LAKE TAHOE TMDL SYMPOSIUM - DAY 1
THURSDAY, DECEMBER 9, 2004
EMBASSY SUITES HOTEL LAKE TAHOE RESORT (NEAR HARRAH'S)
4130 LAKE TAHOE BLVD.
SOUTH LAKE TAHOE

PHASE 1 – POLLUTANT SOURCE IDENTIFICATION
& LAKE RESPONSE RESEARCH

Moderator: John Reuter, U.C. Davis

8:00-8:15	Presentation of Agenda and Goals	Bud Amorfini, Lahontan Regional Water Quality Control Board (LRWQCB)
8:15-8:35	Opening Remarks: Water Quality Protection in Lake Tahoe Basin	Harold Singer, LRWQCB
8:35-9:10	Lake Tahoe TMDL Overview	Dave Roberts, LRWQCB
9:10-9:40	Scientific Program for TMDL Phase 1	John Reuter, U.C. Davis (UCD)
9:40-10:20	Lake Tahoe Clarity Model	Geoff Schladow, UCD
10:20-10:40	BREAK	
10:40-11:00	Atmospheric Deposition	Eileen McCauley, California Air Resources Board

LAKE TAHOE TMDL SYMPOSIUM - DAY 1 (CONT'D)
THURSDAY, DECEMBER 9, 2004

11:00-11:40	Lake Tahoe Watershed Model	John Riverson, Tetra Tech
11:40-12:00	Reconstruction of Meteorological Input	Michael Anderson, UCD
12:00-1:00	LUNCH	
1:00-1:20	Storm Water Quality Monitoring	Alan Heyvaert, UCD Jim Thomas, Desert Research Institute (DRI)
1:20-1:40	Land Use – Water Quality Relationships	Melissa Gunter, DRI Bob Coats, Hydroikos
1:40-2:00	Development of GIS Land Use Layers	John Riverson, Tetra Tech
2:00-2:20	Stream Channel Erosion	Andrew Simon, National Sedimentation Laboratory
2:20-2:40	BREAK	
2:40-3:00	Nearshore Water Quality	Ken Taylor, DRI
3:00-3:20	Biologically Available Phosphorus	Jerry Qualls, University of Nevada - Reno
3:20-3:40	Groundwater Pollutant Loading	John Reuter, UCD
3:40-4:00	BMP Evaluation and Integration into Watershed Model	Eric Strecker, GeoSyntec
4:00-4:20	BMP Inventory	Chad Praul, Nevada Tahoe Conservation District
4:20-4:35	Scenario Development and Model Application	Dave Roberts, LRWQCB
4:35-5:00	Wrap up & Final Comments	John Reuter, UCD

Lake Tahoe TMDL Symposium – Day 2

Friday, December 10, 2004
Embassy Suites Hotel Lake Tahoe Resort (near Harrah's)
4130 Lake Tahoe Blvd.
South Lake Tahoe

Phase 2 – Pathway 2007 Public Involvement & TMDL Implementation Planning

Moderator: Dave Roberts, Lahontan RWQCB

8:30-8:45	Presentation of Agenda and Goals	Chuck Curtis, LRWQCB
8:45-9:05	Opening Remarks	Tom Porta, Nevada Division of Environmental Protection (NDEP)
9:05-9:25	Technical Overview of TMDL Phase 2	John Reuter, UCD
9:25-9:45	BREAK	
9:45-12:00	Development of the Tahoe TMDL Modeling Tool Box and Proposed Phase 2 Projects:	Dave Roberts, LRWQCB
	• Load Reduction Estimating Methodology	Eric Strecker, GeoSyntec and Ed Wallace, Northwest Hydraulic Consultants
	• Load Reduction Matrix	Jason Kuchnicki, NDEP
	• New and Innovative Technologies	Jason Kuchnicki, NDEP
	• Best Management Practices Model	Leslie Shoemaker, Tetra Tech
	• Tahoe Integrated Information Management System	Dave Roberts, LRWQCB
	• Pollutant Reduction Tracking & Progress Monitoring	John Reuter, UCD
	• Water Quality Trading Feasibility Study	Jack Landy, LRWQCB
12:00-1:00	LUNCH	

Moderator: Michelle Sweeney, Center for Collaborative Policy

1:00-2:30	Pathway 2007 Overview and Public Participation	Tahoe Regional Planning Agency United States Forest Service NDEP LRWQCB
2:30-3:00	Proposed Phase 2 Issue Workshops and Closing Comments and Questions	Dave Roberts, LRWQCB

LAKE TAHOE TMDL SYMPOSIUM

GOALS & OBJECTIVES

1) Highlight the role of the TMDL (Total Maximum Daily Load) in water quality protection at Lake Tahoe.

2) Familiarize participants with the purpose and component features of a TMDL.

3) Discuss the relationship between the TMDL and Pathway 2007. Introduce the concept of adaptive management through the establishment of a basin-wide environmental management system.

4) Demonstrate that the TMDL is a logical process that is guided by science and broad stakeholder input to ensure that basin-wide environmental restoration will be conducted in the most effective manner possible.

5) Review and update participants on progress of scientific studies as they contribute to the Technical TMDL.

6) Highlight the importance of models in developing a basin-wide TMDL implementation plan.

7) Introduce the Tahoe TMDL Tool Box as a means to enable regulatory and planning agencies and restoration project proponents to design, monitor and track implementation projects. Explain existing tools and present new tools that are currently being developed or proposed.

8) Announce future opportunities for stakeholders to learn more about and provide input into the TMDL process.

Glossary of Key Terms

Note: there are many technical phrases associated with the various and diverse aspects of the TMDL and its associated science, management and policy. This is not intended to be a comprehensive glossary, rather a start to a basin-wide product that can be enhanced and used by all.

Beneficial Use: Desirable uses that water quality should support. While the Lake Tahoe TMDL is being developed to ensure protection of Lake Tahoe's extraordinary aesthetic value, implementation efforts will also act to protect other uses such as water supply and aquatic life.

Best Management Practices (BMPs): Methods or measures that have been determined to be the most effective and practical means to reduce or eliminate the discharge of pollutants, typically from nonpoint sources and storm water runoff.

Environmental Improvement Program (EIP): An implementation strategy of the TRPA Regional Plan and capital improvement program for Lake Tahoe Basin to achieve regulatory goals by identifying physical, scientific, and regulatory program improvement needs and mobilizing the resources to achieve them. The 1998 EIP emphasized capital project expenditure needs of approximately $908 million for 1997-2006, shared between private, local, state and federal funding sources.

Geographic Information System (GIS): Computerized mapping program to present, manipulate, and analyze spatial information.

Intervening Zone: Areas between stream mouths that directly drain into Lake Tahoe.

Load Allocation: The portion of the TMDL allocated to existing or future nonpoint sources and natural background.

Loads or Loading: The mass per unit time of a pollutant discharge into a water body, typically calculated by multiplying the concentration and flow rate of the discharge, both of which can be monitored.

LSPC: Load Simulation Program in C++, the water quality simulation model being used to develop the Lake Tahoe Basin Watershed Model.

National Pollutant Discharge Elimination System (NPDES) permit: Clean Water Act permit to control point source discharges, including municipal and industrial storm water runoff.

