

***Using Science as a Tool in Restoration and Water
Quality Management in the Tahoe Basin***

Lake Tahoe (LTEEC) Higher Education & Research Symposium

May 13-14, 2002

Abstracts Proceedings

M. E. Grismer, M.P. Hogan & H. Segale
LTEEC Higher Education & Research Committee

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PROGRAM

May 13-14, 2002

The **Symposium purpose** is three-fold:

- a) to annually bring together the diverse group of scientists working in the Basin for cross-fertilization of ideas and project discussions;
- b) to collect summaries of ongoing research in the Basin into a central location for dissemination to interested parties; and
- c) to educate the interested public about ongoing research in the Basin.

Monday (May 13)

- 8:30-9:00 **Registration** (North Tahoe Conference Center, 8318 North Lake Blvd, Kings Beach, CA 96143)
- 9:00-9:15 **Opening Remarks** – Symposium Purpose
Organizers – Mark Grismer & Heather Segale
- 9:15-9:45 **Key Management Questions in the Tahoe Basin** - Lauri Kemper
- 9:45-10:00 **Stakeholder Beliefs Regarding Environmental Policy at Lake Tahoe, 2001** - Paul Sabatier, Chris Weible, Maryann Hulsman & Mark Nechodom
- 10:00-10:15 **Numerical Models for Lake Tahoe: Science, Management and Information Transfer** - S. Geoffrey Schladow, Joaquim P. Losada, Francisco J. Rueda, Sveinn Ó. Pálmarsson & Simon J. Hook
- 10:15-10:30 **Particle Fluxes in Lake Tahoe due to Boundary Mixing** - Sveinn Ó. Pálmarsson & S. Geoffrey Schladow
- 10:30-10:45 **Role of Biofilms and Biological Processes in Particle Formation in Lake Tahoe** - Stefan Wuertz, Rachel Terpstra, Don Thompson, Banu Sunman & S. Geoff Schladow
- 10:45-11:00 **Break** (refreshments)
- 11:15-11:30 **Assessing Effects of Reservoir Operations on the Reservoir Ecosystem Using Food Web-Energy Transfer and Water Quality Models** - Laurel Saito, Brett Johnson, John Bartholow & Blair Hanna

Monday (continued)

- 11:30-11:45 **Comparing Lakes Taupo and Tahoe's Physical, Chemical and Political Issues: Can both Areas Learn From Each Other?** - Michael R. Rosen
- 11:45-12:00 **Lake Tahoe Water Budget Estimates: Historical Review and Update** - James C. Trask, Graham E. Fogg & Gayle L. Dana
- 12:00-12:15 **Improved Evaporation Measurements from Lake Tahoe, California** - Gayle L. Dana, James C. Trask & David McGraw
- 12:15-12:30 **Variations in the Near Shore Turbidity at Lake Tahoe** - Kendrick Taylor
- 12:30-1:30 **Lunch** (provided at Center)
- 1:30-1:45 **A 7000 Year Record of Sediment Accumulation from Lake Tahoe** - David Osleger, Joseph Stoner, Alan Heyvaert & Kenneth L. Verosub
- 1:45-2:00 **Paleolimnological Reconstruction of Baseline Conditions and Ecosystem Response to Anthropogenic Disturbance in the Tahoe Basin** - Alan C. Heyvaert, John E. Reuter, Charles R. Goldman & David N. Edgington
- 2:00-2:15 **Conserving the Lake Tahoe Basin's Biological Diversity: Landscape-scale Considerations and Questions** – P. N. Manley & D. D. Murphy
- 2:15-2:30 **A Landscape-scale Approach to Monitoring Bat Species in the Lake Tahoe Basin: A Work in Progress** - Michelle McKenzie, Ted Weller & P. N. Manley
- 2:30-2:45 **Bioassessment in the Lahontan Region of California** - Thomas J. Suk & D.B. Herbst
- 2:45-3:00 **Break** (refreshments)
- 3:00-5:00 **Field Trip to Restoration Sites** – Michael Hogan, Integrated Environmental Services

Tuesday (May 14)

- 8:00-8:15 **Registration** (North Tahoe Conference Center, Kings Beach)
- 8:15-8:30 **A Modeling Study of Nitric Acid Deposition to the Lake Tahoe Basin** - Jülide K.Koraën, Leland W. Tarnay & Alan W. Gertler
- 8:30-8:45 **Sources of Atmospheric Dry Deposition of Inorganic Nitrogen in the Lake Tahoe Basin** - Leland W. Tarnay & Alan W. Gertler
- 8:45-9:00 **Aircraft Measurements of Nitrogen and Phosphorus in and Around the Lake Tahoe Basin** - Cort Anastasio, Qi Zhang, J. J. Carroll & A. J. Dixon
- 9:00-9:15 **Characterizing Impacts of Snowmobile Emissions on the Winter Environment and Watershed** - Mark R. McDaniel
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Tuesday (continued)

- 11:45-12:00 **The Lake Tahoe Nutrient and Sediment TMDL: An Overview of the Coordinated Restoration Planning Process** - Jeremy Sokulsky
- 12:00-1:00 **Lunch** (provided at Center)
- 1:00-1:15 **Sediment and Nutrient Monitoring and Modeling in Trout Creek, Lake Tahoe, California** - Katrina Smolen
- 1:15-1:30 **Quantifying Erosion Sediment Yield and Infiltration on Disturbed Steeply Sloping Soils Following Revegetation** - M. E. Grismer, M.P. Hogan & Vic P. Claassen
- 1:30-1:45 **A Soil Resource Evaluation Process for Identifying and Remediating Plant-growth Limiting Conditions on Drastically Disturbed Sites** - Vic P. Claassen
- 1:45-2:00 **The Source Control Demonstration and Development Program: An Adaptively Managed Program for the Control of Erosion in the Lake Tahoe Basin** - Michael Hogan
- 2:00-2:15 **Hydrology Tools for Mere Mortals** – Jeff Wallace
- 2:15-2:30 **Tahoe Integrated Information Management System** – Tricia York
- 2:30-3:00 **Break** (refreshments)
- 3:00-4:45 **Panel Discussion – Where will the Tahoe Basin be in 2030?**
Moderator: Mark Grismer
Members: John Cobourn, UN- Cooperative Extension
 Charles Goldman, UC Davis Tahoe Research Group
 Carl Hasty, Scientific Advisory Group, TRPA
 Mike Hogan, Integrated Environmental Services
 Laurie Kemper, Lahontan Regional WQ Control Board
 Mark Nechodom, USFS Sierra Nevada Research Center
- 4:45-5:00 **Closing Remarks**

Key Management Questions in the Tahoe Basin

Laurie Kemper

Lahontan Regional Water Quality Control Board, 2501 Lake Tahoe Blvd.

South Lake Tahoe, California 96150

E-mail: lkemper@rb6s.swrcb.ca.gov

The Tahoe Basin Scientific Advisory Group (SAG) and other resource agency and research staff compiled a detailed list of management issues and questions of importance in the Basin. Addressing these questions is critical towards development of effective management strategies that will at least maintain, or better yet, restore the Basin ecosystem in a sustainable manner for generations to enjoy. The management questions are broadly categorized into four different areas including;

- a) Lake clarity, air quality and water quality,
- b) Forest health and biodiversity,
- c) Socio-economic factors, and
- d) Adaptive management.

Aspects of each of these four areas is considered in this Symposium and is reflected in the range of titles of the various presentations. Issues affecting Lake clarity and air & water quality requiring further study are;

- Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?
- What methods are available for reducing sediment inputs into the lake, and how can the greatest reduction be accomplished in the shortest time period?
- What and where are the sources of these pollutants and in what quantities and relative contributions are they entering Lake Tahoe? (What are the watershed loadings? Within each watershed, what are the major sources?)
- What spatial and temporal factors affect the deposition of air pollutants to the lake and forest, and ultimately how do these pollutants contribute to lake clarity reduction?

Issues affecting forest health and biodiversity requiring further study include;

- What constitutes a “healthy”, ecologically sustainable forest ecosystem that most closely reflects pre- settlement conditions, and how do we best achieve it given the current and foreseeable development at Lake Tahoe?
- What constitutes “healthy” and ecologically sustainable aquatic, riparian, and meadow ecosystems in the basin, and how do we achieve them?

Issues affecting socio-economic conditions in the Basin requiring further study include gaining a better understanding of how recreation, ecosystem restoration, environmental quality and community health are inter-related and best managed. Finally, adaptive management is a crucial process in the Basin and how can we focus and coordinate scientific research, monitoring and modeling activities among all of the agencies working at Lake Tahoe to yield the most important information in the shortest time at the lowest cost? What role should research, modeling and monitoring play in adaptive management? And in the end, how should the results of adaptive management be used to affect thresholds, standards and procedures?

Stakeholder Beliefs Regarding Environmental Policy at Lake Tahoe, 2001

Paul Sabatier¹, Chris Weible¹, Maryann Hulsman¹ and Mark Nechodom²

Department of Environmental Science & Policy¹

University of California, Davis, CA 95616

Telephone (530) 752-8898 and (530) 752-3074, E-mail: pasabatier@ucdavis.edu

²U.S. Forest Service, University of California, Davis, CA 95616

Abstract: This marks the initial presentation of partial results from our Fall 2001 survey of environmental policy participants in the Tahoe Basin (n=365, response rate=56%). We present descriptive data concerning the views of various stakeholder categories regarding (1) basic policy orientations, (2) perceived seriousness of various problems, (3) preferred management strategies, and (4) policy preferences regarding water quality and transportation. The results show that water quality and transportation remain the two most important perceived problems in the Basin, with fire hazards ranked as third. In addition, there is widespread support for collaborative policy processes and for the use of transferable development rights.

Numerical Models for Lake Tahoe: Science, Management and Information Transfer

S. Geoffrey Schladow¹, Joaquim P. Losada¹, Francisco J. Rueda², Sveinn Ó. Pálmarsson¹ and Simon J. Hook³

¹Department of Civil & Environmental Engineering, Environmental Dynamics Laboratory
University of California, Davis, CA 95616

Telephone (530) 752-6932, Email: gschladow@ucdavis.edu

²School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853

³Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

In the last 5 years a suite of numerical models has been under development for application to Lake Tahoe. These models range from one-dimensional management models that are capable of making long term predictions of changes in the lake's clarity, to three-dimensional scientific models which seek to better understand the details of the lake's complex motions, to "now-casting" models which will integrate remotely sensed data with telemetered on-lake data systems to provide real-time predictions of wind, surface currents, algal concentration and contaminant transport.

