern middle portion of the lake and the Northwest Lake station located between the Mid-lake 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 will need to 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 UC Davis atmospheric deposition monitoring is needed to assess basin-wide loading along with directed monitoring focusing on actions to determine load reductions within the atmospheric source category.

13.2.5 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 US Forest Service Lake Tahoe Basin Management Unit, California Tahoe Conservancy, Nevada Division of State Lands, California State Parks, and many local municipal jurisdictions are responsible for managing the forested uplands. 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 Lake Tahoe TMDL program 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 non-urban uplands is that there are currently 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 or sub-basin level to determine if the measures are not increasing pollutant loading (fine sediment and nutrients) important to the TMDL. Research is planned through Southern Nevada Public Lands Management Act funding for evaluating the potential effects from various fuel reduction practices. The TMDL partners will work with groups such as the US Forest Service Lake Tahoe Basin Management Unit to develop these monitoring plans.

13.2.6 Stream Channel Erosion

The US Forest Service Lake Tahoe Basin Management Unit, California Tahoe Conservancy, 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 markers and monitor changes in stream cross-sections in relation to erosion or aggregation of sediment for stream reaches of interest. 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. The stream channel evaluation will include long term stream monitoring offering a more comprehensive assessment of how channel restoration efforts integrate with watershed actions to improve water quality.

13.3 Tributary and Lake Response Monitoring

13.3.1 LTIMP for the Lake

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 1963, 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 Lahontan 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 and mass balance.

The current list of parameters at the Index and Mid-lake 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.

13.3.2 LTIMP for Tributaries

Stream water quality monitoring and suspended sediment load calculations are regularly done as part of LTIMP. LTIMP is a cooperative program including both state and federal partners and is operationally managed by the U.S. Geological Survey (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/.

