LAKE TAHOE NUTRIENT AND SEDIMENT TOTAL MAXIMUM DAILY LOAD

SPRING 2004 NEWSLETTER

Nevada Division of Environmental Protection   Lahontan Regional Water Quality Control Board

LAND USE WITHIN LAKE TAHOE BASIN AND ITS APPLICATION TO RESTORING LAKE CLARITY

In order to determine the reductions of fine sediment and nutrient loads necessary to reverse the decline in Lake Tahoe's clarity, it is necessary first to quantify current loading of these pollutants to the lake. Recent Total Maximum Daily Load (TMDL) newsletters have focused on efforts to characterize the many pollutant sources within Lake Tahoe Basin, including atmospheric deposition, groundwater loading and stream channel erosion. Another major source category is surface runoff, or pollutant loading from various land uses, either directly into the lake from storm water runoff or by delivery through the stream network. The following articles describe four research projects that will assist the Lahontan Regional Water Quality Control Board (RWQCB) and Nevada Division of Environmental Protection (NDEP) in determining the pollutant contributions from the primary land uses in the basin. Linking water quality to land use is critical to developing the Watershed Model and simulating the sources and magnitude of runoff to the lake, such that we can plan meaningful control measures to restore lake clarity.

LAND USE REPRESENTATION IN THE LAKE TAHOE WATERSHED MODEL

In support of the Lake Tahoe TMDL, Tetra Tech, Inc. is developing the Lake Tahoe Watershed Model using the Loading Simulation Program in C++ (LSPC), which was described in a previous newsletter (see http://www.swrcb.ca.gov/rwqcb6/TMDL/Tahoe/Winter_2002-03_TMDL_Newsletter.pdf). The watershed modeling system includes algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. Tetra Tech will model pollutant loading from discrete "subwatersheds" throughout the Lake Tahoe Basin.

Land Use Category		Pervious/Impervious
Single Family Residential		Pervious
		Impervious
Multi Family Residential		Pervious
		Impervious
Commercial/Institutional/ Communications/Utilities		Pervious
		Impervious
Transportation		Impervious
		Impervious
Ski Runs		Pervious
		Impervious
Vegetated	Unimpacted	Pervious
	Recreational	Pervious
	Burned	Pervious
	Timber Harvesting	Pervious
	Grazing	Pervious

Table 1. Land use categories represented in Lake Tahoe Watershed Model

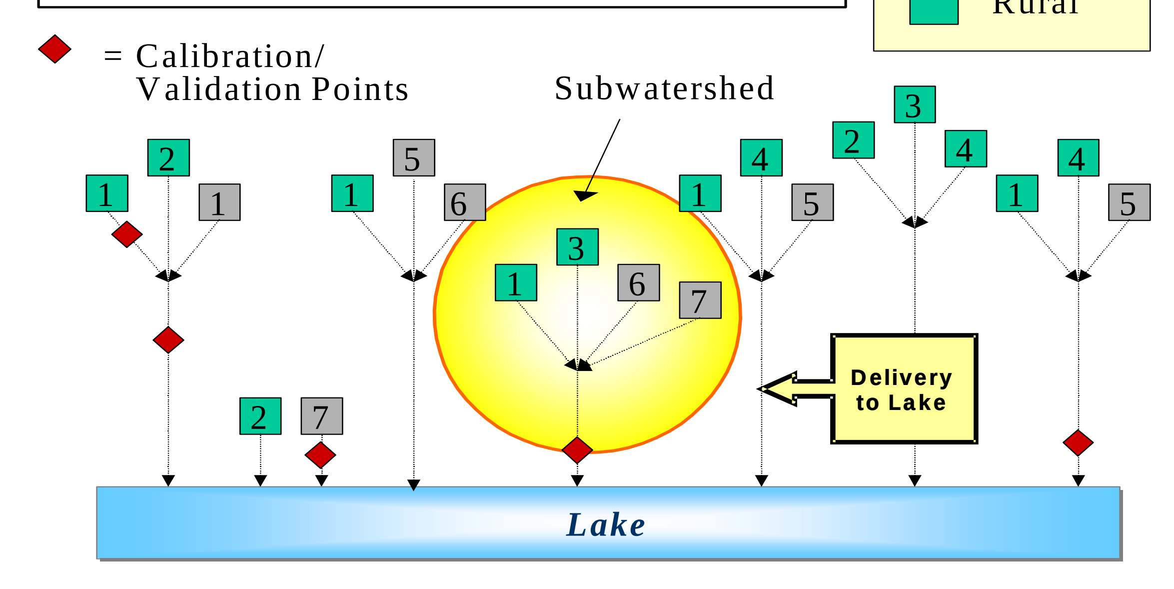
Land use categories are defined in the Watershed Model for purposes of evaluating pollutant loading from the watershed. Table 1 describes each land use category, including pervious and impervious conditions for non-vegetated categories. The total area of each land use category within each subwatershed is computed, and pollutants generated by land use categories are calculated, based on average soil, slope, and other characteristics. Pollutant loads are then routed to a representative stream segment in the subwatershed. The great variation in topography and uses of land within the basin requires that the subwatersheds be small enough to minimize these averaging effects and to capture the spatial variability. Thus, Lake Tahoe's drainage area was divided into 184 subwatersheds, an average of nearly three sub-basins for each of the 63 tributary streams to the lake. Areas between stream mouths that directly drain into the lake ("intervening zones") are modeled as separate areas in each of nine hydrologic zones around the perimeter of the lake. Figure 2 (next page) includes maps of subwatersheds and examples of land uses being represented in the watershed model.