DLM-WQ is a deterministic model describing changes in the clarity of Lake Tahoe. The model describes the vertical mixing processes in the lake in response to daily meteorological forcing, the daily loadings of nutrients and particles from streams, groundwater and the atmosphere, and the growth and fate of algae (chlorophyll) in response to these nutrients and the ambient light field. The vertical distribution of algae and particles determine the light absorption and scattering, which is calculated by the model, and is then used to make a prediction of lake clarity over time. The model may be used to evaluate the consequences of management practices, nutrient loads, climatic conditions etc. on lake clarity and other water quality parameters.

SI3D-L is a three-dimensional hydrodynamic and temperature transport model, which has been used to identify and analyze the complex internal wave field that exists in Lake Tahoe. To date, at least 4 distinct internal wave modes have been identified using the model, each of which has subsequently been verified to exist by in-lake data collection. The importance of internal wave interactions with the boundaries of the lake is presently being investigated. The model is also used to study the importance of upwelling events on Tahoe's clarity.

3D-NOW is presently under development. Using meteorological data that is telemetered to UC Davis and JPL from a series of on-lake and shoreline measurement stations, a real time, interpolated wind field over the lake will be developed. This wind field will be used to "drive" a modified version of SI3D-L in real time. The predicted surface currents and the wind field will be publicly available on the Internet. Near daily remotely sensed data, as well as lake profile data will be used to continuously re-initialize and validate the model, and to provide maps of chlorophyll distribution.

Particle Fluxes in Lake Tahoe due to Boundary Mixing

Sveinn Ó. Pálmarsson and S. Geoffrey Schladow

Environmental Dynamics Laboratory, Department of Civil & Environmental Engineering,

University of California, Davis, CA 95616

Telephone (530) 752-9482, E-mail: sopalmarsson@ucdavis.edu

Recent studies have demonstrated the importance of various particles, including fine inorganic particles, to Lake Tahoe's clarity. Understanding the mechanisms by which particles are introduced and maintained in the aquatic system is fundamental for determining their impact on water clarity and the fate and transport of particle bound nutrients and contaminants.

Internal waves, generated by wind acting on a density-stratified lake, produce a velocity shear at the water-sediment boundary. Along with the transfer of energy from the internal wave field to turbulence, through wave steepening and breaking, these processes may lead to the resuspension of sediment back into the water column, where nutrients may become more biologically available. Lake Tahoe, California-Nevada, is a large pristine freshwater lake that is very deep and facilitates a highly energetic internal wave field with extremely great vertical oscillations of the basin-scale waves.

A collaborative field program, was undertaken by UC Davis, UC Santa Barbara and Stanford University at Lake Tahoe during September 2001. The program was designed to address the transfer of energy from the internal wave field to turbulence over sloping bottoms and topographic features. This involved the monitoring of internal wave shearing and breaking at the lake boundary, and the associated particle fluxes. A variety of instruments were deployed at a site on the western slope of the lake, and temperature chains were deployed around the lake perimeter and in the central basin. The experimental setup that contributed directly to the monitoring of particle fluxes included deployments of both high- and low-resolution thermistor arrays that recorded temperature for estimates of density dynamics, acoustic Doppler velocity meters to record water velocity, and optical beam attenuation and backscatter sensors for the direct measurement of particle dynamics. An intensive full water column profiling program was implemented, with recorded parameters such as temperature, radiance and irradiance, optical beam attenuation and backscatter and chlorophyll fluorescence.

Our results show that direct wind forcing and shearing of basin-scale waves, having periods from a few hours to a few days, are controlling factors for particle resuspension and the particle concentration dynamics within and above the bottom boundary layer. The basin-scale internal wave climate in the lake changes with seasons and variable meteorological conditions, since the density structure is modified and the frequency of the wind forcing may be different. Nevertheless, intensive internal wave oscillations are expected throughout the year in Lake Tahoe, with fluxes of particles over the sloping bottom.

Role of biofilms and biological processes in particle formation in Lake Tahoe

Stefan Wuertz, Rachel Terpstra, Don Thompson, Banu Sunman and Geoff Schladow
Department of Civil and Environmental Engineering
University of California, Davis, CA, 95616
Telephone (530) 754-6407, E-mail: swuertz@ucdavis.edu

During the last 40 years, escalating sediment and nutrient loads in Lake Tahoe are believed to have caused it to become progressively more turbid. The University of California-Davis has embarked on a new project to study particles, aggregation and clarity in Lake Tahoe. The Tahoe Clarity Model predicts long-term effects of mitigation efforts and can be used to determine the total maximum daily load (TMDL) of sediments and nutrients. This work will augment the model by providing more detailed information about particle size distribution, aggregation, flocculation, and sedimentation.

The focus of our study is two-fold involving (1) the collection of undisturbed particle “flocs” using sediment traps and their analysis using a range of microbiological techniques and particle imaging techniques, and (2) the collection of actively growing biofilms (that is, microorganisms and their extracellular products forming at interfaces) from within the lake and their analysis using a range of microbiological and particle imaging techniques. The basic research question is to what extent biota and biological processes may account for increasing turbidity in Lake Tahoe.

(1) Water samples from Lake Tahoe are analyzed for the presence of particulate biota or biogenic components of aggregates. We use a FACSCalibur flow cytometer for particle size distribution and apply fluorescent DNA stains to visualize the biota. Once the presence of microbial cells has been confirmed, molecular biology techniques such as fluorescent in situ hybridization (FISH) are applied to further characterize any organisms present.

(2) Biofilms may coat particles entering the lake and subsequently play an important role in promoting and mediating the particle aggregation and enhanced settling. Their importance is investigated both in the field and in the laboratory. Sediment traps which will be modified to include collection of “undisturbed” particle aggregates using acrylamide gels to capture “undisturbed” aggregates will be installed adjacent to two existing vertical arrays in the lake at the index (120 m depth) and mid-lake (460 m depth) stations. The acrylamide gel aggregates (i.e. the undisturbed aggregates) will be subjected to detailed microscopic analysis. They will be sized using a combination of light microscopy and digital image analysis. Selected flocs in certain size fractions will be analyzed by confocal laser scanning microscopy to determine their three-dimensional physical structure. To grow biofilms in a natural setting, a taut line mooring will be installed in the lake near the present mid-lake station and near the present index station with small strips of polycarbonate attached. These polycarbonate strips provide a substrate for the subsequent growth of the biofilms. Microbial community analysis using FISH will show whether the microorganisms found in biofilms reflect those seen in flocs.

Assessing Effects of Reservoir Operations on the Reservoir Ecosystem Using Food Web-Energy Transfer and Water Quality Models

Laurel Saito¹, Brett Johnson², John Bartholow³, and Blair Hanna⁴

¹Environmental and Resource Sciences Department, University of Nevada-Reno/MS 186,
1000 Valley Road, Reno NV 89512

Telephone (775) 784-1921, E-mail: lsaito@cabnr.unr.edu

²Fishery and Wildlife Biology Department, Colorado State University, Fort Collins, CO 80523

³USGS, Midcontinent Ecological Science Center, 4512 McMurry Ave, Fort Collins, CO 80525

⁴Civil Engineering Department, Colorado State University, Fort Collins, CO 80523

A linked modeling approach was used to investigate the effects on the reservoir food web as a result of a new temperature control device (TCD) on the dam at Shasta Lake, California. The linked modeling approach used a two-dimensional reservoir water quality model (CE-QUAL-W2) to predict operation-induced changes in phytoplankton production. A food web-energy transfer model was used to propagate predicted changes in phytoplankton through the food web to the predators and sport fishes of interest. Stable isotope analysis provided an efficient and comprehensive means of estimating the reservoir's food web structure with minimal sampling and background data. An optimization procedure was used to simultaneously estimate the diet proportions of all food web components from their isotopic signatures. This linked modeling approach demonstrated the value of interdisciplinary efforts to address concerns that the individual models could not have dealt with separately. Potential uses for linked modeling and food web analysis using stable isotopes in the Tahoe Basin and adjacent areas will also be discussed.

Comparing Lakes Taupo and Tahoe's Physical, Chemical and Political Issues: Can both Areas Learn From Each Other?

Michael R. Rosen

Institute of Geological & Nuclear Sciences, Wairakei Research Centre, Taupo, New Zealand

Present address: Nevada Basin and Range Study Unit Chief,

U.S. Geological Survey, 333 West Nye Lane, Carson City NV 89706

Telephone (775) 887-7683, E-mail: mrosen@usgs.gov

Lake Taupo is New Zealand's largest lake (area of lake: 616 km²; maximum depth: 198 m). It was formed as a volcanic explosion crater approximately 1800 year ago, although precursor lakes have existed in the basin for up to a million years. It is comparable in size and depth to Lake Tahoe and has also experienced a recent decline in water clarity caused by anthropogenic modifications to the watershed as a whole. The Lake Taupo region is a tourist destination for both domestic and international tourists (although domestic tourism accounts for 80% of the people who visit the lake annually). Politically, there is a strong local ethic to try to manage the lake sustainably and prevent further degradation of water quality in the lake, but there are many competing views on how this should be done and what controls should be placed on land use practices in the basin to achieve this goal. There is also a strong cultural attachment to the lake by New Zealand's indigenous Maori population (Tuwharetoa Tribe) who own the bed of the lake. The lake and its tributary streams are also an internationally renowned trout fishery.

Current research at Lake Taupo has focused on nitrogen inputs from various land uses around the lake. The lake is thought to be nitrogen limited due to abundant phosphorus available from volcanic rocks that dominate the geology of the basin. The major land uses in the basin that contribute nitrogen to the lake include, exotic pine forestry, sheep and cattle farming, increasing urbanization (including storm water runoff), native vegetation, and hydropower developments. There is currently a trend to convert non-irrigated sheep and cattle farms to dairy farms. The likely result of such conversions would be to increase the nitrogen load to the lake.

Evidence from stream monitoring indicates that some rivers have increasing trends in nitrogen concentrations particularly in farming areas. Although surface water volumes account for 95% of the water budget for the lake, it has been calculated that between 20-30% of the mass load of nitrogen comes from cold ground water sources. In addition age dating of one stream in a pasture-dominated catchment suggests that the base-flow water (ground water component) is more than 30 years old. This indicates that nitrogen concentrations will increase for many years to come even if nitrogen inputs were "turned off" immediately.

