Reconstruction of Historical Atmospheric Data over Lake Tahoe

M. L. Kavvas, Z. Q. Chen, M. L. Anderson, N. Ohara, J.Y. Yoon
Department of Civil and Environmental Engineering
University of California, Davis

A 40 year reconstruction of precipitation and atmospheric data over the Lake Tahoe Basin has been constructed for the Lake Tahoe TMDL Study. The data reconstruction provides hourly distributed data on precipitation, surface air temperature, dew point temperature, downward longwave radiation, downward solar radiation, relative humidity, latent heat flux, and wind speed at a 3 km by 3 km square horizontal resolution for a 43-year time period spanning 1958-2000. Such meteorological input is necessary for the successful implementation of distributed parameter hydrologic models. However, such data are rarely found in archived observations. Without such information, statistical manipulation of available observed data is required to set parameters within the distributed parameter hydrologic model. As a result, the uncertainty associated with model results increases dramatically. This database provides a physically based alternative to the statistical manipulation of available observed data.

The meteorological output was constructed using a regional atmospheric mesoscale model, MM5, and archived global atmospheric data from the National Center for Atmospheric Research (NCAR) and the National Center for Environmental Prediction (NCEP). The archived global data are at a horizontal spatial resolution of approximately 210 km x 210 km which is not suitable for hydrologic modeling. The MM5 model provides a physically based means of downscaling the archived global data from the 210 km resolution to a 3-km resolution, suitable for hydrologic modeling.

The derived precipitation from the MM5 simulations was compared to available observed data in the Lake Tahoe Basin for a five year time period. The model-derived precipitation matches the timing and relative magnitude of the observed basin precipitation quite well. The model also captures the wet to dry trends in the north, south, east and west quadrants of the Lake Tahoe Basin. Similarly, the simulated temperature matches the day-to-day, seasonal, annual and inter-annual fluctuations found in the observed record.

Sediment Loadings and Channel Erosion: Lake Tahoe Basin

Andrew Simon, Eddy Langendoen, Ron Bingner, Robert Wells, Amanda Heins, Nick Jokay and Igor Jaramillo

USDA-ARS National Sedimentation Laboratory, Oxford, MS asimon@ars.usda.gov

The study was designed to combine detailed geomorphic and numerical modeling investigations of several representative watersheds with reconnaissance level evaluation of approximately 300 sites to determine which basins and areas were contributing sediment to Lake Tahoe. Numerical modeling of upland- and channel-erosion processes over then next 50 years was conducted using AnnAGNPS and CONCEPTS on three representative watersheds, General and Ward Creeks, and the Upper Truckee River. GIS-based analysis of land use, land cover, soil erodibility, steepness, and geology was used to evaluate upland-erosion across the basin. Channel contributions were determined by comparing cross-sectional geometries of channels originally surveyed in either 1983 or 1992. Sites along General, Logan House, Blackwood, and Edgewood Creeks, and the Upper Truckee River were re-occupied and re-surveyed in 2002. Historical flow and sediment-transport data from more than 30 sites were used to determine bulk suspended-sediment loads (in tonnes) and yields (in tonnes/km^2) for sites all around the lake. Eighteen index stations, defined as those with long periods of flow and sediment-transport data and, located in a downstream position were selected. These stations were used to make comparisons between sediment production and delivery from individual watersheds and between different sides (directional quadrants) of the lake. Fine-grained sediment transport was determined from historical data for 20 sites based on relations derived from particle-size distributions across the range of measured flows.

Suspended-sediment loads and yields vary over orders of magnitude from year to year, from west to east and north to south across the basin. Median annual suspended-sediment loads for index stations range from about 2200 tonnes/yr (T/y) from the Upper Truckee River to 3 T/y from Logan House Creek. Based on the historical data, the largest annual contributors of sediment are in decreasing order, Upper Truckee River (2200 T/y), Blackwood Creek (1930 T/y), Second Creek (1410 T/y), Trout Creek (1190 T/y), Third Creek (880 T/y) and Ward Creek (855 T/y). Data from Second and Third Creeks may be somewhat misleading though because of a short period of data collection in the case of the former, and the fact that data collection occurred during major construction activities in these basins. In fact, analysis of suspended-sediment transport ratings with longer periods of record (17 to 20 years) show that sediment loads from the northeast streams have significantly decreased across the entire range of flows. Per unit area, the western and northern streams produce the most sediment although for different reasons, and sediment yields from the northern streams have been decreasing since the early 1970's.

Fine-grained loads show a similar pattern as total loads with the greatest contributors being the Upper Truckee River (1010 T/y), Blackwood Creek (844 T/y), Trout Creek (462 T/y) and Ward Creek (412 T/y). Blackwood, Third, and Ward Creeks, all disturbed streams have the greatest fine-grained suspended-sediment yields at 21.5, 20.2, and 16.4 T/y/km^2.

A first approximation of total, annual suspended-sediment loadings to Lake Tahoe is made by extrapolating average-annual and median-annual data from the index stations. Using this technique average-annual and median-annual loadings are 28,600 T/y and 18,300 T/y, respectively. About 6,300 T/y of fine-grained materials are delivered to the lake, based on median-annual data. A somewhat more refined estimate of total, annual suspended-sediment loads is made by extrapolating the sum of the average, median-annual values within each quadrant. In this case the annual loadings value to Lake Tahoe is about 25,500 T/y.

The contribution of channel materials to sediment loads also varies widely. Undisturbed channels tend to have greater amounts of their sediment load emanating from upland areas. In the General Creek watershed, numerical modeling shows that about 78% of the fine materials passing the downstream-most gauge, originate from upland sources, with only 22% coming from channel sources. Simulations of the percentage of upland sediment contributions may be overestimated because of overestimates of runoff during the low-flow winter months. Still, similar proportions of upland and channel materials were simulated on Ward Creek, suggesting that this may be typical of the wetter, western watersheds. Per unit of channel length, Ward Creek supplies almost 5 times the amount of sediment and fine-grained material from streambanks than General Creek (Table 7-1). Analysis of monumented cross sections shows that on average, 14.6 m^3/y/km of streambank materials (or 1.5 m^3/y/km of fine-grained materials) are eroded from the lower 8.5 km of General Creek. These values are within 27% of those simulated by CONCEPTS. The disturbed channels of Blackwood Creek provide about 217 m^3/y/km of sediment; 12.2 m^3/y/km of fines. This represents about 14 times the amount of streambank-derived sediment per km of channel than from General Creek, almost 4 times more than Ward Creek, but 66% less than from the Upper Truckee River (Table 7-1).

