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Correspondence: Manuscripts should be submitted to Dr. Michael Strobel, USGS, 2730 North Deer Run Road, Carson City, NV 89701. Inquires: (775) 887-7604, mstrobel@usgs.gov

Cover photo by T.G. Rowe: Lake Tahoe east shore point near Sand Harbor, NV

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SCIENCE AS A TOOL IN LAKE TAHOE BASIN MANAGEMENT

Lake Tahoe Science Plan Special Workshop

October 18-20, 2006

Tahoe Center for Environmental Sciences
Sierra Nevada College,
Incline Village, Nevada

Sponsored by:

California Tahoe Conservancy
Desert Research Institute
Sierra Nevada College
Tahoe Integrated Imformation Management System (TIIMS)
Tahoe Regional Planning Agency
Tahoe Science Consortium
U.S. Forest Service – Lake Tahoe Basin Management Unit
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Editor's Note

Michael L. Strobel, Journal of the Nevada Water Resources Association

In this special edition of the Journal of the Nevada Water Resources Association, abstracts from the 2006 Lake Tahoe Science Plan Workshop entitled "Science as a Tool in Lake Tahoe Basin Management" are presented. These abstracts are published in their original format as presented at the workshop and have not undergone the usual peer review that technical articles usually receive by the Journal of the Nevada Water Resources Association assistant and associate editors. We felt it was important to publish these abstracts in order to make them available to the public, but because they have already been presented at the workshop, additional editing should be withheld. We hope the information provided in this special edition is useful for both describing the present scientific activities in the Lake Tahoe Basin and as a tool for making wise and informed management decisions that utilize research and monitoring.

Letter from the Chair of the 2006 Lake Tahoe Research Symposium

Tim Rowe

On behalf of the Nevada Water Resources Association, Tahoe Science Consortium, Tahoe Center for Environmental Sciences, U.S. Geological Survey, and the entire Planning Committee, we would like to welcome you to the 2006 Lake Tahoe Research Workshop. Also welcome to the new Tahoe Center for Environmental Sciences here at Sierra Nevada College. This is a cooperative venture with Sierra Nevada College, University of California, Davis – Tahoe Environmental Research Center, Desert Research Institute, and University of Nevada, Reno. We'd like to thank the Center and the college for hosting this event and adjusting their schedules for the workshop.

The theme for the biennial symposium again is "Science as a tool in Lake Tahoe Basin management." This year is a special version, as it is the Special Workshop for the Lake Tahoe Science Plan. The recently formed Tahoe Science Consortium (TSC) has a goal to produce a comprehensive science plan for the Basin that addresses critical science need for effective long-term resource management, The workshop will provide a collaborative and open forum in which individuals involved in the science and management of the Basin can learn about, discuss, and help focus the emerging research themes and strategies. The committee thought that the workshop format would provide and encourage many opportunities for participation, feedback and comments. We hope you will roll up you sleeves, get involved in and exchange your ideas/suggestions for the Science Plan.

We also hope that you enjoy the keynote addresses and Science Plan theme overview presentations. Please explore through the approximately 70 posters during the poster session and reception on various levels of the center both evenings. We encourage dialog with poster authors on recent/current research related activities in the Lake Tahoe Basin.

Again, welcome to TCES, and thanks for your involvement and interest in the Lake Tahoe Science Plan.

Letter from the Tahoe Science Consortium Executive Director

Zach Hymanson

On behalf of the Tahoe Science Consortium (TSC), welcome to the 2006 Lake Tahoe Science Plan Workshop: Science as a Tool in Lake Tahoe Basin Management. The TSC was formed to enhance the working relationship amongst the research institutions and between the research institutions and management agencies working in the Tahoe Basin. Our mission is to contribute to the restoration of Lake Tahoe, its watershed, and its air basin by providing the best scientific information possible for management of the Basin's natural resources. It is recognized that substantial gaps exist in our current understanding of ecological processes in the Lake Tahoe Basin, and that a unified and collaborative approach to addressing these gaps in knowledge can provide the most efficient path to restoring and maintaining the Basin's complex ecosystems.

It has been a pleasure to be part of the planning process for this exciting event, which will help the TSC and all of those concerned about the welfare of the Lake Tahoe Basin reach a common goal of developing a comprehensive science plan for the Lake Tahoe Basin. Your participation in this workshop will play a vital role in the development of this plan.

The workshop discussions will allow you to learn about the issues currently facing management agencies and the associated science information needs. In addition, there are numerous opportunities to network with your colleagues. I hope the many discussions you have during the workshop increase your knowledge of the Tahoe Basin, enhance your current professional relationships, and allow you to start new relationships that last throughout your career.