The experiences gained at Lake Taupo are valuable from both a scientific and political perspective. From the scientific viewpoint, it is important to consider all potential sources of loads to the basin on a mass load basis. Even though input volumes may be low, the mass load may be high. Politically, there are many of the same sorts of community, scientific and political groups at both Tahoe and Taupo. The Tahoe situation is complicated by many levels of local, state and federal agencies. Trying incorporating Maori cultural values into European-based scientific assessments of the lake complicates the Taupo situation. This presentation will try to illustrate how lessons from each situation can be utilized to further both the ecosystem and political sustainability of both lake basins.

Lake Tahoe Water Budget Estimates: Historical Review and Update

James C. Trask¹, Graham E. Fogg¹, Gayle L. Dana²

¹Hydrologic Sciences, Dept. of Land, Air and Water Resources

University of California, Davis, CA 95616

Telephone (530) 756-3244, E-mail: jctrask@ucdavis.edu

² Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512

For over 100 years, many studies have estimated the magnitudes of water budget components for the Lake Tahoe basin. These estimates differ in: (a) time period over which the water budget estimate was made, and/or (b) measurements & methods used. All published reports on the Lake Tahoe water budget have large uncertainties implicit in estimates of groundwater inflow and evaporation, due to lack of adequate reliable measurements. Within the last few years, several research groups have been performing measurements directed at or pertinent to Lake Tahoe evaporation. This makes possible the first reliable measurement-based estimates of seasonal and annual Lake Tahoe evaporation, which in turn allows the water budget to be better constrained.

We will briefly compare pertinent studies conducted over the last 100 years that include estimates of Lake Tahoe water budget components. Uncertainty in magnitudes of component estimates will be discussed. Two new independent estimates of Lake Tahoe evaporation rate will be presented, based on (1) recent pan measurements from a well-exposed pan, and (2) recent measurements of humidity and wind speed, applied to a previously published energy budget investigation. Lake Tahoe pan evaporation measurements and lake evaporation estimates will be compared with other pan measurements and lake and reservoir evaporation estimates that have been performed in the Sierra Nevada. Updated water budget estimates will be presented for Lake Tahoe, the watershed, and the Tahoe Basin as a whole.

Improved Evaporation Measurements from Lake Tahoe, California

Gayle L. Dana¹, James C. Trask² and David McGraw³

¹Division of Hydrologic Sciences, 2215 Raggio Parkway, Reno, NV 89512

Telephone (775) 674-7538, E-mail: gdana@dri.edu

² Hydrologic Sciences, University of California, Davis, CA 95616

³ Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512

Accurate measurements of evaporation are important to management of water storage as well as to understanding turnover and nutrient storage in lakes. Evaporation has been a poorly constrained component of past water budget studies of Lake Tahoe, California and is the last major unknown for effective management of the Truckee River basin under the Truckee River Operating Agreement (TROA). Evaporation has traditionally been calculated as a residual from the water budget or estimated from a class-A standard evaporation pan on the west shore of Lake Tahoe at Tahoe City. However, as estimates of lake evaporation, both methods are unreliable. This is because the groundwater portion of the water budget is also not well known and the pan data are suspect due to progressive shading and sheltering over the years due to the growth and maturity of trees between the pan and the lake. In addition, the pan location has been moved four times since its initial setup in the early 1900's.

In order to obtain good evaporation rates from Lake Tahoe two studies of evaporation were conducted from September 1999 to December 2000. The first study was designed to obtain the best possible, and first year-round measurements of evaporation using eddy correlation techniques. The second study was designed to determine the accuracy of evaporation estimates obtained from the Tahoe City evaporation pan measurements. Evaporation was measured with a class-A standard evaporation pan placed in a location with minimal shading and wind obstruction. We will report on year-round evaporation rates measured from Lake Tahoe and examine the reliability of recent and historic evaporation pan measurements from the lakeshore. We will also discuss future evaporation measurements planned for use in TROA.

Variations in the Near Shore Turbidity at Lake Tahoe

Kendrick Taylor

Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512

Telephone (775) 673-7375, E-mail: Kendrick@dri.edu

The clarity of Lake Tahoe is most obvious within 300 m of shore in what we call the near shore zone. Except for atmospheric deposition, all the clarity degrading material such as nutrients and particles that enter the lake pass through the near shore zone, making the near shore zone a good place to search for undesirable inflows to the lake. The near shore zone is the portion of the lake first impacted by disturbances on shore, and will be the portion of the lake that responds first to restoration activities. The clarity of most of the near shore zone cannot be measured with a secchi disk because the water is not deep enough. Clarity can also be described in terms of turbidity, which is a quantitative measure of how much light is scattered by the particles in a water sample. Water with a high turbidity is murky and has a low clarity. We have developed a system to make turbidity measurements from a moving boat, which allows us to efficiently map the distribution of turbidity in the near shore zone.

In our surveys turbidity measurements are typically taken about every ten meters around the entire lakeshore. The samples are collected from a depth of one meter about 50 to 200 m offshore. The one survey we did shortly after spring runoff did not show high turbidity levels near streams outlets. An intense summer thundershower on the northeast portion of the lake did not have any influence on the turbidity in the lake despite causing erosion along the highway. Several surveys show a close correspondence between high turbidity near the shore in summer and development on shore. The areas of the lake that have the highest turbidities are Tahoe City/Lake Forest, Kings Beach, Incline Village, South Lake Tahoe, and Tahoe Keys. In the late winter the turbidity is consistently high off South Lake Tahoe and Tahoe Keys, occasionally high off Kings Beach and Incline Village, and low around the rest of the lake. Detailed turbidity surveys in the Tahoe City area suggest that small portions of the shoreline may contribute a disproportionately large amount of clarity reducing material to the lake.

The area off Tahoe Keys has a turbidity that is typically 4 to more than 10 times greater than other portions of the lake. Turbidity values in excess of the TRPA water quality standard of 1 NTU for areas not influenced by streams (TRPA WQ-1) have been observed in the lake offshore Tahoe Keys.

The results suggest that most of the clarity loss is associated with a few areas and that restoration efforts will be most effective when they concentrate on these areas.

Results from this project can be obtained at <http://www.dri.edu/projects/tahoenearshore>.

A 7000 Year Record of Sediment Accumulation from Lake Tahoe

David Osleger¹, Joseph Stoner², Alan Heyvaert³, Kenneth L. Verosub⁴

¹Geology Dept., University of California, Davis, CA 95616

Telephone (530) 754-7824, E-mail: osleger@geology.ucdavis.edu

²Dept. of Geological Sciences, Univ. Colorado, Boulder, CO 80309

³Tahoe Research Group, Center for Ecological Health Research, University of California, Davis

⁴Dept. of Geology, University of California, Davis, CA 95616

Two piston cores were collected from the southern and northern basins of Lake Tahoe with the intent of obtaining the Holocene history of sediment accumulation. The core from the southern basin (146 cm in length) was collected in 424 m of water and the one from the northern basin (170 cm) was retrieved from a depth of 469 m. Though no tephra was found in either core, the Tsoyowata ash bed (7015±45 years B.P.) was found in a companion core 3 cm below the base of the southern basin core, providing an initial age marker for these sediments. A variety of analyses were done on these sediments at high-resolution sampling intervals. These include 1) particle-size analysis by laser diffraction, 2) paleomagnetic and environmental magnetic measurements, 3) total organic carbon (TOC), and 4) ¹³C of the organic carbon component. X-radiographs were taken of the split cores and select samples were analyzed for their petrographic characteristics. Six radiocarbon dates were determined from pine needles, charcoal and small twigs found in the sediment.

The radiocarbon dates indicate long-term sedimentation rates of ~25 cm/ky for the compacted sediment. The sediments below about 50 cm may be compacted by a factor of 2 to 3, based on comparisons with similar lacustrine settings, so decompacted sedimentation rates may be 2 to 3 times higher. The grain-size data, determined at 1 cm intervals, exhibit a background sedimentation dominated by coarse silt that is interspersed with centimeter-scale pulses of coarser material ranging up to fine and medium sands. The pulses of coarser grains exhibit relatively sharp bases, graded beds, low-angle crossbedding and abrupt shifts back to finer grain sizes, suggesting rapid deposition by turbidity currents. These turbidite intervals are matched by comparable pulsed increases in ¹³C_{org} and magnetic susceptibility, and by abrupt decreases in TOC.

A central question in this study is whether the turbidites were seismically generated or are related to storm runoff following intense episodes of rainfall. Based on several lines of evidence, we have developed a preliminary model which suggests that the majority of the turbidites represent responses to storm runoff. For example, even though the bases are sharp relative to the background record of accumulation, almost all of the turbidites show a gradual coarsening upward trend over the basal few centimeters. We interpret this as reflecting a gradational increase in storm intensity and runoff with time. The corresponding increases in magnetic susceptibility likely reflect increased concentrations of ferrimagnetic material derived from terrigenous sources. The coincident enrichment in ¹³C_{org} and concomitant reduction in TOC could well be due to the isotopic signature of terrigenous plant debris arriving with storm runoff and the dilution of background organic concentrations, respectively. These preliminary results provide new information about the Holocene paleoclimatic history (and perhaps the paleoseismic history) of the Lake Tahoe watershed. The variety of measurements in this study also provides a long-term dataset for comparison with parameters determined from modern Lake Tahoe.

Paleolimnological Reconstruction of Baseline Conditions and Ecosystem Response to Anthropogenic Disturbance in the Tahoe Basin

Alan C. Heyvaert, John E. Reuter, Charles R. Goldman and David N. Edgington

University of California at Davis, Tahoe Research Group

PO Box 633, Tahoe City CA 96145

Telephone (530) 583-3279, E-mail: acheyvaert@ucdavis.edu

Ultra-oligotrophic Lake Tahoe is one of the largest, deepest, and clearest subalpine lakes in the world. Unfortunately, both atmospheric pollution and urban development currently threaten the pristine quality of this unique environmental resource. Although routine monitoring of water quality characteristics in this lake has been continued for over 30 years, these data cannot address the impact from historical perturbations, such as extensive clear-cut logging in the late 1800s. Paleolimnological techniques, on the other hand, provide a scientific basis for assessing pre-disturbance baseline conditions and for understanding system response to historical disturbance. In Lake Tahoe the sediment chronologies reconstructed from event related markers, carbon-14 dates, and lead-210 dating indicate that logging era sedimentation rates increased approximately seven to twelve fold over pre-disturbance rates. In contrast, during the period of recent urbanization these sedimentation rates appear to have been about four times higher than during the pre-disturbance period. Between these two events was a period of recovery, evidenced by reduced sedimentation rates that approached baseline rates. Since diatoms dominate the Lake Tahoe phytoplankton, historical rates of primary production were reconstructed from biogenic silica profiles. Notably, for that interval between clear-cut logging and urbanization the concentrations of biogenic silica decrease, and rates reconstructed for primary production are only slightly greater than baseline rates. This suggests that Lake Tahoe responds at a decadal scale to reductions in nutrient loading, despite its long hydraulic retention of about 650 years. Contemporary efforts at mitigation, therefore, could be expected to show beneficial effect within a similar time frame.