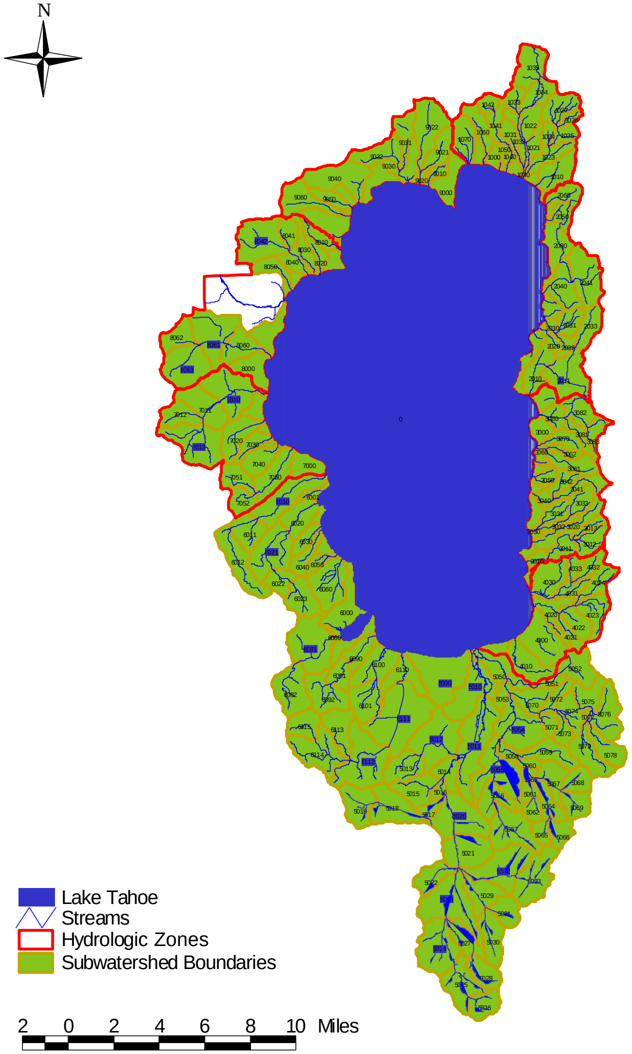
Each land use type is characterized in the model according to an estimated hydrologic and water quality impact. Numerous characteristics affect the amount of pollution generated by each land use type, and additional research is underway to develop more site-specific, localized land use and runoff characteristics, as described in the following articles.

Tetra Tech is currently calibrating and validating LSPC using overall pollutant loadings and concentrations measured at downstream locations that integrate or composite the impacts of numerous land uses above them. The model will then be able to represent existing loads from individual land uses at the subwatershed level, which will be used as a tool to determine load reductions from specific sources that are needed to restore lake clarity.