Nonpoint Source: Diffuse pollutant sources that do not have a single point of origin and do not enter a water body from a discrete manmade conveyance. Pollutants are generally carried off the land by stormwater and cannot be regulated by a National Pollutant Discharge Elimination System (NPDES) permit.

Glossary of Key Terms (cont'd)

Point Source: Any discernable, confined and discrete manmade conveyance from which pollutants may be discharged, including a pipe, ditch, channel, tunnel, conduit, etc. A discharging point source must have a National Pollutant Discharge Elimination System (NPDES) permit.

Secchi Disk: Dinner-plate-sized disk that is lowered into Lake Tahoe until it is no longer visible, providing a measure of the Lake's transparency or clarity. The California transparency standard is expressed in terms of Secchi depth. The U.C. Davis Tahoe Research Group has been collecting mid-lake Secchi depth measurements, every 12 days on average, for over 35 years. Since 1967, Secchi depth has been declining by an average of 0.25 meters, or nearly one foot, per year.

SNPLMA: Southern Nevada Public Lands Management Act, which was amended in 2003 to authorize $30 million per year for ten years to the USFS Lake Tahoe Basin Management Unit for planning and implementation of EIP programs and projects.

TIIMS: Tahoe Integrated Information Management System, a web-based clearinghouse (at http://eh2o.saic.com/tiimsWebsite/) of Lake Tahoe Basin water quality and related information.

Total Maximum Daily Load (TMDL): The assimilative capacity of a water body to accept pollutant loads without violating its water quality standards. TMDLs provide a basis to establish water quality-based controls including wasteload and load allocations, which require pollutant sources to be reduced as necessary to achieve water quality standards.

Waste Discharge Requirements (WDRs): State of California mechanism to control non-NPDES discharges and any other pollutant source that may impact water quality including (as relevant to activities in Lake Tahoe Basin) timber harvest practices, grazing activities, recreational activities, etc.

Wasteload Allocation: The portion of the TMDL allocated to existing or future point sources.

Water Quality Standard: Consists of a beneficial use (e.g, in the case of Lake Tahoe clarity, non-contact recreation or aesthetic enjoyment) and a numeric or narrative criterion for a pollutant or combination of pollutants that protects the beneficial use (for Lake Tahoe clarity, an annual average Secchi disk depth of 29.7 meters). Water quality standards also include a general non-degradation requirement that protects waters that are of higher quality than their standards from being degraded.

Lake Tahoe Total Maximum Daily Load (TMDL) Overview

A Total Maximum Daily Load (TMDL) is a **water quality restoration plan** designed to reduce the amount of pollution contributing to the decline of Lake Tahoe's clarity. Technically, a TMDL is defined as the amount of a specific pollutant that a water body can receive and still meet water quality standards. Research at Lake Tahoe has shown that it is the load or mass (kilograms per year) of fine-sediment and nutrients, and not simply their concentration (milligrams per liter) in stream flow or runoff, that affects the long-term clarity trend.

The 1972 Clean Water Act (CWA) established the TMDL program for water bodies that do not achieve their water quality standards. A TMDL represents the *assimilative capacity* of the water body, or its ability to accept contaminants without exceeding a level of water quality that protects its environmental and social values. TMDLs usually involve an effort to characterize a water body's response to pollutant loads by means of a water quality model, followed by a calculation of the load reduction necessary to restore the water body to its desired condition. The calculated allowable loading is then allocated to existing and expected future pollutant sources. The Lake Tahoe TMDL will provide measurable targets for load reduction that can be used to guide watershed and air quality restoration efforts such as the Environmental Improvement Program, which is a basin-wide restoration plan developed by the TRPA, as well as small scale individual projects.

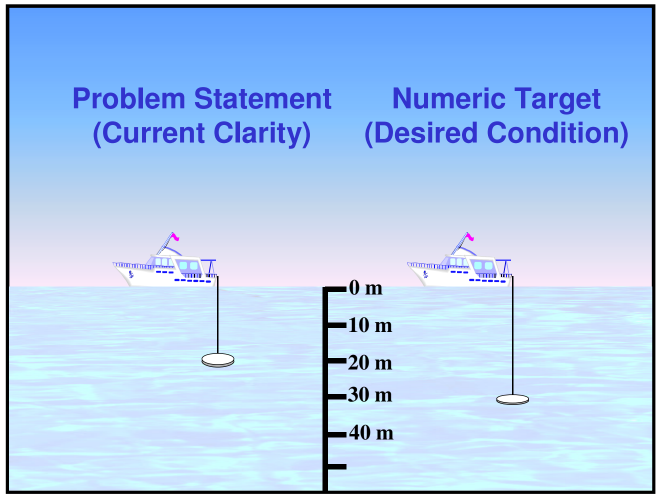
TMDL Approach

The U.S. EPA considers the following TMDL elements critical to meeting Clean Water Act requirements. The problem statement must clearly define the environmental concern and identify the pollutant for which the TMDL will be established. Next, numeric targets must be defined for lake water quality measures of concern (e.g., for Secchi depth, see figure overleaf, and for associated parameters such as algae and particle concentrations). For Lake Tahoe, this has been determined by existing water quality standards. Particularly, the clarity standard for Lake Tahoe is currently being violated, which indicates the problem. The existing annual average Secchi depth is approximately 20 meters (66 feet), while the water quality standard, or numeric target, calls for an annual average clarity of 29.6 meters (97 feet).

Elements of a TMDL

- **Problem Statement**
- **Numeric Target**
- **Source Analysis**
- **Linkage Analysis**
- **Load Allocations**
- **Margin of Safety**
- **Implementation Plan**

The third step is to identify sources of critical pollutants (nutrients and fine sediments) and evaluate their loading. Fourth, and most critical to the process, is to establish the linkage between pollutant loading and lake response. To accomplish this, a clarity model is being developed for Lake Tahoe that ties nutrient and fine sediment inputs to clarity loss. From this linkage analysis, it is then possible to calculate and allocate a target for pollutant loading among contributing sources (including a margin of safety), such that the numeric targets will be achieved. Finally, it is necessary to identify follow-up monitoring needs and establish a plan to ensure adequate TMDL implementation, and to provide for its adjustment in the future if appropriate.



Integration with Other Lake Tahoe Basin Environmental Documents

Participating agencies and other stakeholders will be involved through public education, technical workshops and discussion of implementation scenarios. Successful TMDL development must include a high degree of stakeholder review and input. It is expected that public input participation will be especially significant during the allocation phase, when necessary load reductions are distributed and an implementation plan is developed. The Lahontan RWQCB and Nevada DEP plan to adopt the final TMDL by January 2007, after which it will be submitted to the U.S. EPA for approval. Following its adoption, the TMDL can be revised in the future based on refinement of the science and review of progress toward its implementation.

It is expected that the TMDL and implementation plan will be incorporated into the TRPA's Regional Plan (scheduled for adoption in 2007). Along with the USFS Lake Tahoe Basin Management Unit's Forest Plan, these three planning documents will guide Tahoe's restoration efforts.

AN INTEGRATED SCIENCE PLAN FOR THE LAKE TAHOE TMDL – PHASE 1

John E. Reuter
Tahoe Research Group
University of California, Davis
November 23, 2004

The following document is intended to supplement the Tahoe TMDL Science Plan (available at The Lahontan RWQCB website located at http://www.swrcb.ca.gov/rwqcb6/). It provides a discussion for how the individual science projects, as part of Phase 1, integrate and defines the overall scientific approach for the Technical TMDL.