Conserving the Lake Tahoe Basin's Biological Diversity: Landscape-scale Considerations and Questions

Patricia N. Manley¹, Dennis D. Murphy²

¹USDA Forest Service, R&D/WRWAR Staff, Rosslyn Plaza C, 4th Floor
1601 N. Kent St., Arlington, VA 22209

Telephone (703) 605-5294, E-mail: pmanley@fs.fed.us,

²Research Professor of Biology, University of Nevada, Reno, NV 89557

Strong topographic demarcation of the basin, the natural fragmentation of habitats around the basin, and historic and current disturbance levels within the basin make it vulnerable to the erosion of biological diversity. We are beginning a research project to investigate the relationship between biological diversity and the size, isolation, and disturbance of individual terrestrial habitat patches to biological diversity throughout the basin. We will be investigating a range of taxa, including birds, mammals, plants, and some invertebrates. We are currently working on finalizing the study design, including building a predictive model of the status of biological diversity at the patch and landscape scales which we will then test and refine over the course of the study. Testing and refining the model will provide insights into the primary disturbance factors affecting biological diversity and highlight management options that will lead to its conservation and restoration. We expect to be able to develop models that can be used to predict the consequences of development scenarios on species persistence and biological diversity and to predict the consequences of acquisition and restoration scenarios on the same. In so doing, we may be able to identify species at risk or strong indicator species based on their vulnerability to fragmentation that may be useful for the purposes of monitoring biological diversity.

A Landscape-scale Approach to Monitoring Bat Species in the Lake Tahoe Basin: A Work in Progress

Michelle McKenzie¹, Ted Weller¹, Patricia N. Manley²

¹Redwood Science Laboratory, 1700 Bayview Dr., Arcata, CA 95521

Telephone (707) 825-2924, E-mail: mmckenzie@fs.fed.us

²USDA Forest Service, R&D/WRWAR Staff, Rosslyn Plaza C, 4th Floor
1601 N. Kent St., Arlington, VA 22209

Awareness and understanding is emerging regarding the important role that bats play in ecosystems and the ecological services they provide. Populations of some species in the Sierra Nevada may be declining, and they are rarely acknowledged in land management plans and assessments because so little is known about their distributions, population status, and habitat associations. Bats are particularly vulnerable to land management practices and development because of their communal roosting and nursery habits, their association with aquatic ecosystems, and their insectivorous food habits. In the Lake Tahoe Basin, forest and riparian ecosystems have been highly altered over the past 150 years, and future activities promise to continue to alter these systems. Monitoring bat populations in the Basin would serve to provide valuable information about bats as well as environmental conditions. Typically, bat species composition is described from surveys at a non-random selection of sites and population trends are estimated by monitoring number of individuals at roost sites. However, a systematic, probabilistic approach can provide information on spatio-temporal changes in populations, habitat associations, and potential causal factors for observed changes. We are in our second year of testing a systematic, landscape-scale approach to monitoring bat populations using mist-nets and acoustic recordings. In 2001, we surveyed 36 sites along the western flank of the Sierra Nevada, with the highest elevation sites occurring in the Basin. In 2002, we will be surveying an additional 72 sites in the Basin. Preliminary results provide insights to how to optimize detectability and efficiency. Monitoring results over the next 3 years promise to provide valuable information on species composition, frequency of occurrence, probability of detection, and habitat associations of bats in the Lake Tahoe Basin.

Bioassessment in the Lahontan Region of California

Thomas J. Suk¹, David B. Herbst²

¹Lahontan Regional Water Quality Control Board, 2501 Lake Tahoe Blvd.

South Lake Tahoe, California 96150

Telephone (530) 542-5419, E-mail: tsuk@rb6s.swrcb.ca.gov

²University of California, Sierra Nevada Aquatic Research Lab, Rt. 1, Box 198

Mammoth Lakes, California 93546

The California Regional Water Quality Control Board, Lahontan Region (RWQCB), in cooperation with the University of California's Sierra Nevada Aquatic Research Lab, initiated a bioassessment program in the Lake Tahoe Basin in 1999. "Bioassessment" refers to an evaluation of the biological integrity of water bodies based on direct sampling of instream assemblages of flora and/or fauna. The most common organisms used in bioassessment are fish, benthic macroinvertebrates, and periphyton (i.e., attached algae & diatoms).

Bioassessments based on the community assemblages of benthic macroinvertebrates, coupled with quantitative physical habitat measurements, have been used by the RWQCB throughout the eastern Sierra Nevada to evaluate stream channel re-alignments and other watershed restoration efforts, measure instream responses to the implementation of Best Management Practices (BMPs), assess impacts from land uses and introduction of exotic species, and to develop landscape-scale "reference conditions" to support the establishment of indices of biological integrity (e.g., targets, standards, biocriteria).

Case studies of the applications of bioassessment methods in the Lake Tahoe Basin are compared, and examples presented to illustrate the utility of bioassessments for quantifying the effectiveness of watershed restoration efforts and BMP implementation, and establishing numeric targets to guide adaptive resource management decisions.

A Modeling Study of Nitric Acid Deposition to the Lake Tahoe Basin

Jülide K.Koraèin, Leland W.Tarnay and Alan W.Gertler
Desert Research Institute, 2215 Raggio Parkway Reno, Nevada
Telephone (775) 674-7184, E-mail: jkahya@dri.edu

For last several decades, noticeable degradation of the Lake Tahoe Basin environmental quality and the dramatic declination of the Lake Tahoe's clarity have directed researcher's attention to the area to initiate an ultimate recovery and restoration plan. Related studies suggested that nitrogen and phosphorous were the main contributors to the lake's nutrification. Atmospheric deposition of airborne nitrogen species is predicted to account for the half of the total nitrogen deposition to the lake, according to the Lake Tahoe Watershed Assessment (2000).

Among the nitrogen containing gaseous species, nitric acid (HNO_3) and ammonia (HN_3) have the significant importance due to their abundance in the anthropogenic air pollution fraction as well as vulnerability of the lake's watershed canopy structure to the species. A recent study by Leland Tarnay et al. (2001) showed that ammonia was a minor component of the total nitrogen deposition to the basin but that a significant source of N deposition was attributed to HNO_3 . Furthermore, HNO_3 could have both in-basin and out-of-basin sources. In order to determine the in-basin versus out-of-basin contributions, a meteorological and dispersion/transport modeling system was applied to the problem for defining the air pollutant transport patterns and deposition quantities in the Lake Tahoe Basin. CALMET/CALPUFF meteorological and dispersion air quality modeling system was used as an integrated system with the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) to generate wind fields and other meteorological and micrometeorological parameters needed for the dispersion model CALPUFF, which is a Gaussian puff dispersion and transport model with chemical conversion, wet and dry removal modules. The modeling domain covers San Francisco Bay area and Sacramento valley along with the focus of interest Lake Tahoe Basin. During the summer months under the prevailing westerlies these urban areas have key importance to be considered as regional sources of air pollutants to the basin.

Model simulations were performed for the ambient sampling days during the period from 26 July 2000 through 26 September 2000. Several case studies were investigated during this period.

Results will be discussed in further details.

Sources of Atmospheric Dry Deposition of Inorganic Nitrogen in the Lake Tahoe Basin

Leland W. Tarnay¹, Alan W. Gertler¹, Menachem Luria²

¹Desert Research Institute, 2215 Raggio Parkway, Reno NV 89512

Telephone (775) 674-7079, E-mail: ltarnay@dri

²The Hebrew University of Jerusalem, P. O. Box 1255, Jerusalem 91094, ISRAEL

Deposition of nitrogen-containing gases in the Lake Tahoe Basin has been implicated in Lake Tahoe's eutrophication. As part of a National Science Foundation study, we measured gaseous nitric acid (HNO_3) and ammonia (NH_3) concentrations every six days at five sites simultaneously in the Tahoe Basin from July through September of 2000 for both day and night. Correlations among these sites suggest that both local and out of basin sources contribute to gaseous nitrogen in the Tahoe Basin, with all of the NH_3 from in-basin sources and the HNO_3 from both in- and out-of-basin sources. Analysis of HNO_3 to NO_y ratios (from co-located measurements) combined with HYSPLIT trajectory analysis is consistent with the hypothesis that some of the HNO_3 found in the Tahoe Basin is derived from local precursors. We conclude that local and regional sources contribute substantially to ambient HNO_3 in the Lake Tahoe Basin, while ambient NH_3 is largely local in origin. When combined with local meteorological data and quantitative deposition models, the results also suggest that, to the extent that gaseous NH_3 and HNO_3 deposition are responsible for Lake Tahoe's eutrophication and clarity loss, local sources may be more significant contributors than previously considered.

Aircraft Measurements of Nitrogen and Phosphorus in and around the Lake Tahoe Basin

Cort Anastasio, Qi Zhang, John J. Carroll, and Alan J. Dixon
Atmospheric Science Program, Department of Land, Air, and Water Resources
University of California, Davis, CA 95616-8627
Telephone (530) 754-6095, E-mail: canastasio@ucdavis.edu

Atmospheric deposition of nitrogen (N) and phosphorus (P) to Lake Tahoe plays a significant role in the decline in lake clarity. To characterize atmospheric N and P in and around the Lake Tahoe Basin, we collected samples during the summer of 2001 using an instrumented aircraft flown over three locations: the Sierra Nevada foothills east of Sacramento (“low Sierra”), further east and higher in the Sierra (“mid Sierra”), and in the Tahoe Basin. Similar measurements were made within the smoke plume downwind of the Star forest fire. Samples were collected using a denuder-filter pack sampling system (DFP) and analyzed for gaseous and water-soluble particle components including HNO_2 , $\text{HNO}_3/\text{NO}_3^-$, $\text{NH}_3/\text{NH}_4^+$, organic N (ON), total N, SRP (soluble reactive phosphate), total P and sulfate.