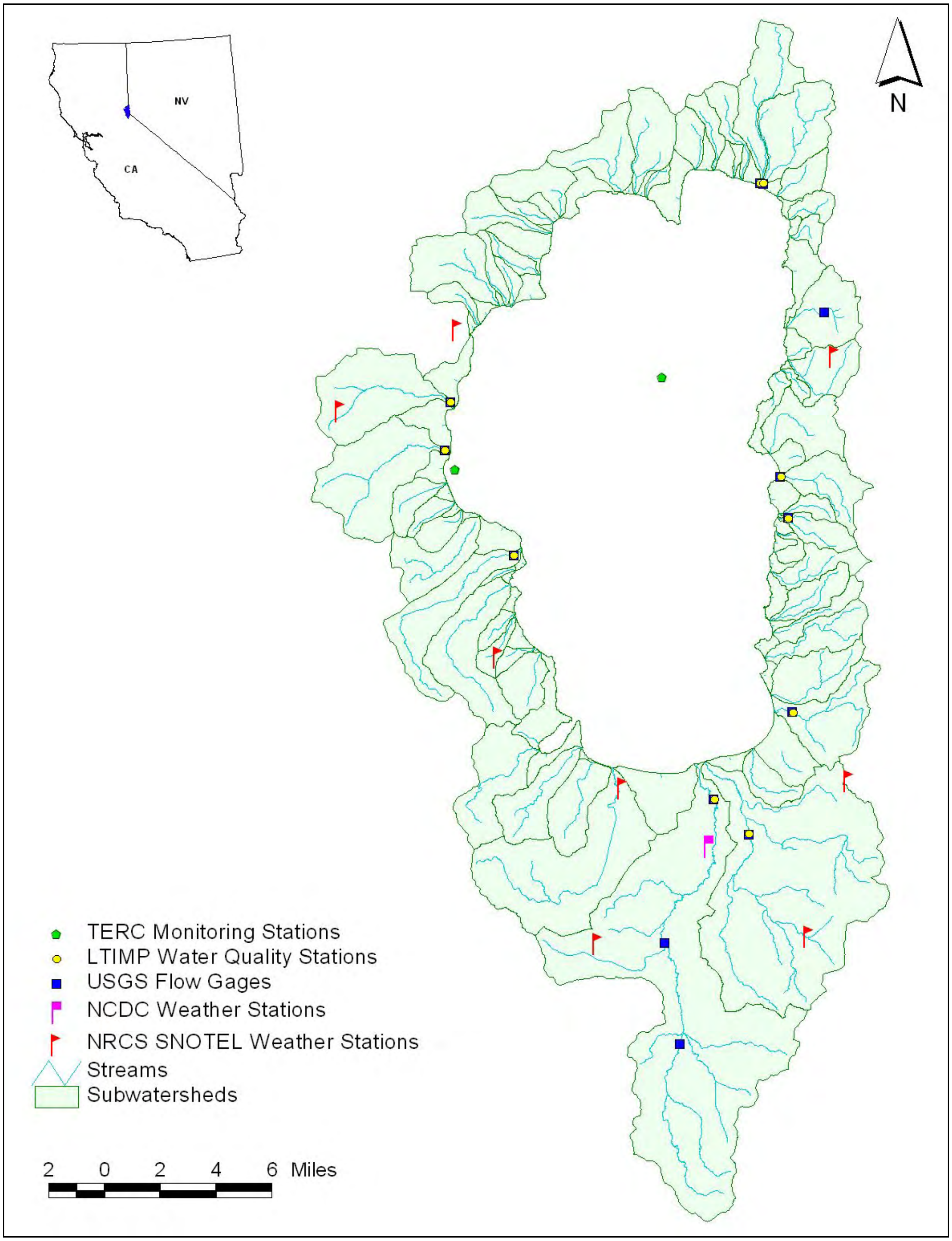

Figure 13-1. Sampling locations for LTIMP Stream and Lake (TERC) sites (Tetra Tech unpublished).

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.

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. While no program can remove all uncertainty, the breadth of analysis and the resources committed is significant (>$10 Million). Maximizing the knowledge concerning the relationship between pollutant source loading and water clarity 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, 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 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 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 and 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 under estimate 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, assumptions were made in the watershed and lake clarity models that quantified average annual pollutant loading rated, the lake's assimilative capacity, and corresponding allocations. Second, conservative assumptions are used to inform pollutant reduction opportunities and 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 2009).
- The 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 Watershed Model. However, estimates of this 'transport loss' were accounted for by the 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 N and P would be modeled to runoff from the vegetated turf land use (Watershed Model Report, p.84).

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 over estimated 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.

Assuming that each of the 4,841 undeveloped lots is 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. With a GIS estimate of 5,000 impervious acres, the 373 acres of new coverage would comprise about 7 percent of total basin coverage (Lahontan and NDEP 2009). However, at build out, active conservation efforts, such as the CTC urban lot program and the Forest Service Burton-Santini acquisition program, will prevent a number of the lots in question from being developed. Retiring these lots prevents the development and reduces the future total of new coverage, making seven percent a maximum assumption that is likely not to be ever reached.

Past development resulted in water quality degradation in part because there was no mitigation to prevent runoff and erosion. Future development will include BMPs to limit and treat 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).

The regulatory structure within the Tahoe basin includes code and policy mechanisms to prevent potential degradation of parcels. To comply with existing regulations, any additional parcel development is not permitted to negatively 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). Additionally, The Lahontan Basin Plan includes a prohibition against the approval and construction of new subdivisions (LRWQCB 1995, Ch. 5.8). Though exemptions to this prohibition can be granted, conditions of an exemption include the requirement of full mitigation.

Similarly to the Basin Plan, TRPA regulations are also in place to prevent the potential degradation of water quality due to future growth. The TRPA is responsible for issuing building permits and TRPA may require special conditions of permit approval. Goal #4 of the TRPA Goals and Policies, Implementation Element, is to "[c]ondition Approvals for new development in the Tahoe region on positive improvements in off-site erosion and runoff control and air quality." Policy 1 of this Goal is that "[n]ew residential, commercial, and public projects shall completely offset their water quality impacts… (TRPA 1986, p.VII-17)."

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 allows for a change to a more restrictive management strategy, such as increasing performance requirements for implementers, should the lake be impacted to a greater extent than estimated by the TMDL analysis.

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 bi-state 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.

The Lake Tahoe TMDL team understands 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. The TMDL team 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 thru Fall 2006, the Lake Tahoe TMDL team 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 Lake Tahoe TMDL team 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 Lake Tahoe TMDL team gave more than 20 presentations to various stakeholder groups from December 2002 through December 2006. The groups included the TRPA Governing Board, Lahontan 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 TMDL team 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 a TMDL Lake Tahoe transparency numeric target of 29.7 meters of annual average Secchi depth is 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 in 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 work 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 is a non-prescriptive implementation approach for the Lake Tahoe TMDL.

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 Lake Tahoe TMDL team 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).

NDEP staff held an additional implementer meeting in 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. The meeting, which featured a discussion of the benefits and drawbacks of the permit system, is summarized in meeting notes available at NDEP offices. At the meeting, attendees acknowledged that the flexibility offered by the Memorandum of Implementation (MOI) approach provided the greatest likelihood for successful implementation for the Nevada-side municipalities.

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 TMDL Team 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.