Numerical simulations of suspended-sediment loadings from disturbed and undisturbed western streams, and the Upper Truckee River for the next 50 years shows a trend of decreasing sediment delivery to Lake Tahoe. This is particularly significant for the western streams because they currently produce some of the highest loadings to the lake and, over the past 20 years these high loads (per unit runoff) have remained relatively constant. That future loadings from the Upper Truckee River are simulated to decrease is significant because: (1) it is the largest contributor of suspended- and fine-grained sediment to the lake, (2) streambank erosion has increased recently, in part due to the effects of the January 1997 storm, and (3) notwithstanding the recent increase in bank erosion, loads (per unit runoff) over the longer term (past 24 years) have been shown to be decreasing. Results of simulations on the Upper Truckee River indicate that this longer-termed trend will continue and that the effects of 1997 event will be short-lived in the modeled watersheds. The accuracy and reliability of the numerical simulations is somewhat less than expected, however, because of a lack of detailed, high-quality climate data that could account for broad variations in precipitation and temperature between watersheds, and within a single watershed with elevation.

Rapid geomorphic assessments (RGAs) at 300 stream sites and stream walks were used to calculate a semi-quantitative stability index based on diagnostic characteristics of the channel and adjacent side slopes. Basinwide maps of the occurrence of bank erosion and the silt/clay content of those banks can be used to evaluate potentially critical stream reaches or specific locations. Streambank-erosion classes, taking into account the proportion of fine-grained sediment in the banks were assigned to almost 50 km of channels including Blackwood, Edgewood, General, Incline, Logan House and Ward Creeks, and the Upper Truckee River.

The most significant findings of this research were that:

- Streambank erosion is an important contributor of suspended-sediment from disturbed streams,
- The Upper Truckee River is the greatest contributor of suspended-sediment and fine-grained sediment in the Lake Tahoe Basin,
- Sediment delivery from the Upper Truckee River could be significantly reduced by controlling streambank erosion in the reaches adjacent to the golf course and downstream from the airport,
- Blackwood Creek is a major contributor of both total and fine-grained sediment, particularly for the size of its drainage area and loads from disturbed western streams remain high.
- Loads from western streams are not increasing with time,
- Median, long term suspended-sediment yields (per unit runoff) from northern streams are high, about the same as the wetter western streams but yields have shown significant decreases from the major development period in the 1960s and 1970s.
- Third Creek still produces a great deal of sediment for its size as a result of both upland and channel contributions.
- Disturbed watersheds contribute considerably more suspended sediment than their stable counterparts in each basin quadrant.
- Eastern streams produce the lowest sediment loads and those studied are net sinks for sediment.
- The major runoff event of January 1997 impacted western streams and the Upper Truckee River most severely, but did not seem to rejuvenate these fluvial systems. Effects were minor in the northern streams,
- The most significant effect of the January 1997 was to flush stored sediment from alluvial valleys resulting in generally lower transport rates in the years following the event,
- Numerical simulations of General and Ward Creeks and the Upper Truckee River show that suspended-sediment loads will continue to decrease from these streams over the next 50 years.

Tahoe TMDL Stormwater Monitoring Program, Water Years 2003-04

Alan Heyvaert[1] and Jim Thomas[2]

[1]UCD Tahoe Research Group
[2]Desert Research Institute
December 3, 2004

Prior to implementation of the Tahoe TMDL stormwater monitoring program, there was no consistent or comprehensive monitoring of urban runoff in the Lake Tahoe Basin. Although a long-term stream monitoring network has been operating at Lake Tahoe since 1980, these data do not provide information focused on the characteristics of urban stormwater runoff. The lack of stormwater runoff data is considered a serious data gap, especially when preliminary grab sampling from urbanized areas around Lake Tahoe suggested that one third of the total phosphorus loading derived from urbanized areas that drain directly into the lake. Runoff from these areas is not represented in the stream monitoring program. To fill this data gap, the Tahoe TMDL stormwater monitoring program was started in October 2002. This program includes sixteen monitoring stations around the Tahoe Basin that were established during Water Years 2003 and 2004 (WY03-04). Each station contains continuous flow monitoring and autosampling equipment. Targeted sites were selected to represent stormwater runoff from residential, commercial and mixed land uses, and from an area of natural vegetation. Data from this stormwater monitoring program are currently under analysis, and will provide information useful to watershed managers and to project planners for model calibrations and improved project designs.

RELATING WATER QUALITY TO CATCHMENT CHARACTERISTICS IN THE TAHOE BASIN

Robert Coats
Tahoe Research Group, UCD

Abstract

The primary goal of this study is to develop quantitative relationships between water quality—concentrations and loads of nitrogen, phosphorus and suspended sediment—and watershed characteristics. Such relationships will 1) help to target problem areas for remedial action; 2) provide a quantitative basis for estimating total basin loads, for input to the lake nutrient and sediment budgets; 3) provide a reality check for TMDL water quality monitoring efforts. Secondary goals are to 1) document time trends in water quality that may result from land use changes, and 2) refine methods for estimating total constituent loads.

Using the LTIMP data set for the period 1990-2002 for 20 stations, we calculated discharge weighted mean concentrations and total constituent loads and yields for ammonium-N (NH_4-N), nitrate-N (NO_3-N), Total Kjeldahl Nitrogen (TKN), Soluble Reactive Phosphorus (SRP), Total Phosphorus (TP) and Suspended Sediment Concentration (SS). We derived watershed characteristics for a suite of explanatory hydrologic, geologic and land use variables, using the Tahoe basin GIS. With Principal Components Analysis and/or Multiple Regression, we then derived predictive equations to relate the concentration and yield estimates to the watershed characteristics. For the dissolved constituents (NH_4-N, NO_3-N, TKN, and SRP), watershed characteristics can explain 64 to 85 percent of the variance among watersheds. For average annual yields (kg/ha/yr) of all constituents, the models explain 40 to 80 percent of the total variance among watersheds. Non-highway percent impervious surface is an important contributor in all of the models for total yield.