In concert with the existing literature/understanding on Lake Tahoe and its watershed, the studies below will provide the scientific basis for the Lake Tahoe Technical TMDL. The benefits from this science program include credible assessments that will fill critical information gaps; provide data at various watershed and airshed scales to inform decision making; allow for development of a more informed TMDL; support EIP implementation; make information more accessible to agencies and other interested parties; and allow for evolution/advancement of existing scientific understanding. The goal of this section is to provide an overview of these projects with emphasis on how they integrate. The important fine details have been left out but are available on the Lahontan RWQCB website at and within each individual project's scope of work.

The long-term decline in water clarity (as measured by Secchi depth) has been selected as the focus of the Lake Tahoe TMDL. As described above, the lake is losing, on average, 0.25 m of clarity each year. Likewise existing research indicates that fine sediments (<20 µm), phosphorus and to a lesser extent nitrogen are all contributing to this observed decline. Consequently, a TMDL for Lake Tahoe must include all three of these constituents in an integrated manner, i.e. allowable loads can not be considered independently for nutrients and sediment since the resulting Secchi clarity is a function of their simultaneous influences on lake optical characteristics (refer to the clarity cube in Figure 8 above). The existing initial nutrient budget allows us to set out a roadmap for the various TMDL components. However, historically, it was not possible to develop even an initial budget for fine-sediment. As discussed below, an important product of the Tahoe TMDL Research Program will be to quantify fine sediment loading (by particle size class) for the major sources including stream discharge, direct runoff and atmospheric deposition. It is acknowledged that groundwater flow is not a source of this material.

At this time there is wide-spread agreement that clarity, as measured by Secchi depth, is a critical key indicator of Lake Tahoe water quality. In addition, algal growth rate is also of importance for the reasons cited above, which include its contribution to the declining Secchi depth clarity (0-20 m) and its even larger contribution to the compression of the lake's euphotic zone. For these reasons and because of their status as either California or Nevada State water quality standards, TMDLs related to Secchi depth, vertical extinction coefficient, primary productivity and phytoplankton biomass (as chlorophyll) will be developed. The Clarity Model is being developed to produce lake response predictions for these parameters.

Water quality standards (WQS) for Lake Tahoe also apply to the nearshore, however, this region has received less scientific and regulatory attention. As part of the Tahoe TMDL Research Program, we begin to address some of the issues related to this unique region. Work completed by Dr. Ken Taylor (DRI) has (1) monitored location and timing of nearshore turbidity around the entire lake, (2) related nearshore turbidity along the South Shore to specific types of precipitation and hydrologic runoff events in the Upper Truckee River, Bijou Creek and the unchannelized intervening zones, and (3) related turbidity to particle size and composition (algae and mineral particles). This work also made an initial effort to identify potential sources of pollutants. In the TMDL this will be further used to compare in-lake distributions of these constituents with spatial loading data generated from the stream and direct runoff modeling and groundwater projects. Resulting EIP load reduction efforts will help improve nearshore conditions; however, depending on the location of these projects we are likely to see some spatial variability in response, i.e. not all nearshore areas will be treated for water quality equally. Future TMDL updates will hopefully incorporate a 3-D Clarity Model that links the nearshore and open-water portions of the lake.

In Figure 1, we provide a schematic diagram that links the various TMDL, Phase 1 research projects and provides a timeline for the technical TMDL document. Note that the Watershed Model and Clarity Model are major components of this approach. Both provide invaluable tools for both management decision-making and further scientific inquiry. The other projects directly support these models. The placement of the four projects inside the matrix (studies of chemically enhanced BMPs, forest runoff, Caltrans and atmospheric chemical signatures) are but a few examples of additional studies that will be incorporated into the Technical TMDL, but were not specifically funded as part of the TMDL Research Program.

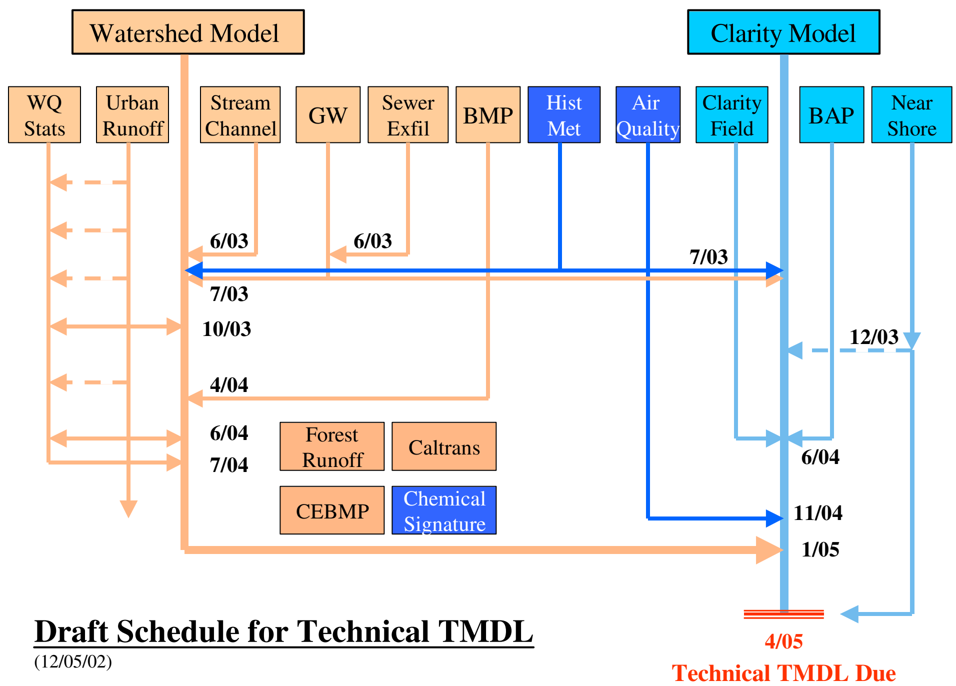


Figure 1. Schematic integration of Tahoe TMDL Research Program projects.

The pollutant source analysis is fundamental to the Lake Tahoe TMDL. As presented above, an initial or preliminary nutrient budget has been developed, complete with a rigorous evaluation of loss terms. It has been acknowledged that additional monitoring and research must provide a more detailed quantification of a number of these sources (Reuter and Miller 2000). This is especially true for stormwater and snowmelt runoff that drains directly to the lake. Given that much of the urbanization in the Tahoe basin is located in the intervening zones which drain directly to the lake, more accurate loading estimates from these regions are especially important, vis-à-vis, implementation of restoration and water quality treatment projects. The stormwater monitoring project represents the first time such an extensive, basin-wide investigation of this sort has been done at Lake Tahoe. Previously, stormwater runoff and water quality data has come from isolated monitoring associated with smaller improvement projects.