The average total N concentrations ($\pm 1\sigma$) measured over the low and mid Sierra were 660 (± 270) and 630 (± 350) nmol N / m^3 -air, respectively. Total airborne N concentrations in the Tahoe samples were one-half to one-fifth of these values. The forest fire plume had the highest concentration of atmospheric N (860 nmol N / m^3 -air) and a greater contribution of organic N (ON) to the total N compared to non-smoky conditions. Airborne P was rarely observed over the low and mid Sierra but was present at low concentrations over Lake Tahoe (~ 2 nmol P / m^3 -air). Phosphorus in the forest fire plume was present at concentrations ~ 10 times greater than over the Tahoe Basin; P in these samples included both fine and coarse particulate phosphate as well as unidentified, possibly organic, gaseous P species. Overall, our results suggest that out-of-basin emissions could be significant sources of nitrogen to Lake Tahoe during the summer and that forest fires can be important sources of both N and P.

Characterizing Impacts of Snowmobile Emissions on the Winter Environment and Watershed

Mark R. McDaniel

Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512

Telephone (775) 674-7180, E-mail: mmcdan@dri.edu

The recreational use of snowmobiles has grown in popularity over the last decade as general interest in outdoor activities has boomed. The snowmobile industry has capitalized on the growing market by developing snowmobiles that are lighter, faster, and easier to use. As a result, not only are there more snowmobiles in use on public lands, but snowmobilers are now traveling further into remote areas. Many of these areas are subject to motor vehicle restrictions, designated Wilderness, or otherwise sensitive to off-highway vehicle use.

Commercial snowmobile touring outfitters have benefited from the growing interest in outdoor recreation. During the 2000-2001 winter, a single snowmobile touring outfitter operating on the Spooner Summit area of Tahoe's eastern rim provided over 5,600 trips in the Tahoe Basin alone, and over 9,700 trips in areas straddling the Tahoe-Carson drainage divide. Over 4,000 visitor days were provided in areas above the North Shore of Lake Tahoe by three different commercial outfitters. Snowmobile tours averaged two hours each.

Snowmobiles emit high levels of their fuel-oil mixture (25% to 33%) with exhaust gases as unburned fuel and oil due to the design of engines used in nearly all snowmobiles; two-stroke engines that have both the intake and exhaust ports open at the same time. There are currently no federal regulations limiting snowmobile emissions. The California Air Resources Board reported in Fact Sheet 2/99 that two-stroke engines, similar to those used in snowmobiles, emit as much ozone forming pollution in seven hours of operation as a 1998 passenger car driven for 100,000 miles. Data are scarce on the chemical composition and specific emission rates of volatile organic compounds and semi-volatile organic compounds, many of which are known to be persistent in the environment and hazardous to terrestrial and aquatic organisms. There is virtually no data on the transport, transformation, and fate of snowmobile-derived pollution in the winter environment and watershed. As such, managers of public lands are at a loss to quantitatively assess the impacts of snowmobile use on ecosystem health.

This research addresses the lack of data on the emission rate and environmental fate of snowmobile derived contaminants. Standardized snowmobile engine testing procedures, quantitative emission sampling and chemical analysis, and environmental monitoring of snowpack contaminants are proposed. Volatile and semi-volatile organic compounds and particulate matter will be collected during emission sampling. Conventional snowmobiles with two-stroke engines and newer models with four-stroke engines will be tested to assess potential improvements that can be achieved with better engine design. Snow along popular snowmobile trails will be sampled in order to determine which compounds present in the exhaust accumulate in the snowpack. Snowmelt and sediment will be monitored in the vicinity of snow samples to determine which compounds disperse with surface water or partition to sediments. Data may be used for assessing snowmobile contributions to the mobile source emission inventory for Lake Tahoe Basin, and how those emissions impact the Basin's water resources. Regulations on permissible numbers of snowmobile users, areas of use, and types of machines used may then be based on scientific data relating snowmobile use to environmental impacts.

Predicting Flow Statistics In The Ungaged Creeks Of The Lake Tahoe Basin For Fisheries Habitat Assessment

Andy Rost and John Tracy
Hydrologic Sciences Program
Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512
Telephone (775) 674-7180, E-mail: arost@dri.edu

Although there are previous studies that investigate the hydrology of the Lake Tahoe Basin (Jeton 1999, Thodal 1997, Myrup 1979, Crippen 1970, McGauhey 1963), there is no comprehensive study that predicts the flow statistics for all the tributary creeks of the Lake Tahoe Basin. This study was undertaken to assess which streams have the highest potential for providing the optimal habitat for salmonid species by predicting flow statistics for each of the creeks. Regional regressing equations were established to predict the flow statistics by correlating existing flow records to individual watershed attributes and transferring these correlations into the ungaged watersheds to establish predictions of flow statistics for these watersheds.

A logarithmic transformation of the flow records from sixteen USGS gaging stations in the Lake Tahoe Basin produced a two-parameter flow probability distribution. Analyses of nine data layers in a GIS format, using Arcview 3.2, produced over 30 attributes for each watershed. These attributes were used as independent variables in multivariate regression equations to produce regression equations that predict the monthly mean and monthly standard deviation for the above mentioned sixteen gaged watersheds. Once satisfactory equations were developed, these equations were used in the ungaged watersheds by using the watershed attributes as independent variables to predict the flow statistics in the remainder of the watersheds in the basin. Once a predicted flow record was computed, probability of exceedence curves were used to compare these predicted flows with optimal flows for salmonid habitat reported in a 1987 study, Instream Flow Requirements; Lake Tahoe Basin; California and Nevada.

The area of the watershed and the location of the spill point relative to the center of the lake are the most statistically significant variables in predicting the flow statistics for the tributary creeks of the Lake Tahoe Basin. Additional, average watershed elevation, drainage density, channel slope and channel length were also statistically significant in predicting the flow statistics. Adjusted R^2 values ranged from 0.87 to 0.97 for the monthly means with an average of 0.95 and from 0.22 to 0.95 for the standard deviation with an average of 0.65. When the probability exceedence curves were compared with the optimal flows described in the above-mentioned report, most of the studied creeks maintained the optimal flows in only the spring snowmelt months, while some studied creeks were predicted to never have optimal flows.

Stream Monitoring in Lake Tahoe Basin

Kip K. Allander
US Geological Survey, 333 W. Nye Lane, Carson City, NV 89706
Telephone (775) 887-7675, E-mail: kalland@usgs.gov

Problem: Deteriorating water quality and clarity in Lake Tahoe prompted the initiation of environmental programs in the Lake Tahoe Basin. Water-quality data, especially nutrient data, for streams and ground-water aquifers that discharge to Lake Tahoe are needed to document the regional and local effectiveness of environmental programs and to assure compliance with the State's water-quality management plans.

Objectives: This study will (1) provide a long-term data base for estimation of streamflow and of sediment and nutrient loadings from major streams tributary to Lake Tahoe, (2) provide a long-term data base for assessment of ground-water levels and nutrient quality in Lake Tahoe Basin, (3) support assessment of the effects of land use and development in the Lake Tahoe Basin on nutrient and sediment loads, (4) provide water-quality data in support of basic research on the processes controlling algal enrichment in Lake Tahoe, and (5) provide insight into the ground-water/surface-water interactions within the Upper Truckee River and Trout Creek watersheds.

Relevance and Benefits: An important part of the USGS mission is to provide scientific information to manage the water resources of the Nation. To effectively assess the Nation's surface-water resources and ground-water resources, the USGS collects water-quality data from lakes, streams, estuaries, and aquifers using standardized methods, and maintains the data from these stations in a national data base. These data are published in annual data reports and an increasing amount of real-time and historical water-quality data are available on the World Wide Web. Long-term, water-quality data characterize the physical, chemical, and biological changes in our water resources in response to natural resources including climatic variations, storms, floods, droughts, and a variety of human activities that exert an influence on water-quality conditions. The data are useful in designing programs to protect watersheds, sensitive aquatic habitats, biota, and drinking water sources from urban runoff, sewage, and industrial wastes. The data also are useful in designing programs to maintain water clarity, aesthetics, contact recreation, and to meet the President's Initiatives at Lake Tahoe. The water-quality data collected in Nevada are an integral part of the nationwide water-quality data program.

Approach: A hydrologic data-collection network of 32 stations on 13 Lake Tahoe tributary streams that drain representative land-use and development areas in the basin will be operated. Continuous-record streamflow data at 18 stations will be used in conjunction with instantaneous nutrient and suspended sediment concentration data to estimate the loads of nutrients and suspended sediment. A hydrologic data-collection network of 34 ground-water sites in the basin will be operated to monitor long-term trends in ground-water quality. Ground-water/Surface-water interactions will be monitored in the Upper Truckee River and Trout Creek watersheds through continuous recording of stream water temperature at 6 sites in both basins, an annual seepage run in both basins, and continuous monitoring of stream and ground-water levels and streambed temperature gradients at two sites on Trout Creek.

In-Situ Measurement of Surface Runoff Water Quality from Sierran Watersheds

Charles Denton¹, Wally Miller¹, Dale Johnson¹ and P.S.J. Verburg²

¹Dept. Environmental & Resource Sciences, University of Nevada, Reno, NV 89557

Telephone (775) 784-4020

²Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512

Diminished Lake Tahoe water clarity has been attributed to enhanced biomass and particulate suspension as a result of increased sediment and nutrient loading from surrounding watersheds. Except in areas of confluence, a direct link between interrill surface runoff (overland flow), tributary water quality, and Lake discharge remains poorly quantified. Historical attempts of measuring stream water quality "above and below" various land management activities has provided data by inference only, without direct measurement. We have developed a versatile intermediate (50 m²) scale in-situ overland flow collector to capture actual interrill overland flow, sediment, and nutrient composition during natural events; snowmelt and/or summer precipitation. Our objective is to better quantify what is actually moving across the surface downslope towards watershed tributaries. Preliminary findings have been surprising. Variable amounts of surface runoff were collected from areas of no visible erosion or overland flow during both snowmelt and summer precipitation. Cumulative runoff from 13 study sites over the period August 10, 2001 through February 12, 2002 ranged from a low of 4.18 L (0.084 mm) at one site to a high of 21.64 L (0.43 mm) at another on slopes of <10%. Importantly, we found NH₄⁺ concentrations as high as 86.2 mg N L⁻¹ and ortho-phosphate as high as 28.7 mg P L⁻¹ in the runoff. Soil solution extracts were >3 orders of magnitude lower for both N and P. We therefore believe the runoff takes place beneath the organic litter and/or forest floor vegetation at the mineral soil interface. Finally, an adjacent plot has yielded no surface runoff at all, suggesting large areas of preferential infiltration. Preferential infiltration has previously been reported, but not demonstrated to take place on a large scale. This latter finding has basin wide implications, particularly to hydrologic and sediment/nutrient transport models.