Figure 1 represents land use and hydrologic routing in LSPC. Rural and/or urban land uses within individual subwatersheds each contribute runoff containing pollutant loads to a stream that flows to the lake. Lands adjacent to the lake contribute pollutants directly to it. The model is calibrated to either historical stream monitoring data, or to data from direct monitoring of stormwater runoff (see following article).

Figure 1: Land use representation (symbolized by numbered boxes) and hydrologic routing (symbolized by lines and arrows) in the Watershed Model.





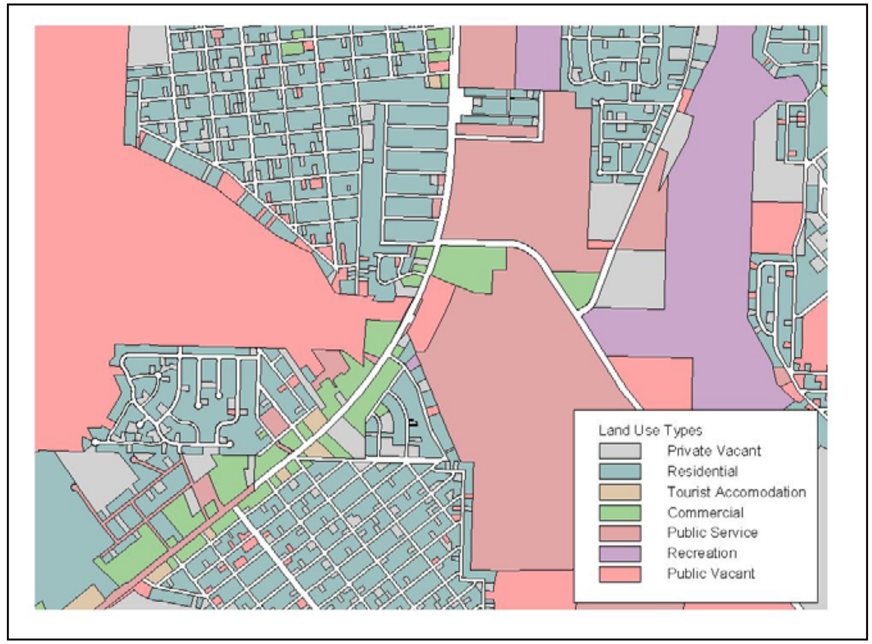


Figure 2. **Development of subwatersheds and land use representation in the Lake Tahoe Watershed Model.** The 184 subwatersheds in the map on the left are classified into nine hydrologic zones (numbered from the 1000s to the 9000s, clockwise from Incline Village to Agate Bay). Each hydrologic zone has one representative intervening zone (numbered 1000, 2000, etc.) that aggregates all areas draining directly into Lake Tahoe within that hydrologic zone. The land use map above shows examples of land use types in the South Lake Tahoe area, which will be further refined using results of IKONOS satellite imagery of impervious surface throughout Lake Tahoe Basin, and combined into the 15 categories listed in Table 1. In each subwatershed, each land use type will be represented by its total area and its average condition for purposes of calculating the quantity and quality of runoff entering the lake.

MONITORING LAKE TAHOE BASIN STORMWATER

Figure 3: The Tahoe Research Group stormwater monitoring team includes, left to right: Raph Townsend, Project Manager Alan Heyvaert, Collin Strasenburgh, Kim Gorman, Kristin Glover, Andrea Parra, and Shawn Beauduy.

Since the early 1980s, the Lake Tahoe Interagency Monitoring Program (LTIMP) has measured streamflow and collected samples for water quality and sediment analyses at up to 35 sites on ten streams in the Lake Tahoe Basin. These ten catchment areas that contribute runoff to the lake include a wide range of soils, vegetation, and land use, and permit water quality managers to estimate directly nutrient and sediment loads from about half of the surface water flow to the lake. However, until now, basin water quality managers and researchers have done only very limited sampling of the contribution of nutrients and sediments from land areas between the tributary streams (referred to as "intervening zones"). Runoff from the intervening zones drains directly to the lake and therefore, is not included in LTIMP stream loading calculations. Some of these areas, particularly in South Lake Tahoe, Tahoe City, and Incline Village, are highly urbanized and are suspected to contribute significantly to lake nutrient and fine sediment loads. Using preliminary data, Jassby et al. (2001) estimated that 30-35% of the total phosphorus load to Lake Tahoe could come from these important intervening zones.