Dr. Alan Heyvaert and Dr. Jim Thomas have lead the stormwater monitoring team, with statistical guidance from Dr. Bob Thomas (Hydroikos). Approximately 16 new sites were equipped with automated samplers to characterize nutrient and sediment loads associated with event-based stormwater flow. Sites were selected to include a wide range of land use characteristics and supplemental data will be provided by other autosamplers already operational in the basin. Based on this monitoring and the results of GIS analysis in the subwatersheds which drain to each of the autosamplers, Dr. Bob Coats (Hydroikos) and Dr. Ania Panorska (DRI) have been able to develop predictive relationships for water quality versus catchment attributes for direct runoff and tributary flow. No significant attempt has been made before at Lake Tahoe to conduct this level of analysis. The new stormwater monitoring data and the statistical relationships not only provide data on stormwater quality and the impact of land-use on water quality, they will also be invaluable to calibrating and validating the Watershed Model and will be used in calculating basin-wide BMP potential for pollutant load reduction.

Of the 63 streams that are tributary to Lake Tahoe, the Lake Tahoe Interagency Monitoring Program has been monitoring ten of these for the past 15-25 years (depending on the individual stream). This has provided a very comprehensive database on tributary loading. While the total flow coming from these monitored streams accounts for approximately 50% of the basin's total annual discharge, and even though they were initially selected to represent various land uses, locations and geomorphology, detailed estimates of loading from ungaged streams has not been attempted. The Hydroikos team will also conduct a statistical evaluation to determine loading from ungaged streams. This will also be a product of the Watershed Model. In this way, we will have two independent estimates.

While a number of investigators have attributed suspended sediment loading to Lake Tahoe to streambank or channel erosion (Leonard et al. 1979; Hill and Nolan 1990), this hypothesis had never been evaluated. As part of the Tahoe TMDL Research Program the USDA National Sedimentation Laboratory (Oxford, MS) studied sediment loading and channel erosion in the Tahoe basin (Simon et al. 2003). These researchers (1) conducted an extensive analysis of the LTIMP data to determine annual suspended sediment yields and loads, and for the first time included the fine fraction, (2) analyzed historic and current stream channel cross sections, and conducted ground reconnaissance monitoring at over channel 300 sites to better evaluate channel erosion risk by stream segment, (3) conducted numerical modeling using AnnAGNPS and CONCEPTS to determine the annual contributions of streambank materials versus upland sources for General Creek, Ward Creek and the Upper Truckee River. They also, (4) used GIS analysis and simple modeling to develop a detailed map of erosion potential from upland areas, basin-wide. The results of this study will be directly incorporated into the Watershed Model and will shed light on the potential importance of stream channel erosion as a source of fine sediment to the lake.

Phosphorus has been identified as a nutrient limiting to algal growth in Lake Tahoe. From the data presented above on the phosphorus component of the nutrient budget, the importance of atmospheric deposition (to the lake surface), stream loading and direct runoff (i.e. runoff which enters the lake directly without first entering one of the 63 tributary streams) to TP loading is clear. Soluble-P loading varied between input category, but on average accounted for 33% of TP. However, considering stream loading and direct runoff, the two major watershed sources of TP, soluble-P represented 19% of TP; i.e. approximately 80% of the TP was associated with suspended particulate matter.

A factor that complicates interpretation and modeling application of phosphorus loading data to Lake Tahoe is the unknown biological availability of the phosphorus loads to lake algae. While it might be assumed, as a first approximation, that most of the soluble-P could be eventually converted to a bioavailable form, the phosphorus adsorbed to inorganic soil particles may or may not be released into the lakes water column before settling to the bottom. Studies have shown that for certain types of suspended sediments, up to 40% of the associated P can become bioavailable over the matter of weeks (e.g. DePinto et al. 1981). On the other hand, Ellis and Stanford (1988) reported that only about 5% of the total-P transported into Flathead Lake, MN in the form of fine particles was bioavailable. This suggests that all sediment is not the same with regard to P-quality and that site-specific differences exist.

Currently, there is not a reliable estimate for Biologically Available Phosphorus (BAP) loading to Lake Tahoe. While it is somewhere between the TP and soluble-P values, the contribution of BAP from each of the primary inputs above, is unknown. This data is needed for two reasons: (1) as input the Clarity Model and (2) to ascertain whether control measures (e.g. BMPs, restoration) designed for TP removal are applicable for BAP removal. Dr. Jerry Qualls (UNR) has lead a team to determine BAP loading to the lake as well as BAP release from particles found in the water column.

Groundwater contributions to nitrogen and phosphorus loading to Lake Tahoe have been evaluated for both specific watersheds (e.g. Loeb and Goldman 1979, Loeb et al. 1987) and on a basin-wide basis (Thodal 1997). The initial nutrient budget includes the findings given by Thodal (1997). The US Army Corps of Engineers (Meegan Nagy – Sacramento District) conducted a groundwater study to help meet TMDL needs. Existing data was used to develop an estimate for nutrient loading to Lake Tahoe transported through groundwater. This effort focused on compiling existing knowledge of groundwater flow characteristics, geology and existing groundwater and nearshore lake nutrient data for the Tahoe Basin. This study also included model that simulated lake-groundwater interactions along the alluvial South Shore.

This study was unique in that it evaluated groundwater nutrient loading by geographic region around the lake (10 regions/subregions) and provide information on both urbanized and undisturbed regions. This information was linked with identified nutrient source including, fertilization of lawns, golf courses, and ski slopes, and the infiltration of road and municipal runoff. Past land uses with the potential to be a current source of nutrients to the lake include abandoned septic tanks and former sewage disposal areas. The COE study also identified alternatives for reducing the nutrient loading to Lake Tahoe through groundwater. The identification of best management practices (BMPs) was included to identify measures for reduction of nutrient loading to Lake Tahoe. Groundwater loading will be directly incorporated into the Clarity Model as an input source.

Adams and Minor (2000) confirmed the initial findings presented in Reuter and Miller (2000) that the contribution of nitrogen and phosphorus from shoreline erosion was minor relative to other sources, however, they did find that on average 7,150 metric tons of sediment per year has been eroded into Lake Tahoe over the past 60 years. This loading rate is comparable to TSS loading from the 10 LTIMP streams during low to moderate flow conditions.

While atmospheric deposition has received some scientific attention (Jassby et al. 1994; Tarney et al. 2001; Hackley et al. 2004), a higher level of confidence associated with whole-lake loading directly from this source is required for the purpose of a TMDL. The long-term monitoring of nutrient deposition on land and on the lake by the University of California, Davis first identified this as a potentially major source for both phosphorus and nitrogen. Data for deposition of fine sediments from wind-blown dust is extremely preliminary (Lui 2002). The importance of direct deposition of pollutants to Lake Tahoe has prompted the California Air Resources Board (CARB) to design a $1.25 million project to study air quality and deposition in the Tahoe basin.

The CARB work plan for their Lake Tahoe Atmospheric Deposition Study (LTADS) is too extensive to summarize here. The reader is encouraged to obtain a copy of their plan directly from Dr. Eileen McCauley, Manager of the Atmospheric Processes Research Section, RD at CARB. Tens of researchers from both CARB staff and outside major research institutions have participated in this project. As taken directly from the CARB December 2001 work plan, the staff of the California Air Resources Board (CARB) proposes to apply a hybrid approach to studying air quality and atmospheric deposition in the Lake Tahoe Air Basin. This approach will include direct measurement of important pollutant species, meteorological conditions, and source-specific emissions, the construction of a basin-specific emission inventory, the adaptation of a mechanistic model to extrapolate those measurements into basin-wide deposition calculations, and the application of a chemical mass balance model for additional source-apportionment.