Table of Contents

Page

Air Quality

Source Characterization and Emissions in Lake Tahoe from Road Dust, Wood Smoke, and Vehicle Exhaust

Hampden Kuhns, M.-C. Oliver Chang, Judith C. Chow, Vic Etyemezian, Lung-Wen Antony Chen, Nicholas Nussbaum, Suresh Kumar K. Nathagoundenpalayam, Dana Trimble, Steve Kohl, Mary MacLaren, Mahmoud Abu-Aliban, Jack Gillies, Alan Gertler
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512
hkuhns@dri.edu

Chris Damm, Cliff Denney, John Skotnik, and Candace Gallery
Sierra Nevada College

This study investigated the chemical composition and emission factors of selected particulate matter (PM) sources in the Lake Tahoe basin. PM is of interest because particles either by themselves or acting as nutrients or attachment points for algae are obscuring water clarity in the lake. Particulate matter (PM) samples directly relevant to major PM sources in Lake Tahoe were collected and analyzed as part of this study. Sources sampled included residential wood combustion, motor vehicle exhaust, and entrainment of road dust, traction control material, and road deicing material. In addition, emissions factors were used to estimate the distribution of emissions in the Tahoe Basin.

The study estimated that emissions from residential wood combustion and road dust were the largest sources of particulate matter on an annual basis. It is likely that road dust will have a larger deposition flux to the lake due to the larger size (2.5 um to 10 um) of the road dust particles versus the smaller size (~0.5 um) of the wood burning emissions.

Estimates of Nutrient and Fine Particulate Matter to Lake Tahoe from Atmospheric Deposition: A Summary of Measurements

John E. Reuter, Scott H. Hackley
Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
(530)304-1473 John Reuter
(530)583-3270 Scott Hackley
jereuter@ucdavis.edu

Thomas A. Cahill
DELTA Group
University of California, Davis
Davis, CA 95616
(530)752-4674
tacahill@ucdavis.edu

Since at least 1994 the importance of atmospheric deposition of nutrients directly to the surface of Lake Tahoe has been recognized as an important contributor of phosphorus and especially nitrogen. The primary source of this data for many years has been the direct collection of precipitation and dry fallout made by the UC Davis – Tahoe Environmental Research Center (TERC). Sampling buckets continue to operate in Ward Valley and on lake-based buoys, with measurements made for various species of nitrogen and phosphorus. In 1997 researchers at the Desert Research Institute (DRI) began to develop estimates of nitrogen contribution from the atmosphere as dry deposition estimates for inorganic-N. The experimental approach used by these groups was fundamentally different - TERC collected material that was directly deposited in buckets to simulate lake conditions. DRI measured ambient air N-concentrations then modeled deposition to the lake surface.

With the onset of the Tahoe TMDL Program in 2002 an effort was made to reduce uncertainty associated with these measurements. At the same time, new research results pointed to the importance of fine particles (< 20 µm diameter) to lake clarity. Data for lake-wide atmospheric deposition of these fine particles was not available. In 2002 the California Air Resources Board funded and conducted the Lake Tahoe Atmospheric Deposition Study (LTADS) to look at the fine particle deposition and provide additional estimates of nitrogen and phosphorus deposition. LTADS also modeled atmospheric deposition using ambient air concentrations. Finally, and at the same time, the UC Davis – DELTA Group began a study of size, time and compositionally resolved aerosols at Lake Tahoe, including phosphorus. Information from those four studies has been used in the TMDL and is summarized in this presentation.

The comparison between TERC (direct measure) and LTADS (air measurements/modeling) for annual dry total-N deposition was remarkably similar at 127 metric tons (MT) and 144 MT, respectively for the 2003-2004 period of record. Inorganic comprised approximately 70% of the TN. DRI, LTADS and TERC estimates for dry inorganic-N deposition during the summer dry period were also very similar. Field measurements of wet deposition made by TERC averaged

approximately 60 MT/yr and accounted for approximately 30% of the estimated bulk TN deposition directly to the lake. Given the low number of sampling sites, the error associated with both modeling and the bucket experimental design, and the difficulty associated with measuring ambient-P in the air, annual dry deposition estimates for total-P by the DELTA Group, TERC and LTADS were also very similar at 5.4 MT (2001, CalTrans using volcanic cinders, 2003 estimated 3.5 MT, CalTrans using granite sand), 2.8 MT and 2.3 MT, respectively. Modeled wet deposition for total-P (LTADS) was 4.2 MT while measured (TERC) was 2.8 MT. Total-P as bulk deposition ranged from 5.1-8.2 MT/yr using all results. Estimates for soil-based particulate matter (PM) come from LTADS, the only year-round study. The best annual estimate for total dry PM-deposition ($PM_{2.5}$+$_{PM2.5-10}$+$PM_{>10}$) was 580 MT/yr. Wet deposition of total PM was approximately 850 MT/yr. The uncertainty associated with PM deposition requires additional study as these were the first estimates and only measured over a limited time.