A time series analysis of data for Blackwood and Ward Creeks, 1976-2004, shows that the Blackwood Creek watershed has improved over time in its ability to retain nitrate-N. The Gondola fire of July 2002 caused spectacular releases of SRP and nitrate-N to Eagle Rock Creek in the Edgewood Creek basin, but the concentrations are gradually returning to pre-fire levels.

Development of GIS Land Use Layers for the Watershed Model

John Riverson[1]

To ensure the most representative land use areas for the watershed model, a composite land use layer was developed for the Lake Tahoe basin using GIS data provided by the Tahoe Regional Planning Agency (TRPA), the USDA Forest Service (LTBMU), Desert Research Institute (DRI), University of California at Davis (UCD), and various California and Nevada state agencies. The main objectives of the land use composition effort were: (1) to locate and compile the most current and representative GIS layers available, (2) to identify the advantages and limitations inherent in each data source, and (3) to layer and combine the various data sources in such a way as to maximize the overall accuracy in representing land use areas in the Tahoe Basin.

The watershed model represents the following land uses:

Land Use Description	Pervious/Impervious	Subcategory Name
Single Family Residential	Pervious	Residential_SFP
	Impervious	Residential_SFI
Multi Family Residential	Pervious	Residential_MFP
	Impervious	Residential_MFI
Commercial/Institutional/ Communications/Utilities	Pervious	CICU-Pervious
	Impervious	CICU-Impervious
Transportation	Impervious	Roads_Primary
	Impervious	Roads_Secondary
	Impervious	Roads_Unpaved
Vegetated	Pervious	Ski_Areas-Pervious
	Pervious	Veg_Unimpacted
	Pervious	Veg_Recreational
	Pervious	Veg_Burned
	Pervious	Veg_Harvest
	Pervious	Veg_Turf

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

Near Shore Water Quality

Ken Taylor, Desert Research Institute

The near shore water quality is of interest because: 1) it is the location where the clarity of the water is most obvious to the largely shore-bound population, and 2) the water quality responds faster and in a more localized way than in the middle of the lake. The fast and local response of near shore water quality to pollutant loading makes near shore water quality an early indicator of the effectiveness of management actions. Two indicators of near shore water quality are: 1) optical properties of the water that control water clarity, and 2) the abundance of periphyton, which is the algae that grows on submerged rocks.

Surveys of near shore clarity were conducted by continuously measuring the turbidity of the water under a moving boat. By driving the boat in a grid it was possible to map how the turbidity of the water changed from place to place. Surveys conducted around the entire lake shore indicate that near shore areas with presently reduced clarity occur along the south shore from the Upper Truckee River to State Line, and to a much lesser degree off Incline Village, Kings Beach, Tahoe Vista and Tahoe City. Intensive surveys along the southeast shore indicate that inflows from the Upper Truckee River and Bijou Creek are the largest cause of reduced near shore clarity. The largest reduction of near shore clarity is caused by mineral particles from urban areas that are mobilized during spring runoff and lake level rainfall. Undeveloped areas always had excellent near shore clarity even after storms that degraded the clarity near developed areas. The near shore monitoring data will be compared to be used to assist in the validation of the Lake Tahoe Watershed Model.

The existing TPRA threshold related to near shore clarity is not exceeded until the water is so turbid that the bottom is not visible in water just 3 feet deep. The existing TRPA threshold is inconsistent with the public's expectations, the high level of environmental protection of other thresholds, and offers no protection for the majority of the near shore zone. A new threshold for near shore clarity should be developed that at least strives to protect existing conditions. A near shore clarity monitoring program should be developed, and linked to the ongoing periphyton monitoring program, so that changes in near shore water quality can be determined to assess the influence of restoration actions.

Availability of Sediment and Dissolved P for Algal Growth in Suspended Sediments, Erodable Streambank Sediments, and Tributary Water at Lake Tahoe.

Joseph Ferguson[1], Robert Qualls[2], and John Reuter[3].

[1,2] Dept. of Natural Resources and Environmental Sciences, MS 370, University of Nevada, Reno, NV, 29557, Tel. (775) 327-5014, Fax. (775) 784-4789, [1]fergusoj@unr.nevada.edu [2] qualls@unr.edu, [3] Division of Environmental Studies, 2132 Wickson Hall, University of California, Davis, CA 95616 Ph.(530) 304-1473, fax (530) 753-8407 (fax) jereuter@ucdavis.edu
[2]Corresponding author, presenter.

Phosphorus (P) is generally the factor that limits the growth of phytoplankton in Lake Tahoe and suspended sediments, dissolved organic P, and erodable streambank sediments from tributary streams may be important inputs of P. However, not all of this P may be available for algal uptake. We concentrated suspended stream sediments onto glass fiber filters, incubated them with P-starved *Selenastrum capricornutum* algal cultures for 21 days and measured the total P released from the filters, which was mostly in the form of algal cells. The same technique was used on samples of erodable streambank soils. A novel technique was used to determine the bioavailability of the dissolved organic P fraction in streamwater in which the DOP was concentrated in a membrane filter pressure cell and then incubated and analyzed similarly the particulate sediment inputs. The data reported here for the suspended stream sediments represents samples from Edgewood Creek (EC), General Creek (GC), Incline Creek (IC), Upper Truckee River (UT), and Ward Creek (WC) collected during the spring, summer, and fall 2003. Sediment concentrations ranged from 1 to 1.8 mg L^{-1} in the spring streamwater, 0.6 to 12.9 mg L^{-1} in the summer streamwater, and 1.9 to 5.7 mg L^{-1} in the autumn streamwater samples. Total P concentrations (sum of three sequential chemical extractions) ranged from 1.1 to 3.6 ug P mg^{-1} sediment in the spring streamwater, 0.7 to 5.2 ug P mg^{-1} sediment in the summer, and 1.9 to 6.7 up P mg^{-1} in the autumn spate. In the spring streamwater, the percentage of total P that was available for algal growth in each creek was EC 3%, GC 34%, IC 27%, UT 30%, and WC 25%. In the summer streamwater the corresponding percentages were: EC 28%, GC 46%, IC 5%, UT 3%, and WC 35%. In the autumn streamwater the corresponding percentages were: EC 22%, GC 25%, IC 8%, UT 15%, and WC 11%. No more than 50% of the P in suspended sediments was available for algal growth, and the variation between streams makes it important to consider bioavailability in ranking the importance of various sources in the eutrophication of Lake Tahoe. The erodable streambank samples were collected at all of the LTIMP sites and analyzed. In erodable streambank samples the percentage of total P that was available for algal growth in each creek was EC 4%, GC 6%, IC 9%, UT <1%, and WC 7%. The DOP samples were collected in the summer of 2004 and represent inputs from EC and UT. A majority of the DOP was not mineralized in a 3-week algal assay.