LTADS products relevant tot he TMDL include (1) annual and seasonal, spatially resolved dry deposition estimates of N, P and particulate matter (PM), (2) an inferential source allocation for major sources, and (3) relative contribution of transport from outside the air basin to observed N, P and PM. CARB published a peer review draft for their annual deposition rate analysis in September 2004 complete with a comparison of LTADS deposition estimates with previous estimates. LTADS has also included contracts with UC Riverside and DRI to improve estimates of key emission categories and sources. Source samples were collected for fire, residential wood burning and road dust. Work was also performed to improve our understanding of activities that generate emissions within the Basin, including driving patterns, the mix of vehicle types and the amount of wood burned.

Estimates of atmospheric deposition directly to Lake Tahoe are now available from studies by the TRG (N, P), DRI (N), CARB (N, P, PM) and Dr. Tom Cahill (P) at UCD. These will all be considered in the development of the Technical TMDL. Atmospheric deposition rates will be directly applied to the Clarity Model as an independent source. It is noteworthy that the LTADS project has provided the first estimate of sediment/particulate matter deposition directly to the lake surface. The LTADS, DRI and Cahill data were for dry deposition only. The TRG wet deposition data will be used to complete estimates of total atmospheric deposition.

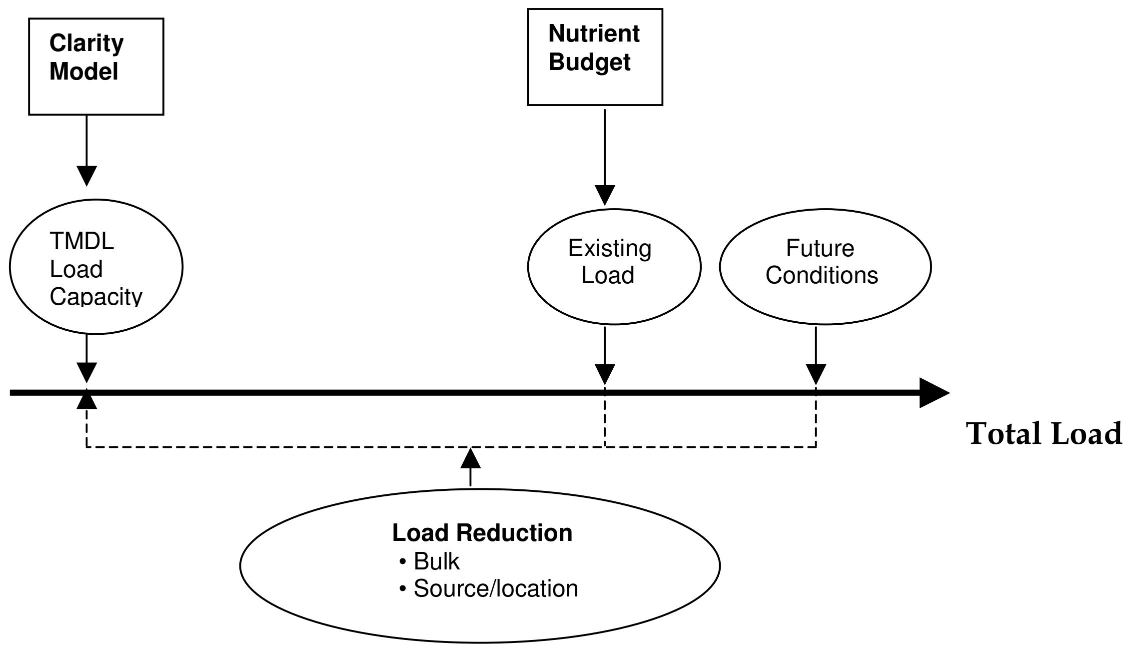


Figure 2. Simplified schematic of TMDL process.

Figure 2 presents a simplified, yet constructive view of the TMDL process while allowing us to see how the projects of the Tahoe TMDL Research Program integrative into this process. Most of the studies presented so far in this section relate directly to refining the nutrient budget – pollutant source. In the larger context, load reduction has become a unifying factors among many groups. Clearly, the EIP program established by the TRPA is at the heart of this endeavor, with many state, federal and local entities very engaged in restoration, BMP implementation and load reduction.

To model the Lake Tahoe watershed, Dr. Leslie Shoemaker and Mr. John Riverson from the consulting firm Tetra Tech have adapted and applied a comprehensive watershed modeling framework developed for the U.S. Environmental Protection Agency (EPA) called “Loading Simulation Program in C++” (LSPC). LSPC is included in the USEPA TMDL Modeling Tool Box. The watershed model will integrate research results from the numerous studies being conducted in support of the Lake Tahoe TMDL with the wealth of historical data currently available. The LSPC watershed modeling system includes algorithms for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes. Key features of the system include a convenient, underlying Microsoft Access database for model input and output data storage, a simplified geographic information system (GIS) interface for visualization, and a TMDL calculation and source allocation tool, as shown in the diagram below (Figure 3).

The primary products of the watershed model are: (1) model for the hydrology of the Tahoe basin, including intervening zones and watershed with stream channels, (2) model for the fate and transport of nutrients and sediments through the watersheds and intervening zones, (3) quantification pollution loading to Lake Tahoe with a moderate degree of spatial resolution (184 subwatersheds) as to the portion of the lake impacted by different pollutant inputs, (4) use of deterministic modeling to determine the nutrient and sediment generation rates from land uses and settings found in the Basin, and (5) model for watershed scale changes in hydrology and pollutant loading resulting from implementation of different BMP scenarios. This model will serve as the framework for refining the nutrient/sediment budget, help to identify regions of elevated load, and allow us to quantify the effect of management scenarios on loading from the watershed.

LSPC is particularly well-suited to modeling the Lake Tahoe watershed, because it can be readily modified to represent Lake Tahoe Basin-specific issues. Data from a number of concurrent research efforts will be incorporated into Tetra Tech’s LSPC modeling effort. The meteorological model described in later sections will provide necessary inputs to drive LSPC’s hydrologic simulation. Specific statistical relationships between land cover, slope, and pollutant loading will be used to generate sediment and nutrient loading estimates. Data from the groundwater assessment, storm water monitoring, and stream channel erosion assessment and modeling efforts will be particularly useful for model testing. Information on (1) the effectiveness of Best Management Practices (BMPs) to reduce runoff and pollutant loading and (2) local and regional BMP planning scenarios will be incorporated into the model to evaluate strategies for achieving the TMDL. Ultimately, flow, sediment and nutrient loading estimates generated by the LSPC model will be linked to the Lake Tahoe Clarity Model. This will provide a sound basis for recreating historical conditions and testing hypothetical “what-if” scenarios.