A water quality model was parameterized and calibrated using Hydrologic Simulation Program – Fortran (HSPF) for a 15-km reach of the Truckee River where river restoration had occurred in October 2003. This restoration included narrowing the channel, raising the river bed, and enhancing two existing riffle sections. The objective of the modeling effort was to simulate changes in nitrogen assimilative capacity that may occur due to river restoration, including changes in nitrogen uptake and regeneration by benthic algae. This was accomplished by comparing model output between pre- and post-restoration scenarios. Results indicated that all simulated levels of restoration resulted in increases in the overall uptake of total inorganic nitrogen (i.e., ~80-300 kg per year), but the species of nitrogen assimilated by benthic algae differed between restoration scenarios. Thus, river restoration combined with river management may result in more effective management of nitrogen assimilation on the Truckee River.

BMP Implementation and Assessment

Targeting Fine Particle and Phosphorus Removal with Chemical Treatment Technologies

Phil Bachand
Bachand & Associates
2023 Regis Dr.
Davis, CA 95616
phil@swampthing.org

Alan Heyvaert
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512
alan.heyvaert@dri.edu

John Reuter
UCD Tahoe Environmental Research Center
P.O. Box 633
Tahoe City, CA 96145
jereuter@ucdavis.edu

Most standard best management practices (BMPs) used for stormwater treatment do not adequately target the removal of fine particles or dissolved phosphorus. Typical urban and highway runoff samples from the Tahoe Basin have a high percentage of particles under 10 microns in size and dissolved phosphorus concentrations that can vary over a wide range, from 0.1 to 1.5 mg/L or more. Settling times for the <10 micron particles in detention basins are on the order of weeks rather then hours or days, so most sediment traps and flow-through basins are not very effective at fine particle removal. Moreover, they are not very effective at removal of dissolved phosphorus either, since the soils of treatment basins are relatively low in phosphorus adsorptive capacity and are not optimized for biotic uptake or mineralized immobilization of phosphorus.

Chemical treatment technologies can be used to enhance pollutant removal by BMPs and have shown promise for removing both fine particles and dissolved phosphorus. Results from our studies have shown that several types of adsorptive media can provide much higher phosphorus sorptive capacity then native soils, and that chemical coagulation can effectively convert dissolved phosphorus to a particulate form in laboratory and microcosm studies. Furthermore, tests with flocculants have demonstrated that settling times can be an order of magnitude faster than for fine particles without flocculants. This study looks at several key design issues that will be important for the implementation of chemically enhanced best management practices and discusses how chemical technologies could be integrated with current stormwater management practices to more effectively target fine particle and phosphorus removal. It also describes our work on logistical, environmental (e.g., ecotoxicological) and performance issues that must be addressed before these technologies can achieve broad-scale implementation in the Tahoe Basin.

Detention Basin Treatment of Hydrocarbon Compounds in Urban Stormwater, South Lake Tahoe, CA

Nicole G. Beck, PhD
Principal
2NDNATURE, LLC
321 Frederick Street
Santa Cruz, CA 95062
(831) 426-9119
nbeck@2ndnatureinc.com

The South Lake Tahoe Hydrocarbon Study was funded by the South Tahoe Public Utility District to evaluate the potential risk of inadvertent hydrocarbon contamination to the shallow groundwater resources as a result of induced urban stormwater infiltration. The field data collection specifically focused on the stormwater introduced to, and infiltrated through, two dry detention basins within the urban limits of the City of South Lake Tahoe, Eloise Basin and Industrial Basin.