LAKE TAHOE FRAMEWORK STUDY
GROUNDWATER EVALUATION
LAKE TAHOE BASIN, CALIFORNIA AND NEVADA

U.S. Army Corps of Engineers
Sacramento District
Meegan Nagy – Principle Author

The Lake Tahoe Basin Framework Study Groundwater Evaluation, which is designed to enhance the understanding of the role groundwater plays in the eutrophication processes reducing lake clarity was conducted in 2001-03 in support of the Tahoe TMDL Research Program. This Groundwater Evaluation is a portion of the Lake Tahoe Framework Implementation Report being completed by the U.S. Army Corps of Engineers (Corps) at the direction of Congress. The primary concerns affecting lake clarity identified by Basin stakeholders are nutrient and sediment loading to the lake. This evaluation provides an estimation of the nutrient loading only, specifically phosphorous and nitrogen, as contributed by groundwater flowing into Lake Tahoe. Within that context, the major objectives of this evaluation were to:

1. Estimate nutrient loading to the lake through groundwater on a regional basis,
2. Identify known and potential sources of nutrients to groundwater, and
3. Identify nutrient reduction alternatives that could be used in the Basin.

This Groundwater Evaluation was initiated in the fall of 2001 with the intention of assimilating and utilizing the vast amounts of existing data for the basis of the evaluation – no new field work was done as part of this scope. Information from other reports, previous investigations, and personal communication with many stakeholders in the basin are used in the evaluation. Scientific principles, professional judgment, interpretation, and modeling were applied to this gathered data.

Nutrient Loading Estimate

Nutrient loading estimates were separated into five regions based on political boundaries and major aquifer limits. The five regions included South Lake Tahoe/Stateline, East Shore, Incline Village, Tahoe Vista/Kings Beach and Tahoe City/West Shore. Depending on the amount and type of groundwater data available, discharge estimates are developed using one or a combination of three methods; groundwater flow modeling, Darcy's Law and seepage studies. The South Lake Tahoe/Stateline aquifer discharge is based on existing data of sufficient quality and quantity to develop a groundwater flow model. The remaining four regional aquifer seepage estimates are developed using either Darcy's Law or existing seepage data. Once the groundwater discharge estimates are calculated, nutrient concentrations are applied to determine annual loading to Lake Tahoe.

The nutrient concentrations used to determine the loading estimates are based on either average nutrient concentrations for a region, measured downgradient concentrations for a region or land use weighted concentrations. The land use weighted concentrations are used in areas with little monitoring data available or areas that did not have meaningful placement of wells in relation to land use.

The table below presents the nutrient loading estimates (amounts contributed by groundwater) determined for each region and overall loading to the lake.

Region	Total GW Nitrogen Loading (kg/year)	Total GW Phosphorus Loading (kg/year)
South Lake Tahoe/Stateline	2,400	430
East Shore	6,200	140
Incline Village	4,200	770
Tahoe Vista/Kings Beach	9,400	1,100
Tahoe City/West Shore	28,000	4,400
Lake Tahoe Basin Wide	50,000	6,800

Notes:

1. All concentrations reported are dissolved.
2. 1 kg/yr = 2.2 lbs/yr

The portion of the overall nitrogen and phosphorus loading contributed by groundwater is estimated by this evaluation to be 13% and 15% of the total annual budget for the lake, respectively. This is similar to the estimates developed by Thodal (1997), 15% and 10%. In addition to independently verifying Thodal's previous estimate, this evaluation has reduced the potential error by separating the data into subregions and estimating nutrient loading by subregion. This estimate indicates that groundwater is a significant contributor of nutrients annually; i.e., 50,000 kg (110,000 lbs) of nitrogen and 6,800 kg (15,000 lbs) of phosphorus into the lake each year. This estimate also shows that the areas most deserving additional investigation, characterization and mitigation are Tahoe Vista/Kings Beach and Tahoe City/West Shore. These two areas appear to contribute significantly to the nutrient loading of the lake perhaps as a result of higher groundwater flow into the lake and denser urban development along the lake shore. A numerical model was developed by the USACE – Hydrologic Engineering Center (Jon Fenske) to estimate the volume, rate and distribution of groundwater flux to the lake along its southern shore.

The portion of the total nutrient loading attributed to undeveloped and undisturbed areas was 17,000 kg and 3,100 kg for N and P, respectively.

Source Identification

This study also identified the known and potential sources of nutrients to groundwater and is integral in determining any alternatives that could be used to reduce the loading from groundwater. The key sources evaluated are fertilized areas, sewage, infiltration basins and urban infiltration. Note that these are potential sources from the land that may be adsorbed in the soil matrix or otherwise lost (denitrification, etc) before reaching the aquifer.

The estimated total nitrogen and phosphorus in fertilizer applied annually is 140 metric tons and 45 metric tons (150 tons and 50 tons), respectively.

Another Lake Tahoe Basin Framework Study funded by the USACE and conducted by Camp Dresser and McKee (CDM) concluded that sewer line exfiltration is not a significant source of nutrients flowing to the lake. However, when evaluating the sources of nutrients to groundwater only, sewer exfiltration may contribute ~5% of the nitrogen and ~13% of the phosphorus groundwater loading from anthropogenic sources. Using the exfiltration rate and average nutrient concentration of sewage, the annual nitrogen loading rate is estimated to be 1,700 kg (3,700 lbs) per year and the annual phosphorus loading rate is estimated to be 470 kg (1,000 lbs) per year, respectively. The effects of decommissioned septic tanks are also evaluated. Based on previous studies, it is estimated that each septic tank could have contributed between 2.1 kg to 4.9 kg (4.6 lbs to 11 lbs) of phosphorus to the groundwater zone. It is estimated that the phosphorus could take as many as 110 hundred years to travel 500 meters (1,600 ft) to the lake. This implies that much of the phosphorus in the groundwater as a result of septic tank use could still be a risk to the lake in the future. Conversely, much of the nitrogen has probably already reached the lake as it typically travels at the same rate as groundwater.