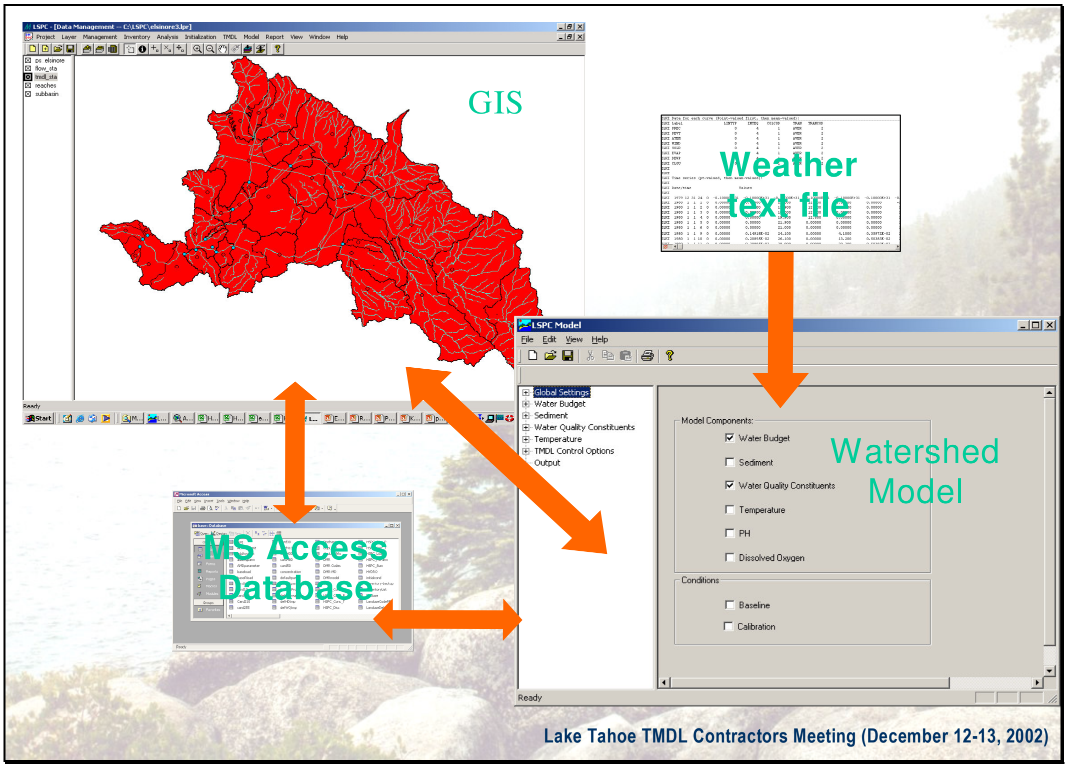


Figure 3. GIS interface to LSPC Tahoe Watershed Model.

The hydrologic component of watershed modeling for Lake Tahoe requires rainfall data for rainfall-induced sediment and nutrient transport simulations. In the case of snowmelt-induced sediment and nutrient transport simulations the models require at least the temperature data (for degree-day snowmelt models), or, preferably, radiation, relative humidity, temperature and wind data (for energy balance snowmelt models) as input for their snowmelt computations. At the same time, the Clarity Model also requires key meteorological input data such as air temperature, relative humidity, wind speed and direction and long/shore wave radiation. However, for most watersheds at Lake Tahoe such atmospheric data are completely lacking. At best, such data are available at a few ground locations, making it very difficult to obtain a description of the spatial variation of atmospheric inputs over those watersheds. Even at these locations many of the parameters are not even measured.

Therefore, for reliable and defensible sediment and nutrient transport simulation results in the TMDL studies at Lake Tahoe, it was necessary to use reconstructed data. This work was done by Dr. Lev Kavvas (UCD) and his team who reconstructed historical atmospheric data for the period 1958-2001 at fine spatial (~ 3-km grids) and time (~ 1 hour intervals) resolutions over ungaged and sparsely gaged Lake Tahoe watersheds. This work was done using MM5, the 5th generation atmospheric mesoscale model from Penn State/NCAR. The model can simulate the full three-dimensional atmospheric dynamics over a variety of space and time scales. MM5 uses archived global gridded atmospheric data an initial, boundary conditions. Four model domains were used to downscale data from 270 km to the 3 km horizontal resolution. The hours data was simulated for seven atmospheric variables including: air temperature, relative humidity, precipitation (snow fall was further modeled within the Watershed Model), latent heat flux, solar radiation, net longwave radiation, and wind speed. The synthetic dataset was validated using the limited observational historical database as appropriate. This product provides a uniform database for forecast modeling. It will be used to drive the hydrology model in each of the 184 separately model subwatersheds. This is a unique work product from the Tahoe TMDL Research Program that will have many and varied uses not only in the TMDL, but into the future.

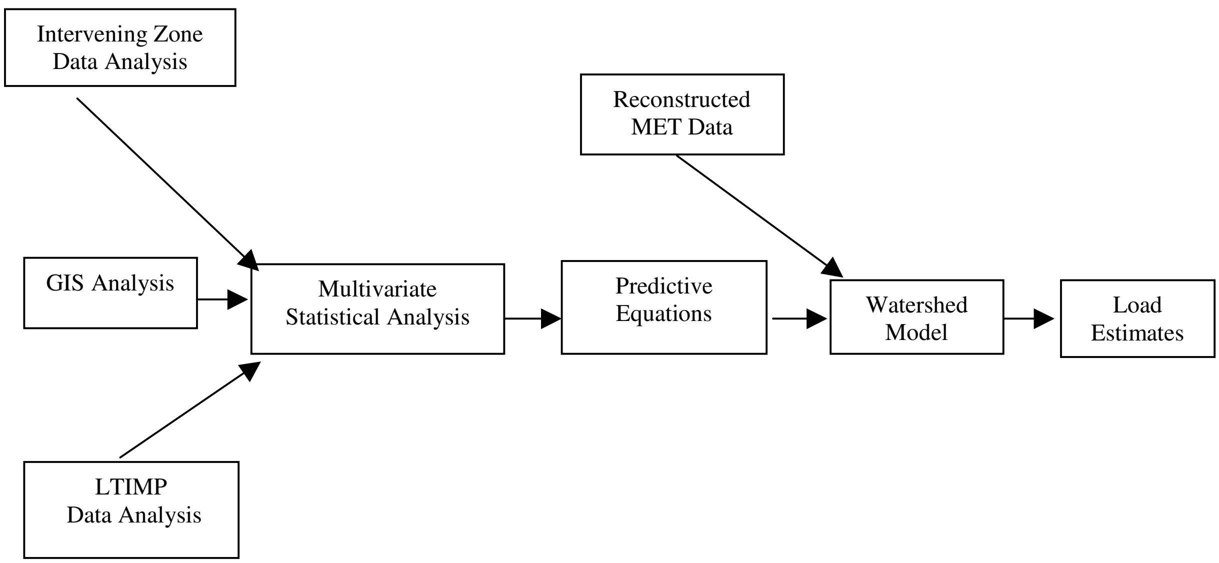


Figure 4. Information flow in model integration (Coats 2002)

The flow diagram in Figure 4 highlights a number of the key elements of projects that will be used to generate nutrient and sediment load estimates from the watershed. Algorithms within the LSPC-based Watershed Model will also be used to determine load estimates.

As previously noted, a considerable effort by many groups is being focused on load reduction. By identifying the sources and spatial distribution of loading, the Tahoe TMDL Research Program will help guide this effort. While it is beyond the scope of this project to fully plan basin-wide restoration/load reduction projects (an expected product of the EIP, Pathway 2007 process and future management), the Stormwater BMP Evaluation and Feasibility Study (Eric

Strecker – GeoSyntec Consultants) began the process of quantifying project level and basin-wide BMP implementation.