The field data collection spanned two complete water years (WY2004 and WY2005) and included monitoring from the first winter rains in WY2006. The field monitoring consisted of stormwater sample collection from the inflow to, and storage within, the respective detention basins during runoff events, coupled with shallow groundwater monitoring surrounding the basin if the local water table showed a hydrologic response to basin infiltration. The detailed hydrogeologic data collection illustrated the distinct differences of two unique detention basins in routing stormwater to the local groundwater table. An expansive, complex basin morphology maximizes the function of key mechanisms that reduce hydrocarbon constituents in stormwater, while also maximizing the potential dilution effect by the local shallow groundwater table. Stormwater monitoring resulted in consistent detections of heavy petroleum hydrocarbons (TEPH and TPH-diesel) with less frequent detections of oil and grease. Low level detections of VOC's were observed in approximately 20% of the stormwater samples collected, primarily toluene and xylenes. Other key petroleum constituents, including benzene, ethylbenzene, and oxygenates (MtBE, TAME, TBA, etc.) were not detected in any of the surface water samples collected. None of the monitoring wells installed for this project (12) contained detectable levels of hydrocarbons, VOCs or oxygenates following the analysis of over 70 shallow groundwater samples collected in locations potentially impacted by detention basin infiltration. One groundwater sample collected from a monitoring well installed for an adjacent LUST monitoring program did contain trace levels of toluene and xylenes, but the lack of other groundwater detections in project wells makes the causal connection to Eloise Basin stormwater infiltration questionable. The levels of TPH-diesel detected in the surface water samples consistently exceeded the LRWQCB numerical groundwater quality objectives for petroleum hydrocarbon constituents to meet municipal beneficial uses. In locations where stormwater is routed to the shallow groundwater and soil treatment is minimal (such as dry wells) the elevated levels of TPH-diesel and TEPH constituents in urban stormwater may have the greatest potential to adversely impact shallow groundwater quality.

Lake Tahoe Basin BMP Monitoring Evaluation Process
Synthesis of Existing Research

Nicole G. Beck, PhD
Principal
2NDNATURE, LLC
321 Frederick Street
Santa Cruz, CA 95062
(831) 426.9119
nbeck@2ndnatureinc.com

The BMP Monitoring Evaluation Process was funded by the USFS, LTBMU to compile and synthesize the existing research on BMP water quality improvement performance. The synthesis consisted of a detailed review and evaluation of study designs, study communications, available data and general BMP performance. The primary BMPs evaluated in the Lake Tahoe Basin to date were detention basins (3), constructed wetlands/wet basin/meadow (3), and mechanical treatment structures (8). One source control study and two controlled experiments were also reviewed and incorporated into the synthesis. Based on the independent nature of Lake Tahoe water quality monitoring studies, the strengths and weaknesses of various studies were used to develop recommendations to standardize pollutant nomenclature, pollutant parameters of concern, monitoring study priorities, study communication structure, necessary BMP design and catchment characteristics to be included in study communications, data reporting structure, etc.

Preliminary quantitative comparisons of inflow and outflow BMP event mean concentrations (EMCs) and reported study BMP load and EMC reductions were conducted for each final report, where applicable. Preliminary comparisons support the need to identify and target the primary pollutants of concern in the inflowing stormwater, in order to properly select and design the appropriate BMP. Evaluations of mechanical treatment structures, such as vaults, sand traps and roadside sediment basins, suggest effective treatment of particulate pollutants as measured by reductions in total suspended solids (TSS), total organic nitrogen (TKN) and particulate phosphorous (PP). The greatest limitation of mechanical treatment structure performance is inconsistent maintenance, which undoubtedly results in the observed elevated effluent dissolved constituents, such as nitrate (NOx), ammonia (NH_4^+), dissolved phosphorous (DP), and soluble reactive phosphorous (SRP). Detention basin evaluations suggest consistent treatment of particulate pollutants, but variable treatment of dissolved constituents. Preliminary comparisons suggest detention basin characteristics may be unable to further reduce dissolved constituents when inflowing concentrations approximate NOx < 250 ug/L, NH_4^+ < 50 ug/L, SRP < 50 ug/L, and DP < 80 ug/L. Wetland/wet basin systems may provide the additional treatment capabilities to “polish” stormwater and further reduce dissolved nutrient loads when concentrations are low, but biogeochemical cycling in eutrophic wet environments may not reduce dissolved nutrients to acceptable levels and management alternatives should be explored. A standardized reduction of data and database creation effort would make the existing and future data directly accessible for Phase II of the TMDL, the BMP Design Manual, and other planning efforts that will be based upon Lake Tahoe specific water quality observations.

Porous Pavement – Implementation and Policies in the Tahoe Basin

Chris Conway, CPSWQ
Kennedy/Jenks Consultants
5190 Neil Road, Suite 210
Reno, NV 89502
Phone (775) 827-7900
Fax (775) 827-7925
chrisconway@kennedyjenks.com

In a number of communities in the U.S., Europe and Australia, porous pavement (concrete and asphalt) has been shown to be an effective BMP in the reduction of the rate and volume urban runoff and the treatment of associated pollutant loads. However, concerns persist that porous pavement has limited applicability, clogs over time, may be problematic in freeze/thaw environments, and is not cost effective. This presentation will provide an overview of several of the existing applications of porous pavement in the Lake Tahoe basin and examine the policies related to its implementation. In addition, the concerns about porous pavement will be examined based on its performance in other communities, particularly those with similar geographic settings to the Lake Tahoe basin. Finally this presentation will examine the policies and procedures developed by other communities to promote the use of porous pavement in new development and significant redevelopment projects.