The TMDL team presented information on how the tools can aid TMDL implementation to public stakeholders in late 2008 and through early 2009. The team expects to use these tools to follow TMDL implementation and to adaptively manage the implementation plans based on new monitoring data and scientific research. The TMDL team is 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

Tahoe Monitoring & Evaluation Program

Title: Lake Tahoe Clarity Conceptual Model & Indicator Framework Briefing

Version 0.72

Date: February 18, 2009

Contact Person: Shane Romsos (*phone:* 775.589.5201, *email:* sromsos@trpa.org)

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 Basic 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. More detailed or more focused versions of the CM may be developed to show specific issues in the context of the larger system, however, this Basic CM is the only official version used by the M&E Program.

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 Lake Tahoe's CMs, (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 of the CM and IF, 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.

Mid-Lake Clarity Objective

Restore and maintain mid-lake 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 Mid-Lake Clarity objective.

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

Both mid-lake clarity and nearshore aesthetic are affected by fine sediment particles and algae abundance. The Lake Tahoe Clarity CM diagram (Figure 17-1) uses bolded box outlines and linkage arrows to show dominant chains of cause and effect for mid-lake clarity and nearshore aesthetic.

Mid-lake clarity

Mid-lake 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.

Nearshore Aesthetic

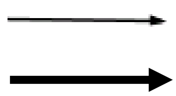
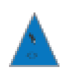
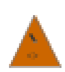
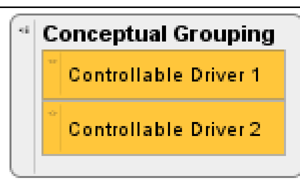
Nearshore aesthetic is an inherently localized issue, different locations will have different expected levels of transparency and benthic algae abundance based on localized conditions. Both attached and floating algae abundance are limited by the availability of biologically available nutrients. Nutrient-laden 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 mid-lake 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 A-2: 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