To fill this data gap, the Lahontan RWQCB contracted with a team of researchers from the University of California, Davis Tahoe Research Group and the Desert Research Institute (DRI) to measure storm flows, and to collect and analyze samples of stormwater runoff. The goal of this project is to determine pollutant concentrations from a variety of urban land use types that drain into Lake Tahoe. This information allows us to calculate existing stormwater nutrient and sediment loads that will be used by statisticians and modelers to predict future pollutant loading from different land types within the basin. This information is important to determine areas where nutrient and fine sediment loading will need to be reduced in the future. DRI is also conducting a related study on land use in the Incline Village area that will be useful to TMDL modelers and is profiled in the next article.

Figure 4: Raph Townsend and Andrea Parra admire a new autosampler installed in a weather- and impact-resistant housing for the TMDL stormwater monitoring project.

Figure 5: Shawn Beauduy collects stormwater samples collected at the South Y (SY on map below) monitoring station in March 2004. Each autosampler contains 24 sample bottles. The sampler can be programmed to collect samples of runoff on either a time interval or flow volume interval.

Monitoring stormwater directly, rather than stream flow, presents a number of logistical challenges including selecting and placing sampling equipment, determining when to collect samples so as to comprehensively characterize the volume and quality of runoff, and operating and maintaining the automated equipment in harsh weather conditions and difficult locations.

Samples of runoff are being collected during periods of rain or snowmelt using automated devices known as "autosamplers" (see Figures 4 and 5), which collect precise volumes of water under specific conditions of flow or duration of a runoff event. Autosamplers enable researchers to combine or "composite" a number of samples collected throughout the event, which provides a more representative estimate of pollutant loading than does discrete grab sampling at a snapshot in time during the event. Sixteen autosamplers have been deployed throughout the Basin (see Figure 6) since October 2002 in an attempt to capture spatial variations in runoff quality and quantity due to inherent physical factors such as precipitation, geology, erosion potential, and urbanized land use type. With a high degree of attention and trouble-shooting, each storm that has produced enough runoff to trigger sample collection has been monitored.

Three quarters of the autosamplers currently in place have been operational for at least twelve months, allowing us to begin to understand the variability in runoff throughout the year at those locations. As of the end of January 2004, between 6 and 37 discrete runoff events were monitored at each site (with an average of 20 per site), for durations of between 20 minutes to over one month. Usually, shorter collection periods reflect discrete rain events such as thunderstorms that produce relatively limited flow, whereas extended flow periods are the result of snowmelt and associated episodes of rain-on-snow.

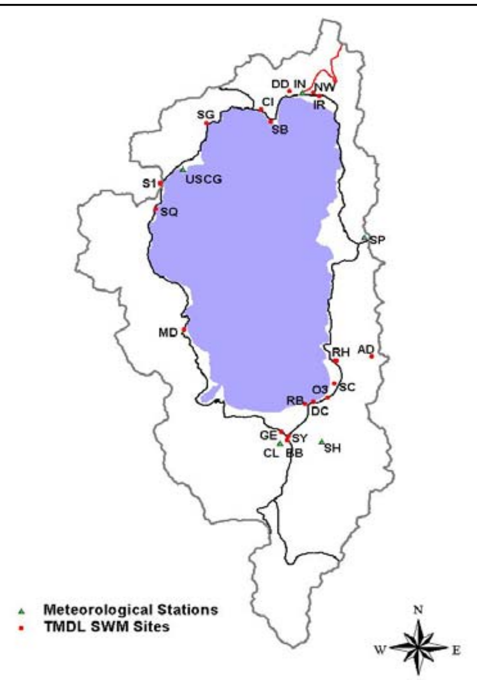


Figure 6: TMDL Stormwater Monitoring (SWM) stations around Lake Tahoe are located in a variety of areas representing residential, commercial and transportation land uses.