Implications of engine emissions in Lake Tahoe soils and sediments

Veronica Edirveerasingam
Sandra Carroll
University of Nevada Reno
Environmental Sciences and Health Graduate Program
Mail stop 199, Reno, 89557
(775) 274-6654
vedirvee@unr.nevada.edu carroll@unr.nevada.edu

Glenn C. Miller
University of Nevada Reno
Environmental Sciences and Health Graduate Program
Mail stop 199, Reno, 89557
(775) 784-4108
gcmiller@unr.nevada.edu

The presence and distribution of polycyclic aromatic hydrocarbons (PAH), petroleum hydrocarbons (PHC) in several Lake Tahoe soils and sediments suggest that vehicle input is a major pollutant contributor. The PAH profile in marina sediments, road runoff locations and from water collected immediately after running a 4 stroke engine in a tank had similar signatures, and data collected in this study offered strong evidence that engine emissions were the primary source of these hydrocarbon contaminants in Lake Tahoe soils and sediments. Two PAH's, fluoranthene and pyrene were observed at relatively high concentrations, and were signature compounds in the sediments. In addition, a strong and positive correlation existed for PAH and TPH in road runoff soils and marina sediments indicative of PAH related to vehicle emission.

Phosphorus is an additive to most 4-cycle engine oils and observed at a concentration of 700-1500 mg/L in new and used engine oils. Although this source of phosphorous is potentially significant for nutrient addition to Lake Tahoe, it comprises only a relatively small fraction in the soils and sediments, compared to natural concentrations. The Tahoe soils examined had a total phosphorus content of 500-1000 mg/kg and an available phosphorus content of 20-100 mg/kg. Assuming 0.1 % of phosphorus content in the oil and a TPH content of 3000-5000 mg/kg in the highly vehicle affected areas, the phosphorus contribution from engine oil is only 3-5mg/kg.

Alternatively, the hydrocarbon contaminated sediments released more phosphorus into the water under anaerobic conditions and suggests that petroleum hydrocarbons can drive anaerobic processes that eventually will release phosphorus. This is likely an issue in marina sediments, as well as flooded catchment basin sediments.

The three catchment basins examined in the Kings beach area appeared effective in retaining the contaminants. The inlets had high TPH, and PAH concentrations in comparison to the outlets and soil cores collected at different depths in each basin had hydrocarbon concentrations low in the native depths and high in the layer where sediment had accumlated. PAH leaching was evaluated in basin soils and the results indicated that only a small fraction (<0.1%) of PAH compounds would leach.

Activated Alumina Filters: Turbidity and Nutrient Removal in Full-Scale Pilots at Lake Tahoe

Dipen M. Patel, Ph.D.
Research Engineer, Office of Water Programs, California State University, Sacramento
6000 J Street, Modoc Hall Room 1001
Sacramento, California, 95819-6025
(916) 278-8119
dipen.patel@owp.csus.edu

Stefan Schuster, P.E.
Project Engineer, CDM, Inc.

John Johnston, Ph.D.
Professor, Department of Civil Engineering,
California State University, Sacramento

Julie Myers, P.E.
Project Coordinator, Division of Environmental Analysis
California Department of Transportation

The California Department of Transportation (Caltrans), which is responsible for more than 500 storm water discharge points in the Tahoe Basin, is developing and testing new treatment technologies to meet Tahoe Basin regulatory numeric effluent discharge limits. Settling and gravity filtration treatment systems are of particular interest because of their relatively low maintenance requirements and potential for deployment within the Caltrans right-of-way.

Two full-scale activated alumina pilot filters were constructed in 2003 on Highway 50 in South Lake Tahoe to evaluate treatment performance, media life, and maintenance needs. These filters, which consist of 6 inches of fine sand overlaying 12 inches of activated alumina, are partial sedimentation Austin-type filters in which sedimentation occurs over the media surface. One filter was sized according to standard design procedures. The other filter was designed with a filter surface area one-third of standard design to increase the hydraulic and pollutant loading rates. This was done to accelerate the onset of surface clogging and/or pollutant breakthrough, and to give insight into the effect of loading rate on treatment performance. The filters have been monitored for three wet seasons and performance data collected for more than 25 rain, rain-on-snow, and snowmelt events at each site.