Specifically, the Stormwater BMP Evaluation and Feasibility Study has evaluated existing data on characteristics of nitrogen, phosphorus and sediment in stormwater runoff from various land uses and locations in the Lake Tahoe Basin and discussed the treatability of the constituents of concern. Stormwater BMP performance data was evaluated to determine treated effluent concentrations. When evaluated in concert, the pollutant concentration by land-use data and the BMP treated effluent concentration data provide estimates of achievable percent reduction. A review of new technologies was also completed.

An important aspect of this work was the use of SWMM (Stormwater Management Model) to simulated BMP performance at the subwatershed and basin-wide scales. This is the first time in the Tahoe basin that BMP-related models were used to evaluate water quality treatment at a scale larger than the individual BMP. In one application of SWMM and an associated water quality model, each of the 52 intervening zones were modeled to evaluate the overall impact of BMPs assuming a certain level of treated effluent. This was compared to modeled loading driven by the reconstructed MET data discussed above. This approach allowed the modelers to evaluate percent load reduction as well as an absolute value for load reduction, as will be needed by the TMDL. The utility of this is very significant first step, and near-term plans are to incorporate a BMP module into the Watershed Model. GeoSyntec also used their modeling to investigate other topics such as sizing of volume based BMPs, optimization of basin sizing criteria, capture of fine-grained size sediment (<20 µm), and non-traditional BMPs.

The Stormwater BMP Evaluation and Feasibility Study also provided an initial financial analysis.

BMP effectiveness at the individual project scale, a treatment-train scales (i.e. hydrologically connected BMPs typical of most EIP projects), and a watershed/basin-wide scale will continue to be an area in need of further research and refinement. The Stormwater BMP Evaluation and Feasibility Study funded by the Tahoe TMDL Research Program was termed a feasibility study because we knew that additional work would be required. The existing report from this study has most definitely set the stage for future investigations during Phase 2 and 3 and the P7 process.

The actual implementation of watershed mitigation projects at Lake Tahoe may take 10-15 years or longer to complete. Since the lake has a retention time of decades for pollutants, monitoring may not detect the direct effect of restoration on lake clarity for many years. Lake modeling provides a tool to overcome this time lag. For TMDL purposes a tool is needed to link pollutant loading with lake response. The Clarity Model will be used to set bounds on loading capacity. Specifically, it will provide guidance on the magnitude and timing of nutrient and sediment loads needed to meet water quality standards for lake optical properties and phytoplankton abundance.

The model is driven by daily inputs of meteorological and hydrologic data. Water quality inputs are from streams, surface runoff, groundwater and atmospheric loading. The model seeks to predict the distribution of nutrient concentration, algal concentration and suspended particle concentration. Water clarity, a function of light absorption and scattering, can in turn be calculated from the algal concentration and the size distribution and concentration of particles. The model consists of three components: (a) hydrodynamics (physical processes) – includes water motions, mixing, waves, particle settling, etc. This portion of the model is largely driven by meteorological forcing factors and lake depth; (b) water quality (algal growth related) – includes nutrient uptake and cycling, dissolved oxygen, zooplankton, etc. and (c) optical properties (Secchi depth) – includes adsorption and scattering of light by organic and inorganic particles, and dissolved matter. The optical model calculates the scattering and absorption characteristics of the water constituents (particulate organic, particulate inorganic, and dissolved matter) based on particle size distribution, composition, and bulk concentration, then calculates the Secchi depth from the inherent optical properties (refer to discussion above).

The Clarity Model will serve as a management tool to allow for the calculation of needed nutrient and sediment load reduction to achieve Lake Tahoe's target clarity of 30 m. Required reductions of fine sediments, phosphorus and nitrogen loads are best viewed as a population of numerous possible combinations of these three pollutants. Any of these combinations would predict a resulting clarity of 30 m. The diagram below (Figure 5) provides a conceptual view of this and is presented only for illustrative purposes. The cube includes fine sediment, P and N reductions ranging from no reduction (upper left hand corner) to the hypothetical case where all pollutant loading is eliminated (lower right hand corner). The solutions for a Secchi depth of approximately 30 m are shown in the "blue zone". It can be seen that there are still a variety of pollutant load reduction options within this zone. The Clarity Model will be used to provide simulated values to define the expected Tahoe "blue zone". To re-emphasize, we currently do not know where the "blue zone" will lie in the cube. This will be included in the Technical TMDL document (scheduled to be completed in late-Spring 2005).

A comparison of current loading with allowable loading will give managers a quantitative target for load reduction. The final step must be comparing these required load reductions to the anticipated load reductions that would be achieved through EIP and other water quality improvement projects.

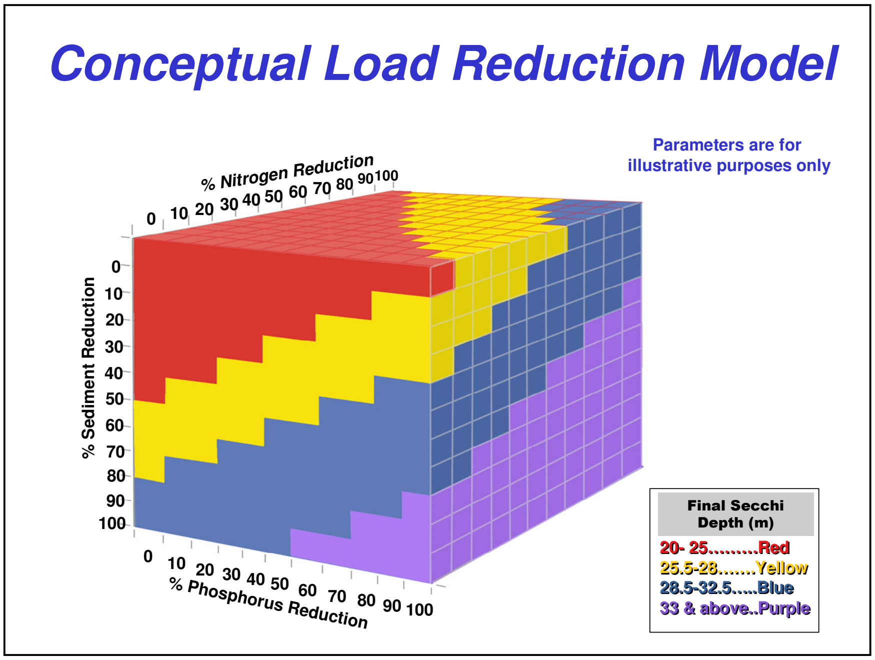


Figure 5. Tahoe “Clarity Cube”.

Development of the Clarity Model is being done by a diverse team, under the direction of Dr. Geoff Schladow (UCD). New research is providing the Clarity Model with required information to develop a more realistic component for describing particles aggregation, flocculation and sedimentation. This work will has four work elements: (1) the continued gathering of vertical profiles of particle size, concentration and flux, supplemented with ICP-MS analysis, (2) the collection of undisturbed particle “flocs” using sediment traps and their analysis using a range of microbiological techniques and particle imaging techniques, (3) the collection of actively growing biofilms from within the lake and their analysis using a range of microbiological techniques and particle imaging techniques, and (4) the production and testing of an aggregation sub-model that can be added to the existing Lake Tahoe Clarity Model. In addition, new algorithms for key processes including, development of the deep chlorophyll maximum, zooplankton grazing and stream plunge entrainment have been developed and incorporated into the model.