Other potential contributors are engineered infiltration basins and urban infiltration. Engineered infiltration basins are constructed specifically to collect stormwater runoff and allow it to slowly seep into the groundwater aquifer below. Not enough information was available to adequately evaluate this source.

Factoring Performance of BMPs into the Development of TMDLs for Lake Tahoe
Presented by Eric Strecker, GeoSyntec Consultants, Portland Oregon

Abstract

The purpose of this Stormwater BMP Evaluation and Feasibility Study was to provide an initial evaluation of urban BMPs effectiveness at Lake Tahoe, under alternative potential project level and basin-wide BMP implementation strategies. Tasks included:

- An evaluation of stormwater treatability information
- Basin-wide modeling of intervening zones
- Assessment of stormwater BMP performance at Lake Tahoe
- Preliminary financial analysis
- Project-scale BMP Performance

This paper describes the approach for gathering and developing this information. The results of this work are intended to ultimately be incorporated into the watershed model to estimate the potential reductions in loading of pollutants to the lake through BMP implementation on a basin-wide scale.

The paper provides a summary of the potential for BMPs to meet future TMDL loading reductions for fine particulates and nutrients. The approach included long-term simulation modeling to ascertain the hydrologic and hydraulic performance of potential BMP sizing and designs, assessment of BMP performance through a combination of statistical assessments of the International BMP Database and unit processes, and local Lake Tahoe BMP performance information. Table 1 presents results of the comparison of effluent quality data from the International BMP database to Local Tahoe Data. The local data appears to be well within the levels reported in the database.

Table 1. Comparison of. EPA/ASCE BMP Database Mean Effluent Quality Concentration (µg/L except as mg/L for TSS) for Best Performing BMPs (ASCE) with Lake Tahoe BMPs aggregated and the Tahoe City Wetland Treatment System

Constituent	ASCE	TCWTS	Lake Tahoe BMPs Mean Effluent Quality
TSS	26	10	79 (n=22)
TP	210	122	153 (n=20)
DP	70	59	100 (n=11)
NO3-N	300	262	67 (n=20)
NH4-N	148	14	14 (n=12)
TKN	930	749	874 (n=12)

ACSE Best performing BMPs mean effluent quality
TCWTS – Tahoe City Wetland Treatment System (Heyvaert et al., 2005)

Tables 2a and 2b present estimates of potential pollution reduction (concentration not load reductions) for selected pollutants by land use when applying the BMP Database Effluent Quality and the Lake Tahoe BMPs Mean Effluent Quality, respectively. The tables demonstrates that with implementation of the better performing BMPs (lowest effluent quality) in the BMP Database or Lake Tahoe Mean Effluent Quality Data set, that meaningful reductions in pollutant loadings are possible at the project scale. This information was used together with long-term simulations of only intervening zones that drain surface runoff directly into the Lake were modeled. Synthetic MET data generated by the UC Davis (Kavvas et al.) provided the crucial data input for the continuous SWMM simulation. The model also accounted for evapotranspiration losses as well as treatment performance.

***Table 2a and 2b**. Potential Achievable Percent Pollution Reductions with Implementation of the better performing BMPs in the International BMP Database by Land Use Type. Values for constituents based on land use are concentrations (µg/L except TSS which is mg/L).*

2a

Constituents	Land Use Type						ASCE Database	Achievable % Reduction					
	Undisturbed	**Roadway**	**Industrial**	**Mixed Urban**	**Residential**	**Turf Grass**	**Achievable Mean Effluent Conc.**	**Undisturbed**	**Roadway**	**Industrial**	**Mixed Urban**	**Residential**	**Turf Grass**
TSS	44	498	202	341	142	NA	26	41%	95%	87%	92%	81%	NA
TP	28	878	800	295	325	866	210		76%	74%	29%	35%	76%
DP	30	57	66	224	30	489	70				69%		86%
NO3	2	35	213	256	56	40	300						
NH4	3	156	212	41	35	53	148		5%	30%			
TKN	140	2,443	4,995	NA	1,636	4,795	930		62%	81%	NA	43%	81%

2b

Constituents	Land Use Type						Tahoe Basin	Achievable % Reduction					
	Undisturbed	**Roadway**	**Industrial**	**Mixed Urban**	**Residential**	**Turf Grass**	**Mean Effluent Conc.**	**Undisturbed**	**Roadway**	**Industrial**	**Mixed Urban**	**Residential**	**Turf Grass**
TSS	44	498	202	341	142	NA	79		84%	61%	77%	44%	NA
TP	28	878	800	295	325	866	153		83%	81%	48%	53%	82%
DP	30	57	66	224	30	489	100				55%		80%
NO3	2	35	213	256	56	40	67			69%	74%		
NH4	3	156	212	41	35	53	14		91%	93%	66%	60%	74%
TKN	140	2,443	4,995	NA	1,636	4,795	874		64%	83%	NA	47%	82%

Cells highlighted blue indicate that TRPA or LRWQCB Standard is exceeded
Cells highlighted orange indicate that there is no significant difference between influent and effluent quality
NA – No available data

With the assumption that all the direct runoff volume could be treated (a condition that does not currently exist), the modeling effort determined that significant reductions in fine particulates and phosphorus are achievable if "better performing" BMP types (wet ponds, wetlands, and extended detention ponds with a small pool) are employed. Given the unlikelihood that all the direct runoff volume can be treated and that in all cases these better performing BMPs could provide the treatment, other treatment options (e.g. hydrologic controls, chemically enhanced removal, and/or improved maintenance, etc.) will likely be critical in meeting potential overall basin-wide TMDL loading requirements. These observations were arrived at by continuous SWMM simulation results that indicated that using the better performing BMPs designed using current design sizing criteria provided improved water quality. In addition, SWMM results also illustrated the implications of design and operational requirements such as permanent pool size and drawdown times in effectively treating fine particulates. Seven scenarios were modeled to evaluate what might be achieved in terms of reductions in pollutant loadings from runoff from paved areas in the interviewing zones and as a percentage of the estimated total loading. In addition, the study developed cost estimates for implementation of the more robust BMPs and found that on a wide scale, the more "expensive" implementation scenario had the lower cost per pound removed for fine particulates. These results will be presented briefly.