Preliminary data analysis indicates that treatment by activated alumina filters is far superior to that possible with conventional sand filters, but that this treatment failed to consistently meet the surface discharge numeric effluent limits for turbidity and phosphorus. About 55 % of effluent samples met the surface discharge limit for turbidity of 20 NTU, and over 80% of effluent samples met the surface discharge limit for total phosphorus of 0.1 mg/L. The full-sized filter reduced average influent turbidity and total phosphorus from 366 to 26 NTU and from 0.35 to 0.06 mg/L respectively. Similarly, the reduced-area filter decreased average influent turbidity and total phosphorus from 165 to 28 NTU and from 0.33 to 0.07 mg/L respectively. Neither

filter showed any indication of turbidity or phosphorus breakthrough over the period of monitoring. The full-sized filter has not required maintenance to date, indicating that activated alumina filters designed according to standard design procedures should operate for at least three years before requiring maintenance.

Restoration and Enhancement of Stream Environment Zones in the Lake Tahoe Basin

Dave Rios
Assistant Program Manager – Environmental Monitoring
Nevada Tahoe Conservation District
PO Box 4605
Stateline, NV 89449
drios@ntcd.org

Scott Brown
Associate Program Manager - Water Quality
Nevada Tahoe Conservation District
PO Box 4605
Stateline, NV 89449

Matt Vitale
Senior Program Manager – Water Resources Group
Nevada Tahoe Conservation District
PO Box 4605
Stateline, NV 89449
(775) 586-1610 x30
mvitale@ntcd.org

Doug Martin
District Manager
Nevada Tahoe Conservation District
PO Box 4605
Stateline, NV 89449
dmartin@ntcd.org

Rosewood Creek drains a small urbanized watershed in Incline Village, Nevada to Lake Tahoe. Since the 1950s, the creek has become incised 6 to 8 ft in some sections and has been documented as a major contributor of fine sediments to the Lake. Although not all reaches are degrading, active down cutting in the incised reaches will continue to occur eventually affecting existing stable reaches. Phase I implementation on Rosewood Creek restored 3,200 feet between Lakeshore Blvd and Highway 28 by constructing a new bio-engineered channel. Two years of post-project monitoring for a series of small, low-elevation snowmelt events suggest the restored reach can reduce sediment load by up to 50%. Phase II of Rosewood Creek restoration is currently in design and would restore or enhance up to 7,400 feet of the creek above the Phase I effort. A new monitoring station was installed in the spring of 2006 upstream of any in-channel restoration activities to document background water quality conditions. Few projects of this magnitude, complexity, and diversity have been implemented in the Tahoe Basin. Specifically, this project poses several funding and implementation challenges because it involves multiple private and public land parcels. Successful completion would reduce suspended sediment load to the lake but also improve the aesthetics and riparian habitat of this creek.

Evaluation of Stormwater Infiltration at the Upper Cutthroat Erosion Control Project

Collin Strasenburgh
UCD Tahoe Environmental Research Center
P.O. Box 633
Tahoe City, CA 96145
cstrasenburgh@ucdavis.edu

Alan Heyvaert
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512
alan.heyvaert@dri.edu

Andrea Parra
UCD Tahoe Environmental Research Center
P.O. Box 633
Tahoe City, CA 96145
atparra@ucdavis.edu

Raph Townsend
UCD Tahoe Environmental Research Center
P.O. Box 633
Tahoe City, CA 96145
rptownsend@ucdavis.edu

Dave Vacarello
Placer County Department of Public Works
10825 Pioneer Trail, Suite 105
Truckee, CA 96161
dvaccare@placer.ca.gov

Charles Goldman
UCD Tahoe Environmental Research Center
P.O. Box 633
Tahoe City, CA 96145
crgoldman@ucdavis.edu

Infiltration is an important strategy for Tahoe Basin stormwater management. Yet, to date there have been only limited data available to determine the effectiveness of different infiltration practices. The Upper Cutthroat Erosion Control Project, constructed by Placer County, implemented a series of infiltration components. This study evaluates the effectiveness of those components under different seasonal conditions and during two simulated events conducted in Water Year 2006 (October 1, 2005 – September 30, 2006).

The Upper Cutthroat Project was constructed within a largely residential area of Kings Beach, CA, on the north shore of Lake Tahoe, in a neighborhood characterized by steep slopes with poor drainage control. To address problems such as high erosion, sediment deposition and localized flooding, several infiltration components were constructed, including sediment traps, an infiltration gallery, an infiltration/sedimentation basin, rock-lined ditches, three infiltration swales, and revegetated areas.