Loads of nutrients and suspended sediment for selected watersheds in the Lake Tahoe Basin

Timothy G. Rowe

U.S. Geological Survey, 333 W. Nye Lane, Carson City, NV 89706

Problem: The USGS, in partnership with the University of California, Davis (UCD), Tahoe Research Group, and in cooperation with the California Regional Water Control Board-Lahontan Region and the Tahoe Regional Planning Agency (TRPA) proposed to estimate nutrient and suspended-sediment loads, yields, and trends for selected tributaries entering Lake Tahoe. Results from this study will provide needed information for resource managers.

Objectives: A quantification of surface water inputs of nutrient and suspended sediment will be developed. Streamflow and water-quality data will be compiled for numeric analysis using Lake Tahoe Interagency Monitoring Program data from water years 1980 to 1998. Five of the 10 gaged basins have multiple gages that will enable load estimates to be calculated for various land use areas.

Relevance and Benefits: An important part of the USGS mission is to provide scientific information to manage the water resources of the Nation. To effectively assess the Nation's surface-water and ground-water resources, the USGS collects data from lakes, streams, estuaries, and aquifers using standardized methods and maintains the data from these stations in a national data base. Long-term data characterize the physical, chemical, and biological changes in our water resources in response to natural resources including climatic variations, storms, floods, droughts, and a variety of human activities. The data are useful in designing programs to maintain water clarity, aesthetics, contact recreation, and to meet the President's Initiatives at Lake Tahoe. The data collected at Lake Tahoe are an integral part of the nationwide data program.

Approach: All streamflow and water quality-data will be assembled. Water-quality data will be checked and documented with respect to field and laboratory methods and laboratory method detection limits. Streamflow data from 20 sites will have missing records filled in. Annual, seasonal, storm loads, yields, and trends will be calculated with load-calculation programs and a trend-calculation program using the assembled streamflow and water-quality data for 20 sites for the 1988-98 period of record.

Progress and Significant Results: Loads and trends of nutrients and suspended sediments for 20 gaged sites for periods of record were calculated. Temporal changes and spatial differences to nutrient and suspended sediment concentrations were related. USGS reports published from this project: 1) Rowe, T.G., Saleh, D.K., Watkins, S.A., and Kratzer, C.R., 2002, Streamflow and water- quality data for selected watersheds in the Lake Tahoe Basin, California and Nevada, through September 1998: U.S. Geological Survey Water-Resources Investigations Report 02-4030, 118 p. Report available on web: <http://water.usgs.gov/pubs/wri/wri024030/> and 2) Rowe, T.G., 2000, Lake Tahoe Interagency Monitoring Program: Tributary sampling design, sites, and periods of record: U.S. Geological Survey Fact Sheet 138-00, 4 p.

Nutrient fluxes in a snow-dominated, semi-arid forest: Spatial and temporal patterns

Dale Johnson¹, Richard Susfalk², Randy Dahlgren³, T.G. Caldwell⁴, And W.W. Miller¹

¹Environmental and Resource Science, College of Agriculture

University of Nevada, Reno, Reno, NV 89512

Telephone (775) 784-4511, E-mail: dwj@unr.edu

²Environmental Studies, University of California, Santa Cruz, CA 95064

³Soils and Biogeochemistry, University of California, Davis, CA 95616-8627

⁴Pacific Northwest National Labs, Richland, WA 99352

We tested five hypotheses regarding the potential effects of precipitation change on spatial and temporal patterns of water flux, ion flux, and ion concentration in a semiarid, snowmelt-dominated forest in Little Valley, Nevada. Variations in data collected from 1995 to 1999 were used to examine the potential effects of snowpack amount and duration on ion concentrations and fluxes. Soil solution NO_3^- , NH_4^+ , and ortho-phosphate concentrations and fluxes were uniformly low, and the variations in concentration bore no relationship to snowmelt water flux inputs of these ions. Weathering and cation exchange largely controlled the concentrations and fluxes of base cations from soils in these systems; however, soil solution base cation concentrations were affected by cation concentrations during snowmelt episodes. Soil solution Cl^- and SO_4^{2-} concentrations closely followed the patterns in snowmelt water, suggesting minimal buffering of either ion by soils. In contrast to other studies, the highest concentration and the majority of ion flux from the snowpack in Little Valley occurred in the later phases of snowmelt. Possible reasons for this include sublimation of the snowpack and dry deposition of organic matter during the later stages of snowmelt. Our comparison of interannual and spatial patterns revealed that variation in ion concentration rather than water flux is the most important driver of variation in ion flux. Thus, it is not safe to assume that changes in total precipitation amount will cause concomitant changes in ion inputs to this system.

Incline Creek Watershed Project

R.B. Susfalk¹, D.W. Johnson², S. Tyler², A. McKay¹, and P. Starkweather³

¹ Division of Hydrologic Sciences, Desert Research Institute, Reno, NV 89512

Telephone (775) 673-7453, E-mail: rbs@dri.edu

² Department of Environmental and Resource Sciences, University of Nevada, Reno, NV 89557

³ Biological Sciences, University of Nevada, Las Vegas, NV 89154

The deterioration of water quality in Lake Tahoe over the last few decades is well documented, but the linkages between upland forests, the hydrologic transport of nutrients, and decreasing clarity of Lake Tahoe are not clear. The objective of this project is to collect baseline data on soils and soil solution, vegetation, and water quality to provide the framework for future scientific collaborations on process-level studies ranging from terrestrial and aquatic system dynamics and health, to the effectiveness of BMP and restoration projects. Studies within the Incline Creek watershed have several advantages over other watersheds within the Lake Tahoe Basin, including: 1) a relatively well defined transition between undeveloped upland forests and lower elevation urbanized areas; 2) predominance of decomposed granite soils derived from grandiorite (Cagwin and Toem series), the dominant parent material within the Lake Tahoe basin; 3) a variety of vegetation types including nitrogen fixers and non-fixers; and 4) historical water quality data collected at numerous sites by the Lake Tahoe Interagency Monitoring Program (LTIMP), the U.S. Geological Survey (USGS) and the Nevada Division of Environmental Protection (NDEP).

The Incline Creek Watershed Project has numerous ongoing activities to collect baseline data on water and nutrient transfers throughout the watershed. Water content held within the snowpack as a function of slope and vegetation density was recently measured during maximum snowpack accumulation. With the onset of snowmelt, N and P are transferred to the terrestrial system, where we are monitoring the ability of lodgepole and white-fir forest stands to uptake, retain, and subsequently release these nutrients back into the ecosystem. We are also monitoring the transfer of water and nutrients within watershed streams by both spatial and temporal. Spatial collections involve the collection of over 20 water samples at a time throughout the watershed, representing different hydrologic and land use conditions. Temporal changes in nitrogen (N) and phosphorus (P) loads are being monitored at three locations on both Incline Creek and its Deer Creek tributary, with emphasis on changes in particulate P and dissolved organic N forms before discharge into Lake Tahoe. Collectively, these studies provide a framework of baseline data useful to understanding processes within both undisturbed and urbanized areas in this important Lake Tahoe watershed.

Will Cattleman's Detention Basin Reduce Nutrients to Lake Tahoe?

David E. Prudic and James L. Wood

U.S. Geological Survey, WRD, 333 West Nye Lane, Room 203, Carson City, Nevada 89706

Telephone (775) 887-7611, E-mail: deprudic@usgs.gov

Cattleman's detention basin was constructed in September 2001 near where Pioneer Trail crosses Cold Creek south of Lake Tahoe. The detention basin was built to capture urban runoff from roads and nearby homes in an effort to reduce nutrient and sediment loads to Lake Tahoe. In October 2000, prior to planned construction of the detention basin, El Dorado County Department of Transportation, California Tahoe Conservancy, and the U.S. Geological Survey developed a cooperative study to assess how effectively the detention basin functions in reducing nutrients and sediments to Cold Creek. California Tahoe Conservancy is providing the majority of funds for the project. Of particular interest is the need to understand any changes in ground-water flow that could result from creating a pond behind the detention basin.

To assess changes in ground-water flow caused by the detention basin, thirty wells were drilled in the vicinity of the basin during November 2000, 10 months prior to construction. The wells were routinely measured for water levels and sampled for chemical composition. This information, along with flow and chemistry of Cold Creek and urban runoff, provide the necessary background information.

Prior to construction of the detention basin, runoff from Pioneer and Cattleman's Trails flowed across an area that once was a meadow associated with Cold Creek. This area had been graded with as much as 5 feet of soil during construction of nearby homes. Ground water beneath this area generally flows northwest, parallel to the slope of the meadow, through sand and silt rich in organic material. Consequently, the shallow ground water has naturally high concentrations of dissolved organic carbon (5 to 10 milligrams per liter), ammonium (1 to 15 milligrams per liter), and iron (10 to 40 milligrams per liter) and little to no dissolved oxygen. Iron staining on the streambed and differences in iron concentrations between upstream and downstream water samples collected during September 2001, suggests that most of the dissolved iron in ground water discharging to the creek precipitates on the streambed sediments.

The purpose of the remainder of the study is to collect sufficient information to assess how effectively the detention basin traps sediment and reduces nutrient loads to Cold Creek. An important aspect of the study will be to assess how infiltrating dilute, oxygenated urban runoff will affect nutrient transport in ground water moving through the organic-rich soils.

Stormwater Monitoring and BMP Effectiveness at Lake Tahoe

John E. Reuter, Alan C. Heyvaert, Matthew Luck, Scott H. Hackley
Tahoe Research Group, University of California, Davis, CA 95616
Telephone (530) 304-1473, E-mail: jereuter@ucdavis.edu

The Tahoe basin is a complex ecosystem with 63 individual watersheds and 52 intervening areas, which discharge nutrients and sediment into Lake Tahoe. Indeed, much of the urbanization is located in these intervening areas. A large number of erosion control and other water quality improvement projects have been constructed in the Tahoe Basin over the past 15 years. Lessons have been learned from the experience of designing and constructing these projects and from observing project performance in the field. This information has been used to help improve the designs of subsequent projects. However, until recently much of the water quality related information has been qualitative in nature, based largely on limited site inspections and observations, or insufficient sampling.