During the periods that autosamplers are activated and collecting samples, project researchers must decide how to collect and characterize the runoff that is passing the sampler. Samples are collected for short durations, in which a pump withdraws a specific quantity of runoff from a culvert or other stormwater collection or channeling structure and conveys the water into a separate bottle. Each autosampler contains 24 bottles to obtain samples from different periods of each storm event or various times of day during snowmelt.

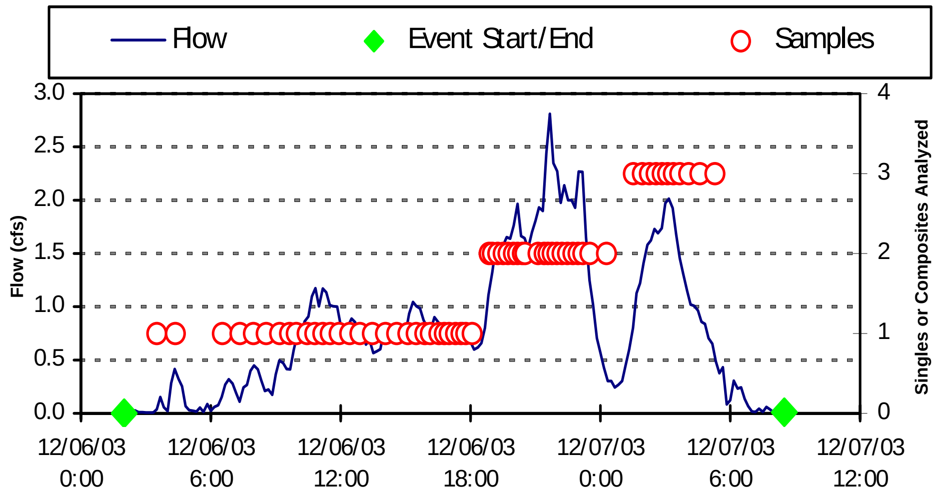


Figure 7: Hydrograph of storm runoff monitored at the South Y station in December 2003. Runoff triggered the start of sampling early in the morning of December 6 and lasted until mid-morning December 7, reaching a peak of nearly three cubic feet per second (cfs). Stormwater samples were collected throughout the storm, enabling researchers to determine variations in runoff quality at different stages of the storm and to calculate an average quality for the entire episode.

Because a classic storm event follows a characteristic pattern of gradual increases in rainfall intensity followed by a maximum or 'peak' and a decline back to dry conditions, a similar response is seen in the accumulated flow of water on the ground during and after a storm (producing a pyramidal hydrograph or record of surface runoff, see Figure 7). In order to properly characterize the loading of nutrients and fine sediment to the lake from these runoff events, it is necessary at each station to monitor both the flow rate and the quality of the water at various points (times) in the hydrograph. This requires anticipating the shape of each storm hydrograph and, ideally, collecting samples at each stage of the storm (during the rising limb, close to the peak, and on the falling limb), which can be achieved by triggering the sampler based either on flow volumes recorded at the sampling station or on specified time intervals throughout the duration of the storm. Either sampling method requires considerable expertise and equipment calibrations to determine how to adequately sample a stormwater runoff event. Sampling of runoff events has improved considerably during the course of the study, as familiarity with each site and its particular runoff patterns is understood. Nutrient and fine sediment samples are composited for each storm event to determine pollutant loading for the entire runoff event. This may involve analyzing all the samples collected during a runoff event and then computing concentrations and flows to determine storm loads (done initially at most sites) or by physically combining the samples (by accounting for runoff volume between samples) to obtain a single, volume-weighted sample for the entire storm event.

Every sample is analyzed for the chemical constituents or physical characteristics crucial to determining the runoff's impact on lake clarity. Dissolved and total nutrients, total suspended solids, turbidity and the size distribution of particles are measured. Particle size distribution analysis is critical because particles smaller than 20 µm in diameter have the most impact on Lake Tahoe clarity. These results are then provided to TMDL project statisticians, who are attempting to correlate storm water runoff quality and fine sediment loads with the predominant urban and vegetated area land types and uses within the basin (see final article), and to the watershed modelers who will use all this information to both reproduce as accurately as possible the basin's past loading characteristics and to predict potential future loading trends. To date, average concentrations have been calculated for all runoff events monitored during Water Year 2003 (October 2002 through September 2003); these will then be multiplied by the total flows recorded during these events to determine pollutant loads at the sampling locations.