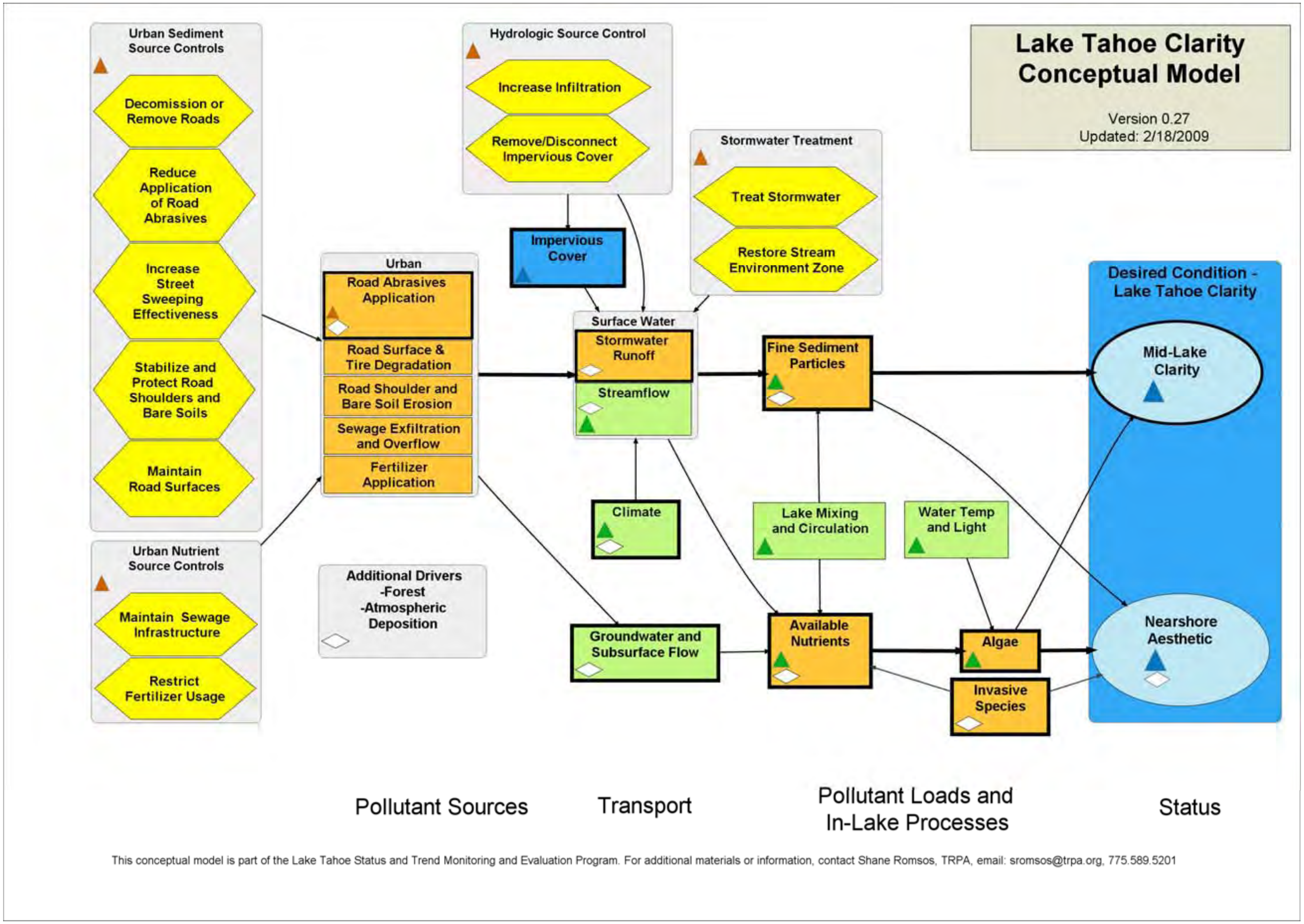


Figure 17-1: Lake Tahoe Clarity Conceptual Model Diagram

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 17-2 is the proposed IF for the Lake Tahoe Clarity DC.

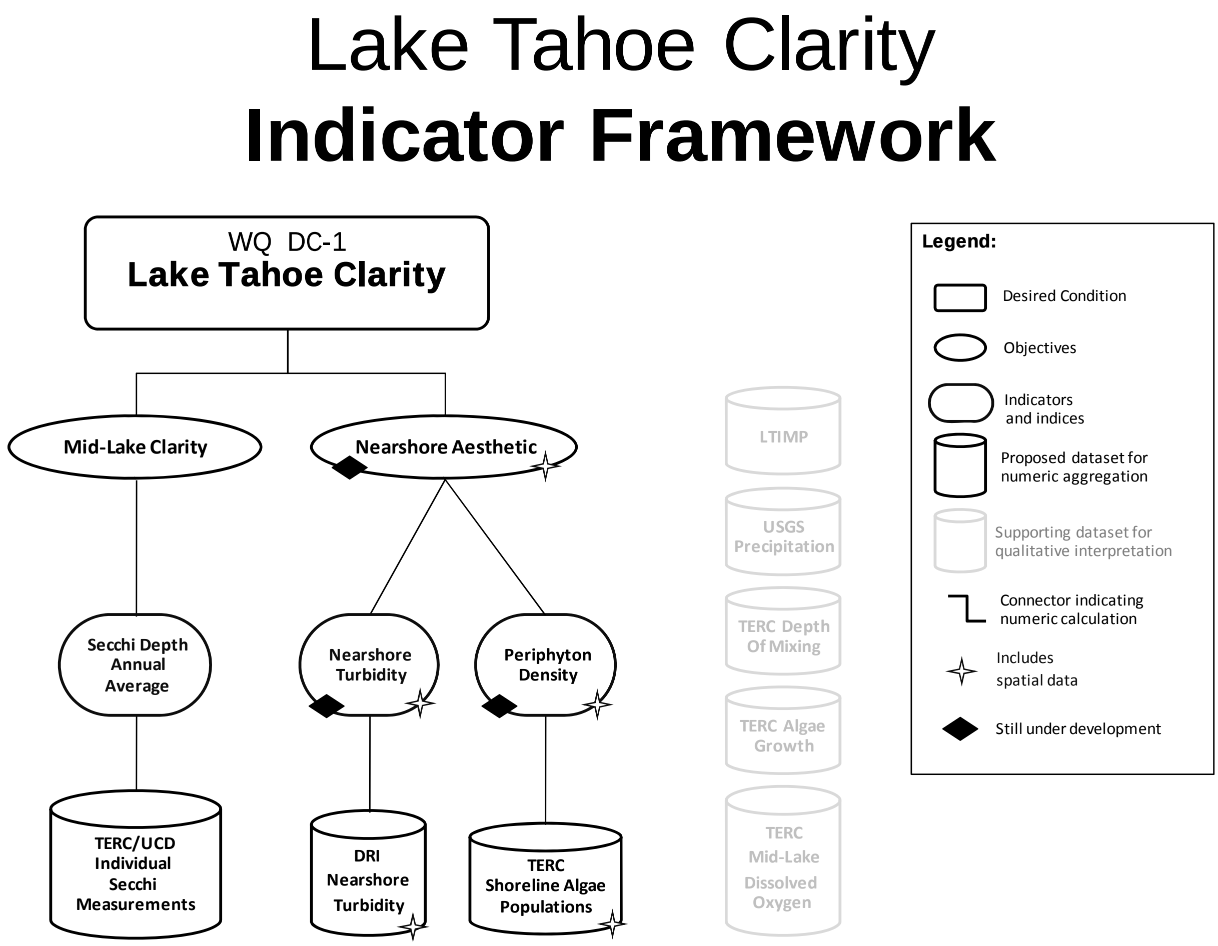


Figure 17-2: Lake Tahoe Clarity Indicator Framework Diagram