The database on stormwater runoff water quality that we analyzed included 17 sites/studies. When grouped by land use category of undisturbed (U), residential (R), commercial (C) and highway (H), all the nutrients and TSS showed a clear increase with increasing urbanization, i.e. relative cover. Mean concentrations for land use categories ranged from 0.002-0.305 mg N/L for nitrate, 0.14-1.64 mg/L for TKN, 0.11-0.138 mg/L for SRP, 0.03-1.48 mg/L for TP and 1-1,307 mg/L for TSS. TP values from individual sites frequently exceeded the Lahontan surface discharge standard of 0.1 mg/L. Nutrient and sediment concentrations in commercial and highway runoff in the Tahoe Basin were similar to values reported by the National Urban Runoff Program.

Our original estimates of nutrient and sediment load from intervening zones which appeared in the Watershed Assessment were updated based on this extended stormwater runoff record. While the updated values were slightly changed, the differences were not significant from a management perspective. It was calculated that TP loading from intervening zones could be reduced by 50% if the Lahontan effluent standard of 0.1 mg/L were met. This represents a 15% reduction, vis-à-vis, the whole-lake P-loading budget.

A total of 43 technical reports were evaluated for information on BMP effectiveness in the Tahoe Basin. Of these there were only 19 individual BMPs contributed sufficient data for use in the quantitative assessment. In general, load based removal efficiencies for TSS, nitrogen and phosphorus were less than that reported from the National Database. This was clearly seen for nitrate, SRP and TP, and to a lesser extent TSS. Nationally, median nitrogen and phosphorus removal efficiency ranged from approximately 35%-50% and 76% for TSS. In the Tahoe Basin, median nutrient removal was typically in the range of (-)15% to (+) 25% depending on the specific constituent. TSS removal in the Tahoe Basin was 45-50%.

Even if the higher removal efficiencies seen in the National Database could be achieved, stormwater runoff in the some of the more urban areas could still exceed Lahontan standards. This clearly points out the importance of enhancing current BMP designs by all means possible, including physical/structural, biological and/or chemical methods.

Lake Tahoe TMDL Research Program

John E. Reuter¹, Jeremy Sokulsky², Bruce Warden² and Dave Roberts²

¹Tahoe Research Group, University of California-Davis, Davis, CA 95616

Telephone (530) 304-1473, E-mail: jereuter@ucdavis.edu,

² Lahontan Regional Water Quality Control Board, 2501 Lake Tahoe Blvd.,
South Lake Tahoe, CA 96150

Based largely on the past investigations of the University of California-Davis, the U.S. Geological Survey and the University of Nevada-Reno, and other there has been a significant effort since 1998 to integrate scientific efforts at Lake Tahoe. This integration is now being done at the programmatic (ecosystem) level as well as among research institutions, and between the scientific community and managers/decision makers. The focus of this collaboration has been to facilitate conversion of science into management. Timely feedback of research for Lake Tahoe restoration activities is central to the adaptive management framework. This requires basic and applied research, expanded monitoring, and best professional judgement. It also requires the development of a more formalized research agenda. In 2000, the Lake Tahoe Science Advisory Group, in conjunction with numerous state, federal and local agencies, and a number of active working groups in the Tahoe basin identified critical information needs that must be supplied for effective management decisions.

Later in 2000 the Lahontan Regional Water Quality Control Board, the Air Resources Board and the TRPA submitted budget requests to the State of California for the funding to implement recommended scientific investigations, many of which are critical for establishing a Lake Tahoe TMDL. In July of 2001, this was approved by the Legislature and provided funding for an ambitious 2-3 year program investigating the following topics for which insufficient understanding is available for decisions at Lake Tahoe. Projects for both LRWQCB and the ARB include: (1) Data management, (2) Nearshore water quality, (3) Reconstruction of historic meteorological data, (4) Fine sediment loading, (5) Stormwater monitoring, (6) Modeling of hydrology and stormwater nutrient/sediment load – response to management, (7) Statistical analysis of loading related to land use characteristics, (8) Assessment of biologically available phosphorus, (9) Monitoring number, size and composition of particles in Lake Tahoe, (10) Particle loss processes from water column, (11) Application of Clarity Model for management purposes, (12) Stormwater BMP evaluations and implementation feasibility, (13) Enhancement of air quality monitoring network and comprehensive sample collections, (14) Characterization of air quality emission sources, and (15) Modeling of atmospheric deposition to Lake Tahoe.

In total, nearly \$6,000,000 has been committed for this work, including a additional effort by the US Army Corps of Engineers (Sacramento District) to investigate the possible sources of nutrients to groundwater. This combined level of effort is very significant and will include time from well over 100-150 participants including academic researchers, agency scientists and environmental consultants. These characteristics are comparable to the national Science Foundation's Long Term Ecological Research Program (LTER) which consists of about 20 locations nation wide. In these terms, the scope and, financial and institutional investment in the Tahoe TMDL Research Program takes on significance at the national level.

The Lake Tahoe Nutrient and Sediment Total Maximum Daily Load: An Overview of the Coordinated Restoration Planning Process

Jeremy Sokulsky

TMDL Unit, Lahontan Regional Water Quality Control Board (RWQCB)

2501 Lake Tahoe Blvd, South Lake Tahoe, CA 96150

Telephone (530) 542-5463, E-mail: jsokulsky@rb6s.swrcb.ca.gov

A Total Maximum Daily Load (TMDL) is a water quality restoration plan. By definition the TMDL designates the maximum amount of a pollutant or combination of pollutants that a waterbody can assimilate and maintain applicable water quality standards.

Each of the major elements of the TMDL combine to create a comprehensive water quality restoration plan. These elements include:

- Problem Statement – describing how Lake Tahoe’s declining clarity and increasing primary productivity violate water quality standards.
- Numeric Target – defining the desired condition for Lake Tahoe.
- Source Analysis – determining the loading of nutrients and sediments from all of the different sources to Lake Tahoe on a coarse scale.
- Linkage Analysis – determining the loading capacity or maximum allowable loading of sediments and nutrients that can enter the lake and still achieve the desired conditions outlined in the Numeric Target.
- Load Allocations – distributing the loading capacity amongst the different sources, which also defines the required load reductions from these different sources.
- Margin of Safety – defined as either a fraction of the loading capacity that is not allocated or as conservative assumptions made during the analysis to assure that errors in analysis do not result in an excess of pollutant loading to the lake.
- Implementation Plan – establishing a timeline for load reductions necessary to achieve the loading capacity with interim load reduction milestones. It also sets out TMDL revision procedures, a monitoring plan, regulatory mechanisms for ensuring load reductions, and methods for incorporating adaptive management into the TMDL.

The TMDL takes a comprehensive and scientifically based approach that will give a sound bases for mapping the next generation of actions to restore Lake Tahoe. The TMDL will be created in coordination with the Nevada Division of Environmental Protection, Tahoe Regional Planning Agency (TRPA), and the United States Forest Service (USFS). These new plans will grow from the existing TRPA Regional Plan, USFS Forest Plan and the Environmental Improvement Program and will result in a coordinated effort reduce sediment and nutrient loads to achieve the desired lake clarity.

Over \$4 million in scientific investigations will be completed by the end of 2004 that will act as the bases for a “Technical TMDL”. The Technical TMDL will be completed in the spring of 2005 and will include all of the elements of a TMDL except an Implementation Plan and specific load allocations. Following an extensive stakeholder engagement process the Lahontan Regional Board will approve the final TMDL by April of 2007.

Sediment and Nutrient Monitoring and Modeling in Trout Creek, Lake Tahoe, California

Katrina Smolen

Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512

Telephone (775) 673-7374, E-mail: ksmolen@dri.edu

The water quality of Trout Creek, South Lake Tahoe, California; is being monitored, by the Desert Research Institute, to ascertain the stream system's response to restoration. This study is a principal endeavor in the Tahoe Basin to conduct a systematic evaluation of sediment and nutrient flux before and after stream restoration. The Trout Creek Stream Enhancement and Wildlife Project has reconstructed 9000 channel feet of stream, enhancing sinuosity and raising the channel bed, increasing sediment deposition in pools and along floodplains. Trout Creek is the fourth largest tributary to Lake Tahoe. The surrounding wetland is a natural filtering mechanism, removing phosphorous-rich sediment from the stream system. The Army Corps of Engineers linearized Trout Creek in the 1950's, moving it to the edge of the meadow. The channel eroded, became wide and incised, rarely capable of overtopping its banks. The Trout Creek Stream Enhancement and Wildlife Project is an effort to restore properly functioning channel conditions to reduce sediment loading into Lake Tahoe

A real-time monitoring system has been deployed to gather data frequently. The relationship between suspended sediment and nutrient concentrations with turbidity is quite strong, enabling the development of predictive modeling. Monitoring real-time turbidity as a surrogate for suspended sediment is more precise than previous methodologies using discharge relationships to calculate sediment load. This study provides promising results for monitoring nutrients and sediments *in situ*. The correlations are exceedingly high and it is possible to make predictions of suspended sediment and nutrients from a disturbed watershed.

Quantifying Erosion Sediment Yield and Infiltration on Disturbed Steeply Sloping Soils Following Revegetation

M. E. Grismer, M.P. Hogan & V.P. Claassen

Dept of LAWR – Hydrology, University of California, Davis, CA 95616

Telephone (530) 752-3243, E-mail: megrismer@ucdavis.edu

The effects of slope, cover (mulch and vegetation conditions) and surface roughness on rainfall runoff, infiltration and erosion rates are determined at several hillside sites in the Tahoe Basin using a portable rainfall simulator (0.64 m² plots centered below 1 m² rainfall). Rainfall simulation (60 mm/hr) experiments at each site included at least three replications of each “treatment” and a bare soil assessment. ANOVA and regression comparisons of time to runoff, infiltration, runoff, average sediment concentration and sediment yield per unit runoff are obtained. Simulator measured steady infiltration rates are also compared with those measured using a “Precision Permeameter” (equivalent to a constant-head Guelph permeameter modified for steep slope measurements). Following rainfall simulations, detailed assessments, not considered in previous studies of soil slope, cover and surface roughness are conducted. Laboratory analyses of runoff water TDP and TKN concentrations as well as sediment particle-size distributions are underway.