LAND USE & WATER QUALITY IN INCLINE VILLAGE WATERSHEDS

Nevada DEP is currently funding a separate TMDL research project to investigate the impacts of specific land uses on nitrogen, phosphorus and sediment loading to Lake Tahoe. This investigation is being conducted by a team from the Desert Research Institute (DRI) in the Incline Creek and Third Creek watersheds, which Rowe et al. (2002) determined to have among the highest combined nutrient and sediment yields of all LTIMP-monitored streams. The watersheds present an ideal opportunity to estimate loadings from specific land uses because a distinct boundary exists between undeveloped forestland in the higher-elevation headwaters and the lower-elevation urbanized commercial and residential areas within Incline Village.

This study complements the urban stormwater monitoring project described previously by characterizing sediment and nutrient loadings from vegetated as well as urban land uses commonly found in the Tahoe basin: undeveloped forestlands, golf courses, ski areas, and residential/commercial areas. Both autosamplers and hand-collected grab samples are being employed at strategic locations above and below these areas. Stream baseflow, summer thunderstorms, rain on snow and snowmelt events are all being sampled (see Figure 8 below).

The information obtained from this study is important because it will yield pollutant loads for land uses for which limited information is available in the Tahoe basin. For example, the study is measuring background loading of pollutants from undeveloped forestland, which comprises 85% of the Lake Tahoe Basin. Furthermore, although pollutant concentration data exist for ski resort and golf course runoff, loading calculations are difficult to derive because flow data were not collected at the time of sampling. Information collected on these land uses in the Incline Creek and Third Creek watershed may be extrapolated to the Lake Tahoe watershed as a whole because the soils are dominated by decomposed granite, the dominant parent material within the Tahoe basin.

The DRI Land Use study is also intended to provide a comprehensive view of nutrient sources and transport pathways by linking streamwater observations with concentrations measured in snow and soils. Atmospheric nutrient deposition is being assessed by measuring concentrations in the snowpack during the spring and in precipitation in the summer and fall. Furthermore, the role of soils as sources or sinks of nutrients is being determined by measuring soil solution chemistry of each land use. Tension lysimeters installed at each land use are sampled monthly for soil water solution. Measurements for various dissolved nutrient species will yield time courses of the major contributors to streamwater chemistry, thus providing a comprehensive view of which sources (and land uses) likely drive streamwater chemistry.

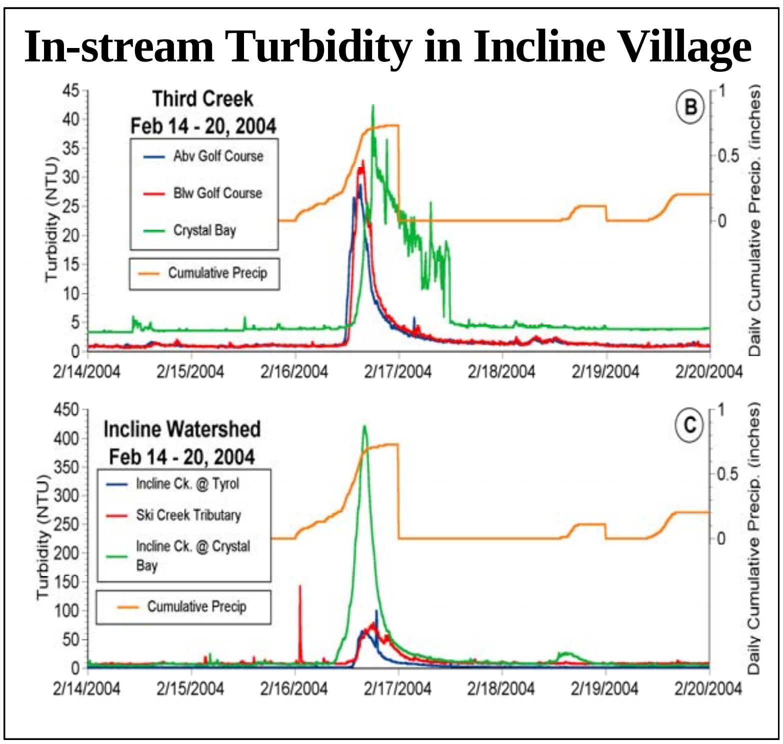


Fig. 8 Continuous turbidity data from Third (B) and Incline (C) Creeks during a winter rain event February 14-20, 2004. Precipitation data is from the Incline Creek Watershed Project's meteorological station (http://www.wrcc.dri.edu/weather/incc.html) located near Tyrol Village.