Water Quality Project Inventory

Chad Praul, Nevada Tahoe Conservation District,
Tom Gavigan, Lahontan Regional Water Quality Control Board

The loss of historic clarity within Lake Tahoe has resulted in the collaborative effort to develop a Total Maximum Daily Load (TMDL) between the States of California and Nevada. The TMDL is a science-based management plan that is aimed at restoring and protecting Tahoe's extraordinary water clarity. The Lake Tahoe TMDL Project features the use of ecological process models to determine the allowable load of pollutants that the Lake can receive and still achieve clarity objectives.

Prior to and concurrent with TMDL development, many urban stormwater treatment projects and best management practices (BMPs) have been implemented throughout the Lake Tahoe Basin. The accurate calibration and simulation of pollutant loading to the Lake within the TMDL Watershed Model is directly dependent upon the representation of these treated areas within the model. However, the complex network of funding and implementation agencies in the Tahoe Basin has resulted in the fragmentation of this information and no centralized repository currently exists to contain it.

This effort is compiling an inventory of urban stormwater project areas in the Lake Tahoe Basin. The final products will be a GIS coverage and Access database that contain the project area and BMPs associated with each project. The benefits of the Water Quality Project Inventory are not limited to the TMDL application. The information will allow funding, regulatory, and implementing agencies to track water quality assets, quickly research each other's efforts and use these results to find efficient solutions to Environmental Improvement Program (EIP) issues.

Model Applications and Scenario Development

Dave Roberts
Lahontan RWQCB

Development of the Lake Tahoe TMDL includes a significant research component that addresses a broad range of topics and issues. The application of this science, as well as, the inclusion of large amounts of existing information, is being accomplished with the use of several models capable of simulating complex systems. Most of these models are also deterministic in their application which means they have the ability to provide estimated results of "what if . . ." type scenarios that simulate potential management actions. This provides the opportunity to scientifically estimate outcomes of different management applications within days rather than having to wait to see the results first hand. The development and refinement of these models will provide powerful planning tools to resource managers and project implementers.

This presentation will provide an overview of how these tools will be applied to the development and integration of the TMDL, Pathway 2007 and the future application of these tools within a basin-wide management system. Specific examples of how the models will be applied within each of these processes will be presented along with general discussion of scenario development and application.

Integrated Approach for Phase 2 of the Tahoe TMDL

Development of an Approach and Set of Tools for a Basin-Wide Water Quality Management System

Dave Roberts[1], John E. Reuter[2] Jack Landy[1], Jason Kuchnicki[3] and Tom Gavigan[1]
[1]Lahontan RWQCB, [2]University of California, Davis, [3]Nevada DEP

November 23, 2004

Planning for Water Clarity Restoration

The Lahontan Regional Water Quality Control Board (RWQCB) and Nevada Division of Environmental Protection (NDEP) are now collecting data and developing models to quantify existing basin-wide, land-use-specific pollutant loads and the needed reductions to complete a Total Maximum Daily Load (TMDL) for nutrients and sediment inputs to Lake Tahoe. Over 100 individuals from a variety of institutions are involved in a TMDL research program to support this effort. The TMDL will become part of the larger Pathway 2007 effort to develop a Regional Plan that will guide implementation of the Environmental Improvement Program (EIP). Water quality standards for Lake Tahoe call for an annual average Secchi depth clarity of approximately 30 meters. In 2003 the Secchi depth value was 21.6 meters.

A time series model for Lake Tahoe Secchi depth was recently developed, incorporating a mechanistic understanding of interannual variability based on actual lake response using a 32-year historical dataset (Jassby 2003). This statistical model has been used to determine - with a very high degree of certainty - that the increasing Secchi depths in 1999, 2000, 2001 and 2002 were climate-driven and did not represent a recovery of the lake. This highlights the need for a science-based, basin-wide water quality management system so that restoration efforts can be carried out in a progressive, organized and considered manner.

For planning purposes, the development of the TMDL has been divided into two phases. Phase 1 will result in the development of a Technical TMDL that will provide a basin-wide estimation of pollutant loading by sources, as well as, an estimation of pollutant load reductions necessary to achieve water quality standards for clarity and transparency. The Phase 1 Tahoe TMDL Research Program consists of monitoring urban runoff; developing statistical relationships between stormwater quality and land use; modeling stream channel and upland erosion; development of supporting GIS layers; quantifying groundwater loading; reconstruction of Lake Tahoe's historical meteorological data, developing a predictive watershed model; conducting a preliminary BMP evaluation; quantifying atmospheric deposition; evaluating the occurrence of biologically available phosphorus; and creating a lake water clarity model to establish the pollutant loads that will achieve the lake's clarity standards. The integration of these projects is discussed in a companion, Phase 1, document (soon to be available at the Lahontan RWQCB website: http://www.swrcb.ca.gov/rwqcb6/).

Tools initiated and/or completed during Phase 1 include; Tahoe Basin Watershed Model, Lake Tahoe Clarity Model, model-ready GIS layer package, South Shore Groundwater Flow Model, preliminary air emission inventory, reconstructed meteorological data, stream channel erosion model, and Tahoe Integrated Information Management System.

Phase 2 of TMDL development will be part of a much larger public process to determine required load reduction allocations and the development of an implementation plan that outlines how load allocations will be achieved. This effort will utilize the information and tools developed during Phase 1 and Phase 2.

Description of Phase 2 Tasks

This phase of the TMDL will result in specific load reduction allocations and an Implementation Plan to achieve required load reductions. The planning tools developed during Phase 1 such as the Watershed Model, Lake Clarity Model, and other tools will be used to provide loading estimates and necessary load reductions for application during a large public participation process. It is anticipated that this process will help guide the development of load reduction allocations that are most feasible and cost effective. Once these allocations have been identified, an Implementation Plan will then be developed that is specifically tailored to achieve load reduction allocations. The tasks discussed below, in combination with others, will build upon the work completed as part of Phase 1.