To guide TMDL development, the model will be run to examine lake response to a range of possible future loading conditions for nutrients and fine-sediments. As discussed above, these model runs will be used to populate the ‘clarity cube’. These will be developed in conjunction with the Regional Board and the TMDL Development Team. The model will also be run to examine expected changes in lake condition based on various management scenarios that will result in a decreased nutrient and fine-sediment load. These include the effects of erosion control, watershed restoration and storm water treatment the effects of fire (insofar as they affect the loading to the lake), the effect of various climate change scenarios (both independent of and in conjunction with changed management practices) and potential changes in lake ecology (e.g. shifts in algal population). As part of this project, the model will be modified to provide the user with useful output on primary productivity, vertical light extinction coefficient, chlorophyll and phytoplankton cell concentration (to the extent possible) as well as Secchi depth clarity.

Finally, the Tahoe Regional Planning Agency (TRPA) has developed of a bi-state, multi-agency information management system to house and disseminate information on the Lake Tahoe Basin. The Tahoe Integrated Information Management System (TIIMS) will develop a comprehensive information management system based on the latest Internet technologies that will enable a wide range of users to contribute, identify, share and access valuable information about the Lake Tahoe watershed. TIIMS will provide a means of accessing, exchanging, and analyzing data and information across a spectrum of information types – primary data, summary data, reports, fact sheets, maps, etc. TIIMS will also provide managers with a tool to support adaptive management and decision-making regarding environmental thresholds, the Environmental Improvement Program (EIP), and other emerging agency issues.

The Lake Tahoe Clarity Model

S. Geoffrey Schladow
Tahoe Environmental Research Center, UC Davis

The Lake Tahoe Clarity Model is a process-based model that explicitly represents the hydrodynamic, thermodynamic, water quality, ecological and optical behavior of the lake in a one-dimensional framework. The model has been calibrated and validated using data collected at the lake during the last 5 years. Inputs to the model include measured daily meteorology, daily stream flow and stream quality data, and atmospheric loading of particles and nutrients. The results of the model compared with measured data will be presented. In order to use the model for long term prediction of possible future clarity changes, it is necessary to use synthetic input. This is being supplied through the synthetic meteorological data set that has been produced (Anderson et al.) and a hydrology model (Tetra Tech) which itself is driven by the synthetic meteorology. The results of multiple other research projects to quantify nutrient loads, urban runoff, effectiveness of Best Management Practices (BMPs), etc, are being incorporated into the hydrology model. Atmospheric deposition loads in future years will be based upon modeling performed by the California Air Resources Board. By using these modeled inputs to drive the lake model, predictions of future lake clarity, biomass and nutrient concentrations can be obtained. The effect of implementing particular types of BMPs or particular treatments in individual watersheds can also be examined, and a rational basis for load reduction can be attained.

The Lake Tahoe Atmospheric Deposition Study

Leon Dolislager, Ash Lashgari, Eileen McCauley, James Pederson, Tony VanCuren
Atmospheric Processes Research Section, Research Division, Air Resources Board

The Lake Tahoe Atmospheric Deposition Study (LTADS) was conducted by the Air Resources Board as part of an effort to develop improved estimates of atmospheric deposition to Lake Tahoe. The presentation will briefly summarize the background, field study, and preliminary results of LTADS. The field study was conducted from November 2002 through December 2003 and resulted in a wealth of data regarding air quality and meteorological conditions above, on, around, and upwind of Lake Tahoe. ARB staff have integrated the air quality and meteorological data to develop estimates of dry atmospheric deposition to the Lake. For nitrogen, the initial estimate of dry deposition is comparable to historical estimates. However, the initial estimate for phosphorus is less than half of historical estimates. LTADS constituted the first attempt to quantify the amount of particulate matter being directly deposited to the Lake from the atmosphere. Staff's methodology and estimates have undergone peer review and staff is currently refining the atmospheric deposition estimates in response to the comments.

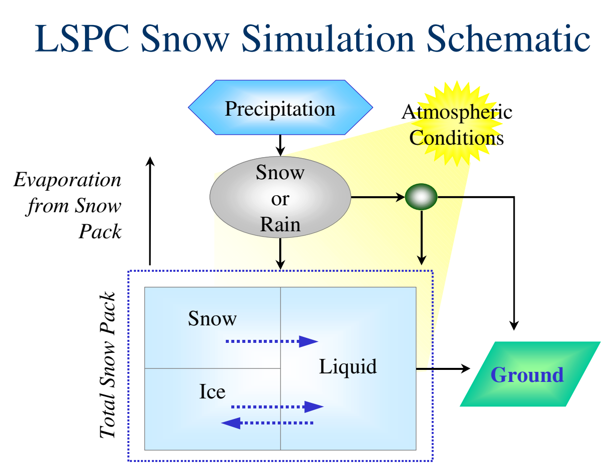
Development of the Lake Tahoe Watershed Model: Lessons Learned through Modeling in an Alpine Environment

John Riverson[1], Clary Barreto[1], Leslie Shoemaker[1]

Abstract

A comprehensive watershed model has been developed for the Lake Tahoe basin. Integral to this effort was the adaptation of the model to include research results from the various parallel ongoing efforts, as well as consideration of special physical and process-specific watershed features unique to this alpine environment. The Loading Simulation Program in C++ (LSPC) was the modeling platform selected for this application. LSPC is a watershed modeling system developed by Tetra Tech for U.S. EPA to support large, complex watershed modeling applications. The system includes algorithms for simulating snowfall/snowmelt processes, watershed hydrology, erosion, general water quality processes, and in-stream sediment and pollutant transport processes.

The primary reasons for developing a watershed model were 1) to determine estimates for watershed loading of sediment and nutrients to Lake Tahoe, 2) to provide input to the Lake Clarity Model, 3) to evaluate management scenarios and their ability to meet projected loading targets, and 4) to estimate load allocation components for the required technical Total Maximum Daily Load (TMDL). No such model had been previously developed for the Lake Tahoe basin. Nonetheless, the effort involved in compiling and organizing the required data for modeling not only represents a beneficial contribution for the TMDL program, but also, for many other future efforts.



Several insights and observations were noted or confirmed during the modeling process. A few of these include 1) the importance and relatively significant impact of potential evapotranspiration in the alpine hydrologic cycle, 2) the effect of climate patterns on elevation-based lapse rate estimates for basin-wide temperature and snow simulation, 3) the domineering impact of alpine snowfall/snowmelt sequences on hydrology, sediment, water quality, and the required management practices, 4) the predictive capability of the model for extreme rain-on-snow weather events and the associated watershed response, and 5) an assessment methodology for distinguishing watershed sediment loads from instream bank erosion contributions. This paper will present detailed model results and describe in detail lessons learned, as well as the insights and the greater understanding gained through the evaluative modeling process for this alpine watershed environment.

[1] Tetra Tech, Inc.: 10306 Eaton Place; Suite 340; Fairfax, VA 22030
Emails: john.riverson@tetratech-ffx.com; clary.barreto@; leslie.shoemaker@