WATER QUALITY AND WATERSHED CHARACTERISTICS

Dr. Robert Coats, Principal of Hydroikos Associates, is providing a critical component of TMDL research by quantifying relationships between watershed characteristics, including land use, and the loads and concentrations of water quality constituents that impair Lake Tahoe clarity. With quantitative relationships between the most important land uses in the basin and the quality of runoff from them, TMDL researchers will be able to: 1) identify and prioritize problem areas; 2) improve the nutrient and sediment loading budgets for the lake; and 3) provide input data for the Watershed Model (that will also help verify that the model adequately replicates historic watershed conditions).

Two sources of water quality data provide the "dependent variables" (or physical basis) for this statistical analysis. The first source is the Lake Tahoe Interagency Monitoring Program (LTIMP), which samples and continuously measures stream discharge in 20 subwatersheds around the Lake Tahoe Basin. Data collected since 1990 will be included in this analysis. The LTIMP data set provides loads of sediment and nutrients from the primary tributaries that collectively represent about half of surface runoff to the lake, including the Upper Truckee River and Trout, Ward, and Incline Creeks among others. The second data set is provided by the stormwater monitoring program (described in the previous section), which is measuring discharge and collecting water quality samples during hydrologic events at 16 stations around the basin that represent a variety of land uses. This data set for the first time characterizes pollutant loading from the intervening areas that drain directly to the lake without entering the major tributary channels. These two monitoring programs provide flow rate and concentration data for suspended sediments and various forms of nutrients, and combined represent the major components of surface flow to Lake Tahoe. To develop the TMDL, researchers must determine pollutant loads to the lake on time scales of months and years. Loads from the entire watershed can be calculated by combining pollutant concentration data associated with specific land uses with the modeled hydrology (or runoff flow rates) from the various land use categories.

Dissolved Nutrients Forms	NH_4-N	TKN	NO_3-N	SRP
Multiple R^2	0.67	0.64	0.85	0.65
Area, ha	-	-	0	-
Mean Annual Precipitation, cm	-	-	0	-
River Density, km/km2	-	+	+	0
Riparian Rivers, pct.	+	0	0	0
Alluvial rivers, pct	+	0	-	0
Area volcanic soils, pct.	-	0	+	0
Area granitic soils, pct.	0	-	0	0
Average Slope, pct.	+	0	+	0
Soil Index	0	-	0	0
ln(soil index)	-	+	+	-
Low intensity residential, pct.	+	0	0	+
Industrial/transportation, pct.	+	0	+	+

Table 2. Results of multiple regression of discharge-weighted mean concentrations against watershed characteristics, for 19 subwatersheds in the Tahoe basin. A "+" sign indicates a positive effect on the constituent, a "-" sign a negative effect, and a "0", no effect. The multiple R^2 value is a measure of the goodness of fit between the listed watershed characteristics and water quality (a value of 1.0 denotes a perfect correlation).

Using the concentration data described above, the Hydroikos team applied statistical techniques (principal components analysis and multiple regression) to relate discharge-weighted mean pollutant concentrations to watershed characteristics such as soils, geology, precipitation, land use, and other "independent variables" in the 20 LTIMP subwatersheds. Watershed information was derived from an updated version of the Tahoe Environmental Geographic Information System (TEGIS). Table 2 presents results of the analysis for pollutants for which statistically significant relationships with certain watershed characteristics were found, using the LTIMP stream data. Generally, only the dissolved nutrients had multiple R^2 values (measures of the statistical robustness of a relationship) that were significant. The particulate constituents such as total suspended sediment and total phosphorus were generally non-significant. (Note: total Kjeldahl nitrogen or TKN, is composed of both dissolved and particulate fractions). Staff at the Desert Research Institute (DRI) will soon use the results of IKONOS satellite imagery to calculate the percent impervious surface in each of the LTIMP and stormwater sampling catchments. The relationship between water quality and impervious surface will then be statistically evaluated.