Over $3 million have been obtained the U.S. Army Corps of Engineers, Southern Nevada Public Lands Management Act (SNPLMA Round 5), and the U.S. EPA to help develop Phase 2. In 2004, the Lahontan RWQCB and Nevada DEP jointly applied for and received a $1.14 million grant from the U.S. EPA Targeted Watershed Program. Tahoe was one of 14 watersheds nationally to be awarded this grant. Brief descriptions of Phase 2 tasks follow:

<u>Pollutant Load Allocations</u> – A critical deliverable for Phase 2 of the TMDL will be pollutant load allocations. These are the quantitative estimates of load reduction that will be required to meet the TMDL. Allocations can take a number of forms, e.g. by watershed, by jurisdiction, a percentage of current loading, based on reduction opportunities, or other approaches. Whichever method ultimately determined will provide, for the first time, quantitative targets for pollutant load reduction and a focusing of research necessary to achieve these obligations.

TMDL Implementation Tool Box - The TMDL program is currently developing a Tahoe TMDL Implementation Tool Box that will include models and other tools that can be used by agencies, resource managers, planners, scientists, engineers, and EIP project implementers to help achieve basin-wide load reduction goals. Tools resulting from Phase 1 have been previously discussed.

Specifically, the TMDL Implementation Tool Box is intended to:

- Provide a forum for the development and application of all the tools identified as needed for both water quality planning and implementation.
- Develop and apply these tools so that they are integrated and compatible.
- Develop a system to allow for timely and appropriate changes to these tools as new information and/or needs are identified.
- Create a forum for close collaboration and interaction between regulatory and implementation agencies.
- Develop a unified set of planning and implementation needs to be funded with existing and/or future sources.
- Focus research/monitoring needs and agency resources.

The Tahoe TMDL Implementation Tool Box is fashioned after the national U.S. EPA TMDL Modeling Toolbox (U.S. NERL, Athens, GA). The EPA modeling toolbox is a collection of models, modeling tools and databases. While each tool is a stand-alone application, the Tool Box is designed to promote exchange of information through common linkages. We have a similar vision for our program, and the Tahoe TMDL Implementation Tool Box is being designed to accommodate new knowledge and to be updated as needed.

Stakeholders will be highly involved in the development and application of these tools, which will be designed to provide the opportunity for conformity in water quality planning. This is of critical importance in that it provides a set of common methodologies (i.e. 'rules') (1) for project implementers to quantify the water quality benefits of restoration projects and receive appropriate TMDL credit, (2) to assure regulatory agencies that load reduction estimates are reliable, and (3) that allows us to quantify progress towards meeting the TMDL loading requirements from a planning perspective. When done on the scale of the entire drainage area, this forms the foundation for a basin-wide water quality management system.

Evaluation of New/Alternative BMP Technologies – Given the importance of dissolved nutrients and fine sediment particles to water clarity, traditional BMPs may not be completely effective in treating surface runoff. The objective of this project is to identify approaches to either enhance the currently used BMPs (e.g. chemical aggregation, biological enhancement) or to pursue new engineering solutions (e.g. treatment facility, electro-coagulation, water storage in large underground cisterns, diversion of the most polluted stormwater to the regional sewer system). In addition, methods to treat pollutant loads from other sources, such as atmospheric deposition, groundwater and stream channel erosion, need to be evaluated. The hydraulic transport of the most polluted runoff to engineered treatment facilities outside the existing drainage course is part of this consideration.

Load Reduction Matrix – The Load Reduction Matrix (LRM) will include all feasible BMPs for load reduction (including both source control and treatment) available for use in the Tahoe basin. Existing and new BMPs will be included and will address the major pollutant sources. This will largely include information on individual BMPs and include data on effectiveness, expected effluent concentration, cost per unit effort, constraints (legal, regulatory, construction, etc.) and opportunities for deployment in the Basin. As field data on BMP effectiveness become available, effectiveness values will be more certain and values used to determine load reduction credit will be updated to reflect new knowledge. The adaptive management approach will be critical in this regard. Enhanced by stakeholder involvement, the LRM can serve as a reference source for data needed by models to estimate project credit, assist in project design, and help track basin-wide progress toward TMDL implementation.

Methodologies to Estimate Pollutant Load Reduction – This product will include a set of methodologies to estimate pollutant load reduction from water quality restoration projects. The methodologies developed for this task will form the cornerstone for TMDL and water quality management planning and implementation. These methodologies will allow for the accurate estimation of pollutant load reduction and will provide for quantitative determination of progress towards achieving TMDL loading requirements. It is expected that these methodologies will provide a uniform approach to calculating expected load reductions from projects, assigning credit toward allocations, and measure progress towards achieving required pollutant reductions. The initial focus of this tool will be land-runoff; however, methodologies for atmospheric and groundwater pollutants are envisioned.

BMP Model – To calculate load reduction on a basin-wide scale, a BMP model will be developed as a module to the existing Tahoe Watershed Model. The watershed model is land-based and driven by basin hydrology. The BMP model is intended to simulate the effects of individual projects or a collection of multiple projects, at the sub-watershed, watershed, or basin scales, with respect to expected load reduction. A direct comparison of this information with the TMDL requirements will allow us to track progress and will provide insights for future management steps.

Urban Hydrology Model – BMP modeling in the less steep (low topographic gradient), urbanized regions of the Tahoe basin, requires a more detailed understanding of urban hydrology. Urban hydrology can be heavily influenced by stormwater routing, conveyance, and collection, which can make accurate calculations of pollutant load difficult for BMP design. Much of this routing has been modified by human intervention; therefore, transport cannot be ascertained only from watershed digital elevations. This modeling tool will act in concert with the BMP-watershed model to plan and simulate sub-watershed scale restoration planning in urban areas.

Pollutant Load Reduction Tracking Systems – A pollutant reduction tracking system is critical to water quality restoration in that it provides resource managers and project implementers with an up-to-date assessment of progress towards meeting the TMDL and associated load reduction allocations. These systems will allow for the tracking of trends and modification of the Implementation Plan based upon milestones, program progress, and new information. It is envisioned that these tracking systems will be housed within the Tahoe Integrated Information Management System (TIIMS), and would form the basis for issuing annual progress reports on load reduction to managers, the public and elected officials.

Potential Water Quality Trading System – Funds received as part of the US EPA's Targeted Watershed Program will be used to assess the feasibility of developing a pollutant load reduction trading system to help meet TMDL goals. A critical objective will be to create units of trade and define appropriate trading areas. If determined to be feasible, this system could provide greater regulatory flexibility to project implementers in selecting which restoration projects to implement.