Following a preliminary land survey of the site and establishment of plots and plot frames (0.8m x 0.8m), the rainfall simulated is centered over the plot frame and leveled. Three soil samples are collected form around the plot frame for assessment of pre-rainfall soil moisture conditions (typically 5-10% by mass). A plexiglass sheet is placed on the simulator structure above the plot frame and the rainfall rate is established at 59-61 mm/hr after which the sheet is quickly removed and rainfall initiated. Rainfall is allowed to continue until either steady runoff is obtained, or 60-70 minutes have elapsed. The simulator is moved and the surface topography of the plot is measured as well as the visible wetting front depth.

The Table below summarizes Summer 2001 example results from the Dollar Hill road cut. The Summer 2002 field campaign will include additional “natural” sites in Blackwood and Ward Canyons as well as on ski runs at NorthStar, Homewood and Heavenly Mountain Resorts.

Treatment	Down Slope	Rough-ness	Time to Runoff	Infilt.	Runoff	Sed Conc.	Sed Yield	Avg TKN
	(%)	(mm)	(sec)	(mm/h)	(mm/h)	(g/L)	(g/mm)	(mg/L)
Bare soil	48.48	10.19	325.00	47.31	12.75	4.19	2.78	1.53
PN. Mulch	54.30	11.91	263.33	55.35	7.65	0.66	0.52	2.44
PNM+Bgrass	55.84	14.27	237.25	46.15	15.35	2.10	1.46	3.19
PNM+BG+duff	54.58	14.21	384.50	57.25	2.75	1.70	1.09	1.81
OldPNM+Yarrow	49.76	9.33	272.00	41.03	19.97	7.76	5.66	1.36

A Soil Resource Evaluation Process for Identifying and Remediating Plant-growth Limiting Conditions on Drastically Disturbed Sites

Vic Claassen

Soils and Biogeochemistry Section, Dept. of Land, Air and Water Resources

University of California, Davis, CA 95616

Telephone (530) 752-6514, E-mail: vpclaassen@ucdavis.edu

Native plants possess an extraordinary array of beneficial behaviors and attributes that can reduce weedy invasion, protect against erosion, provide habitat and mitigate some types of fire risk. Many of the benefits and characteristics attributed to native plants are, however, generated from or facilitated by the soil resource upon which these plants grow. Often, the soil materials at disturbed sites have been stripped of soil organic matter, nutrients and biological activity during construction or erosion, making regeneration of native plant cover difficult.

In order for plants on the disturbed site to grow, persist, and perform “like natives,” they require substrates that have at least some of the characteristics of the original native soil. The steps outlined in this soil resource evaluation process are designed to measure the soil characteristics of drastically disturbed substrates to determine if they are sufficient to support plant growth. The information is compared to that from reference sites with acceptable vegetative cover, as determined by the land managers of the site. Suitable amendments can then be identified that regenerate the deficient plant-growth supporting functions. The seven steps currently used in this process are organized chronologically, starting with planning and design (Steps 1 and 2), construction and earthmoving (Steps 2 and 3), amendment (Steps 3, 4 and 5), inoculation (Step 6) and temporary erosion control (Step 7). If a particular site already has adequate soil resources, then plant materials installation can proceed with the confidence that plant growth will not be limited by soil conditions. Because of the wide variety of plant-soil interactions at wildlands field sites, specifications are made both by example from adequately vegetated sites as well as by a fundamental understanding of soil fertility.

**The Source Control Demonstration and Development Program:
An Adaptively Managed Program for the Control of Erosion in the Lake Tahoe Basin**

Michael Hogan

Integrated Environmental Restoration Services, PO Box 580, Tahoe, CA 96142

Telephone (530) 525-1335, E-mail: revegetate@earthlink.net

Scientific inquiry may be categorized as descriptive and prescriptive. Prescriptive science uses the scientific method to *address* solutions to physical, chemical, or environmental issues that have been *defined* through the descriptive process. In the Lake Tahoe Basin, a great deal of descriptive inquiry has been undertaken developing important information about the state of the Lake. One of the issues affecting Lake Tahoe's water quality is sediment delivery, especially from disturbed soils such as road cut and fills and dirt roadways. The ability to control erosion at its source through the use of revegetation techniques has proven problematic on Tahoe's thin, poorly developed soils. One reason for this may be application of techniques developed in agricultural settings to what are essentially wildland, nutrient-poor soil systems. The program described here uses prescriptive science to address wildland soil erosion and soil-plant restoration issues. The program employs an adaptive management framework as its foundation. Following this model, we are gathering information, defining information gaps and addressing some gaps through additional research, as well as developing a monitoring protocol that can actually measure the outcome of research-based field plots and whether those plots actually meet the goal of erosion reduction. This program is designed to bridge the crucial and often overlooked connection between descriptive and prescriptive science by field-truthing information gained in laboratory and greenhouse studies. Further, by applying this approach to a broad range of land management issues, we can produce cost-effective and definable output data for use in meeting specific land management goals. We are currently applying this approach with Caltrans, Northstar-at-Tahoe, Cave Rock Estates and elsewhere with unprecedented and measurable results.

Hydrology Tools for Mere Mortals

Jeff Wallace

EarthView Environmental Technologies, 15152 Northwoods Boulevard, Truckee, CA 96161

Telephone (530) 587-5806, E-mail: Earthview@thegrid.net

Anyone can understand hydrology, right? All it takes is a Ph.D. in math, 4 years of chemistry, a few terms of physics, and a solid grounding in geology (a background in computational fluid dynamics wouldn't hurt). But what about the majority of us who are challenged by the Discovery Channel? How can we ever hope to understand sound environmental management practices?

Here an overview of two online hydrology models designed to be used by people without extensive scientific backgrounds is presented. These models allow users to configure their own Best Management Practices (BMPs) and investigate the impacts (decrease or heaven forbid - increase) on runoff.

The first of these tools was designed for the Los Angeles County Department of Public Works (LADWP) to enlist community support for a BMP approach to an intractable flooding problem in the Sun Valley watershed. It allows users to size and "install" twenty-three virtual BMPs and investigate the impacts on runoff. The tool was so successful at convincing stakeholders of the feasibility of a BMP-oriented approach that LADWP is has incorporated these designs into its \$42 million stormwater management retrofit of the watershed. (A demonstration version of the model is available at www.parconline.com/runoff.html).

The Parcel Runoff Calculator (PaRC) is a tool for southern California developers who are required to capture the first $\frac{3}{4}$ of runoff onsite. One of the developers' major complaints was that the algorithm they were required to use (the Modified Rational Method) was too complex for them to calculate. PaRC addresses this problem by allowing developers to design and model the installation of storage, infiltration, and treatment BMPs to meet the $\frac{3}{4}$ goal – without needing to understand the calculations. (A demonstration version of PaRC is available at www.parconline.com).

Tahoe Integrated Information Management System (TIIMS)

Tricia L. York

Research, Monitoring and Evaluation Unit, Environmental Improvement Division

Tahoe Regional Planning Agency, P.O. Box 1038, Zephyr Cove, NV 89448

Telephone (775) 588-4547 ext.201, E-mail: tyork@trpa.org

The Tahoe Regional Planning Compact, ratified by Congress in 1969, identified the need to balance economic development with scenic, recreational, educational, scientific, natural, and human health values for the entire Lake Tahoe Basin. Through this compact, the Tahoe Regional Planning Agency (TRPA) was given a mandate for among other things, assessing the environmental quality of the Lake Tahoe Basin.

Since the Compact was ratified by Congress, federal, state, local, tribal, university, and non-profit organizations have spent large sums of money and collected volumes of data on over 30 parameters related to the nine thresholds, as well as non-threshold-related parameters. Though collecting the data is critically valuable to the long-term benefit of the basin, the benefit gained from the funds and the efforts are not being fully realized because the data are not being made available for use. The goal of the Tahoe Integrated Information Management System is to make this information available to TRPA and partner agencies, researchers and to the general public.

TRPA is required to assess the status of each of the nine thresholds throughout the basin every 5 years. For these evaluations, each monitored parameter for a threshold category is assessed against past years, and against the standard set for that threshold. Some of these parameters are evaluated more often, and some are monitored in near “real time,” but a comprehensive review of all threshold values occurs on a 5-year cycle.

During meetings and workshops and in most reports on the status of the basin, statements are often made that data being collected by the various groups must be well-integrated and readily available to researchers and decision-makers to effectively assess the status of the thresholds, evaluate effectiveness of mitigation efforts, and develop predictive models. However, no cultural or technical vehicle currently exists to facilitate this integration and the exchange of existing data. Therefore, despite the immense quantity of data collected, environmental managers are unable to effectively use the information to answer fundamental questions such as How do current thresholds stand compared to 2, 5, or 10 years ago? Have our mitigation efforts had an impact? or Where will we be in 10 years?

The Elemental Compositions of Lake Tahoe's Water and its Suspended Particles

Peter G. Green

Department of Civil and Environmental Engineering
University of California, One Shields Avenue, Davis, CA 95616
Telephone (530) 752-8581, E-mail: pggreen@ucdavis.edu

The clarity of Lake Tahoe is diminished by the scattering of light by particles. These particles are of biological and non-biological origin. Arrival of non-living particles may be through streams or from the air – the latter can be both dry deposition of ‘dust’, or in precipitation. Since the finest particles settle slowly, they can persist in such a deep lake. The elemental composition of water, and of fine particles in the water can be determined very sensitively and accurately with a new technique available in our department: ICP-MS, or Inductively Coupled Plasma – Mass Spectrometry.

With samples kindly delivered by the Tahoe Research Group, we have been analyzing whole (un-filtered) water to look for variations in composition – at different depths in a profile, for example. More recently, we have been trying to digest particles themselves collected on filters – effectively concentrating the suspended solids while leaving aside the various elements which are dissolved in the Lake as trace amounts of salts.

In the un-filtered water, we see strong depth-profile variations of elements like Aluminum (the most common metal in the Earth's crust) as well as Lead (usually associated with human influence). Many other elements are fairly well-mixed throughout the water column of the Lake – especially away from shore.

Our first attempts at analyzing the concentrated particles themselves have been fruitful, and will mark the beginning of a funded research project for a new graduate student. We can see much of the composition common in rocks, with enhanced levels of several elements. Our goal will be to sample the 12 major streams monthly, filter the particles into appropriate size groupings, and create both a ‘budget’ for this input as well as ‘finger-prints’ for the different creeks. Preliminary analysis of old stream samples (un-filtered) suggests several have strikingly different elemental compositions.

This is an entirely new aspect of Water Quality being considered, but it has already been helpful in identifying the major sources of non-biological particles, can direct remediation efforts, and be useful in measuring changes as improvements are implemented.

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