Once the stormwater monitoring is complete, a similar statistical analysis will be performed using those results to more quantitatively inform watershed modelers about the relationship between the water quality of urban and non-urban stormwater runoff and land use characteristics.

TMDL TIDBITS

❖ SNAPSHOT DAY 2004

The Lake Tahoe Environmental Education Coalition (LTEEC) has scheduled the fourth annual Snapshot Day in the Lake Tahoe watershed for May 22, 2004. This event mobilizes dozens of citizen-volunteers, working with water quality management agencies including Lahontan RWQCB and NDEP, to gather valuable water quality information in the form of visual assessments, photos, and water quality data. For the second straight year, the data obtained will be applied directly in calculating the TMDL. To join LTEEC's Clean Water Team for stream monitoring and to participate in TMDL research, please contact Heather Segale at (775) 832-4138.

❖ TMDL RESEARCH PRESENTATIONS DURING MAY 17-19 CONFERENCE

A symposium entitled "Research as a Tool in Tahoe Basin Issues - 2nd Biennial Conference on Tahoe Environmental Concerns," is being held May 17-19, 2004, at the Cal-Neva Resort, Spa & Casino. It is being hosted by a variety of academic, government, non-profit and consulting entities, and is coordinated by the Nevada Water Resources Association. The purpose is to provide all groups working on Lake Tahoe Basin issues an opportunity to improve their understanding of what their colleagues are doing by bringing critical issues to the table for discussion. The conference will include technical presentations and posters on TMDL and other research. Summaries of ongoing research will be compiled in a central location for distribution to all interested parties. This symposium intends to educate the interested public about ongoing research and the potential implications for environmental regulation and management in the Basin. For further information, contact donnabloom@charter.net.

❖ TRG PUBLICATION: CLIMATE IMPACTS ON LAKE TAHOE CLARITY

Alan Jassby of the UC Davis Tahoe Research Group (TRG), along with TMDL Research Director John Reuter and Charles Goldman, published an article entitled "Determining long-term water quality change in the presence of climate variability: Lake Tahoe (U.S.A.)" in the December 2003 edition of the Canadian Journal of Fisheries and Aquatic Sciences (see abstract at: http://pubs.nrc-cnrc.gc.ca/cgi-bin/rp/rp2_abst_e?cjfas_f03-127_60_ns_nf_cjfas). This peer-reviewed article begins by observing that Lake Tahoe transparency, as measured by Secchi depth, is extremely variable year-to-year, making it difficult to determine if an observed mean annual Secchi value represents a meaningful change in lake response resulting from pollution control efforts. However, a new TRG statistically-based time series model (different from the Lake Clarity Model) demonstrates that interannual variability in summer lake transparency is largely predicted by differences in annual precipitation as it drives pollutant loading. The model shows that increasing transparency measured during 1999-2001 (and reported in the Winter 2002-03 TMDL Newsletter) was largely climate-driven and does not represent a long-term recovery of the lake. This conclusion did not change when the 2002 and 2003 Secchi depth values were considered. The model also further supports the TRG hypothesis that the long-term declining summer trend is most likely due to inorganic mineral suspensoids originating from the watershed, rather than other sources such as algae growing in the lake (refer to Summer & Fall 2003 Newsletter). This model provides us with a new tool to statistically analyze annual Secchi depth changes to evaluate lake recovery.

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD,
LAHONTAN REGION
2501 Lake Tahoe Boulevard
South Lake Tahoe, CA 96150

Contact Information

Dave Roberts – Project Lead
(530) 542-5469
droberts@rb6s.swrcb.ca.gov

Jack Landy – Development Section Lead
(530) 542-5443
jlandy@rb6s.swrcb.ca.gov

John Reuter – Research Director
University of California Davis
(530) 304-1473
jereuter@ucdavis.edu

Randy Pahl – Nevada Lead
Nevada Division of Environmental Protection
(775) 687-4670
Rpahl@ndep.state.nv.us

Lahontan RWQCB Website
www.swrcb.ca.gov/rwqcb6/

Nevada Division of Environmental Protection Website
www.ndep.state.nv.us