The principal objectives of this study were to:

- Quantitatively demonstrate under natural and simulated conditions whether these infiltration components are effective at reducing run-off volumes within the project area.
- Provide empirical data for model development to improve future project designs.

Data were obtained by monitoring flow through selected infiltration components as well as monitoring total outflow from the project area on a continual basis through the year. Additionally, water levels were monitored at the infiltration gallery and in groundwater piezometers. Simulated events introduced water to each project component in series and monitored the steady state infiltration rates during both seasonally moist and seasonally dry soil conditions. The specific infiltration rates for each project component were calculated from these experiments. These data are discussed in the context of seasonal soil moisture conditions, event runoff volumes, infiltration design factors and model calibrations.

Methodology to Estimate Pollutant Load Reductions

Eric Strecker
GeoSyntec Consultants
55 SW Yamhill Street, Suite 200
Portland, Oregon 97204
estrecker@geosyntec.com

P.E., Edward Wallace
Northwest Hydraulic Consultants
3950 Industrial Blvd.
West Sacramento, CA. 95691
ewallace@nhc-sac.com

P.E., Marc Leisenring EIT,
Brent Wolfe P.E., Peter Mangarella Ph.D., P.E.
Northwest Hydraulic Consultants
3950 Industrial Blvd.
West Sacramento, CA. 95691

Lake Tahoe is considered impaired for fine particulates (<20 um), and nitrogen and phosphorus, and is listed under Section 303(d) of the Clean Water Act by the California Regional Water Quality Control Board, Lahontan Region, and Nevada Department of Environmental Protection. A key element in the TMDL program is the use of an accepted and consistent methodology for estimating pollutant load generation and reduction associated with land development, and other activities.

This paper describes the results of a project conducted jointly by the Army Corps of Engineers and the Lahonton Water Board to develop and test a methodology that can be used to estimate pollutant load reductions for water quality improvement projects in the Lake Tahoe Basin.

The methodology consists of a hydrologic component, a load generation component, and a load reduction component. The methodology addressed inorganic particulates <20 microns, nitrogen species, and phosphorous species; and is generally applicable to catchments 5 to 100 acres in size. The spreadsheet runs EPA SWMM, a continuous hydrologic simulation model, to run "in the background" based on simplified input parameters, and automatically links this simulation to load generation and load reduction computations. In addition to simulating the runoff characteristics of a project area, the spreadsheet tool allows for input of design criteria for sizing treatment BMPs and for specifying the rates at which treatment BMPs will drain. The average annual runoff volume from the continuous simulation is used by the pollutant load generation element to determine average annual pollutant loads generated.

The methodology employs two techniques to estimate pollutant load generation: 1) spatially distributed source accounting (land use based pollutant loading), and 2) specific source accounting (e.g., gully erosion, eroding disturbed areas, road sand). Spatially distributed source accounting estimates pollutant load generation using the land use based event mean

concentrations (EMCs), taken from Tahoe Basin monitoring data. Specific source accounting estimates pollutant load generation for sources that are generally not associated with land uses (e.g., road sand, gullies, drainage system degradation, etc).

The reduction in pollutant load achieved by a treatment BMPs depends on the portion of the runoff treated and the extent of treatment achieved. The methodology also takes into account multiple treatment units and flow routing through and around the treatment unit(s).

Results of initial testing of the methodology have been promising, but the methodology and the associated spreadsheet tool will require additional testing and refinement before wide-scale application.

Stormwater BMP Evaluation and Feasibility Study- An Initial Assessment of the ability of BMPs to meet Potential TMDLs for Lake Tahoe

Eric Strecker
Jim Howell
Andi Thayumanavan
Marc Leisenring
Marcus Quigley
GeoSyntec Consultants
55 SW Yamhill Street, Suite 200
Portland, Oregon 97204
estrecker@geosyntec.com

John Reuter
Tahoe Research Group
University of California, Davis
Davis CA, 95616
(530) 304-1473
jereuter@ucdavis.edu