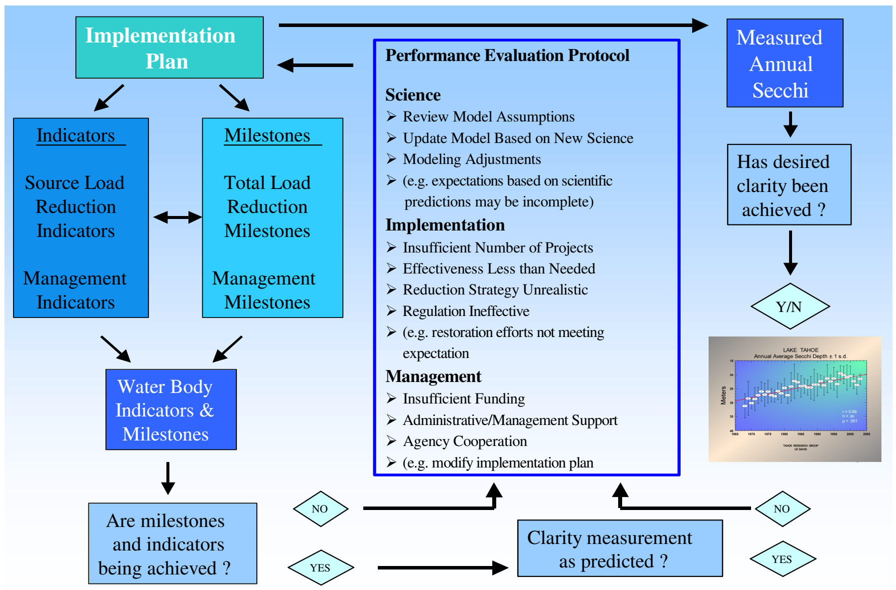
Outreach/Education – An important aspect of Phase 2 of the TMDL is to engage stakeholders in the projects presented in this section. Achieving the load reduction goals of the TMDL will require considerable collaboration. Development of the Tahoe TMDL Implementation Tool Box is a major step in this direction. A considerable effort will be made to have stakeholders involved in the development of these mutually beneficial tools and consequently, the development of the final TMDL.

Phase 2 Integration

Linkage Between Individual Tools – Linkages exist between most features of the Tahoe TMDL Implementation Tool Box. Data on BMP effectiveness for all reasonable options serves as the basis for determining credit and assessing progress towards the TMDL load reduction requirements. Within the framework of adaptive management, new monitoring data can be used to update effectiveness estimates as found in the Load Reduction Matrix (LRM). Furthermore, new and innovative techniques for pollutant/hydrologic control can be placed in the LRM to be used along with the more traditional BMPs currently in use.

Since most EIP projects are not designed as individual, single BMPs, the Load Reduction Estimation Methodologies will be used in conjunction with the LRM data on effectiveness to determining load reduction potential from projects. While this approach will provide good information on load reduction at the EIP project scale, an effective basin-wide water quality management system requires integration at the scale of the entire drainage area. Phase 1 produced the Watershed Model that will serve as the foundation for this larger evaluation. When supplemented with a BMP module, the Watershed Model will be able to address load reduction planning at a scale comparable to the TMDL requirements. The Urban Hydrology Model will allow us to refine the Watershed Model to better account for flow routing in the important urban areas. By placing the locations of opportunity for load reduction projects throughout the basin on a GIS layer, the combined modeling effort can hopefully evaluate the extent of restoration projects required.

The Pollutant Load Reduction Tracking System allows agencies, implementers, scientists and water quality planners, to compare actual environmental response to modeling milestones. Should goals not be met, a Performance Evaluation Protocol contained in the tracking system spells out options for adjusting the EIP Implementation Plan. This represents a true adaptive management approach to meet water quality goals. The figure below is an example of such a Conceptual Load Reduction Tracking System.



<u>Stormwater Master Plans</u> – Following development and integration of (1) the products in the Tool Box and (2) the other features developed as part of Phase 2, the next logical step will be development of science-based, regional/jurisdictional plans for control and treatment of stormwater. Depending on the results reported in the Technical TMDL on pollutant sources, atmospheric deposition, stream channel erosion, and groundwater components could be added. In that regard, these would become pollutant reduction master plans. Indeed, many of the Phase 2 tools being developed were done to expressly assist in the development of these types of plans. Tool Box models can be used to evaluate the potential effectiveness of these plans and direct comparisons can be made to TMDL load reduction requirements. As progress is tracked, these plans can be updated regularly, in a consistent and informed manner.

<u>The Pathway 2007 Planning Process</u> - In 2007, TRPA will be updating its 20-year Regional Plan and Water Quality Management Plan (208 Plan) to incorporate new regulations and programs including the Lake Tahoe TMDL, Storm Water NPDES permit requirements and the Source Water Protection Program (SWPP). California, Nevada, TRPA, the U.S. Forest Service, and others are collectively updating and integrating relevant plans and regulations to achieve program consistency across the two-state, multi-jurisdictional watershed. Existing programs such as impervious land coverage and restoration credit/transfers, and stormwater treatment requirements on new and existing

development, provide support to and a model for a water quality trading program for the pollutants causing clarity decline. Stakeholders have expressed the desire to engage in science- and market-based watershed management where they can compare measures to reduce pollutant loads and select pollutant reduction strategies with the greatest opportunity to achieve clarity goals and protect drinking water supplies.

Final Comments

The incorporation of the TMDL within the Pathway 2007 Planning Process provides an opportunity to develop a technical and science-based approach for water quality planning in the Tahoe Basin. If successful, EIP projects can be quantitatively evaluated for pollutant reduction potential. When applied on a basin-wide scale, direct comparisons can be made between expected load reduction and load reduction required by the TMDL to achieve existing water quality standards. Creation and use of the Lake Tahoe TMDL Implementation Tool Box provides techniques for project implementers and resource agencies to credit activities directed towards meeting allocation requirements. A Pollutant Load Reduction Tracking System with a defined performance evaluation protocol will allow us to adaptively manage by laying out a specific set of issues to consider if load reduction milestones and environmental response milestones are not met.