Over the past several decades, there has been a noticeable decline in the clarity of Lake Tahoe. The subject has been one of much study and the scientific community agrees that this decline is largely due to increased human activities within the watershed tributary to the lake as well as potential atmospheric deposition from regionally adjacent areas. Although BMPs have been implemented to reduce pollutants in surface runoff, water quality of the Lake has still not improved to desired levels. Therefore, enforceable restrictions on nutrients and sediment being carried to the lake via surface water, Total Maximum Daily Loads (TMDLs), are being established for the Lake's watershed. The purpose of this Stormwater BMP Evaluation and Feasibility Study was to evaluate the potential cost-effectiveness and other attributes of alternative project level and basin-wide enhanced BMP implementation for reducing urban runoff pollution to Lake Tahoe. As part of this study, the effectiveness of a variety of currently implemented BMPs, viable improvements to these BMPs, and potentially effective new and enhanced technologies were evaluated. This presentation will describe the approach for gathering and developing this information. This information was intended to be an initial assessment of potential BMP strategies for meeting as yet defined TMDLs. The results of this work were intended to ultimately be incorporated into the watershed model to estimate the potential reductions in loading of pollutants to the lake through BMP implementation on a basin-wide scale. The current and potential future performance of BMPs (and their costs) will be considered within the context of TMDL development as well as in future Tahoe Basin plan development efforts. The paper provides a summary of the potential for BMPs and enhanced BMPs to meet potential loading reductions for fine particulates and nutrients.

The approach included assessing the performance of BMPs by applying a combined unit processes and observed BMP performance data approach. It included long-term simulation modeling to ascertain the hydrologic and hydraulic performance of potential BMP sizing and designs to assess the amount of runoff that could be treated under various sizing and hydraulic designs. For water quality, sedimentation was estimated by modeling particle removals based on particle settling theory. Other water quality constituents were modeled via a statistical approach based upon the observed performance of BMPs from the International BMP Database as well as local Tahoe BMP monitoring Data.

The effort determined that significant reductions in fine particulates and phosphorus are achievable if appropriate BMP types (wet ponds, wetlands, and extended detention ponds with a small pool) are employed. The figures below include a summary comparison of BMP performance information from the International BMP Database and local Lake Tahoe BMP data. The second figure shows the effects of pond sizing vs. release rates vs. expected runoff captured (treated) and removal of fine particulates. It was interesting to note that given a desired release rate (drawdown time) that building larger basins then optimal could reduce the amount of particulates removed. The project demonstrated the importance of BMP selection, sizing and hydraulic design for maximizing potential performance. The project demonstrated the value of applying a combined unit processes and observational data approach for estimation of potential BMP performance.

Ground-Water Quality and Flow Responses from Storm-Water Detention Basins—Best Management Practices, South Lake Tahoe, California

Carl E. Thodal and Jena M. Green
Hydrologists
U.S. Geological Survey
Nevada Water Science Center
2730 N. Deer Run Road
Carson City, NV 89701
(775) 887-7685
(775) 887-7692
cethodal@usgs.gov
jmgreen@usgs.gov

In 1983, Lake Tahoe (Nevada–California) was designated an "outstanding national water resource" by the U.S. Environmental Protection Agency, in part, for its exceptional clarity. Decreasing clarity of Lake Tahoe has been attributed to human activities that increase nutrient inputs, which stimulate algal growth. Different methods of estimating nutrient inputs from ground water to Lake Tahoe have been used. However, these estimates rely on regionalized aquifer properties and assume average nutrient concentrations in ground water. A more detailed understanding of ground-water flow and nutrient transport is necessary because Environmental Improvement Program projects encourage infiltration of urban runoff to ground water in order to comply with total maximum daily load regulations.

South Lake Tahoe, California, is the most urbanized community in the Lake Tahoe Basin and has numerous storm-water-control projects constructed to mitigate runoff. One study instrumented two adjacent detention basins at South Lake Tahoe in order to study storm-water and shallow ground-water quality and the effects storm water has on ground-water quality over the course of one seasonal cycle. For this study, nutrient loads from ground water to the lake will be estimated as the product of representative nutrient concentrations in ground water and modeled ground-water discharge to the lake. Locations where nutrient-enriched ground water seeps directly into Lake Tahoe also will be investigated.

Water and bottom sediment from the infiltration basins are being sampled for dissolved major ions, nitrogen and phosphorus, organic carbon, selected trace elements associated with storm water, and stable isotopes of the water molecule. Samples from surface-water inflow, selected nearby wells, and ground-water discharge to Lake Tahoe also are being collected for chemical analyses. Water-temperature surveys along the lakeshore will be made to identify zones of ground-water seepage. Several methods will be employed, in 2006–07, to estimate ground-water flow away from the detention basins and into Lake Tahoe. These methods include eddy-diffusion calculations, delta Oxygen-18, and hydraulic gradients measured in temporary piezometers and numerical modeling.

Performance Evaluations and Maintenance Considerations for Wetland BMPs

Raph Townsend
Andrea Parra
Collin Strasenburgh
John Reuter
UCD Tahoe Environmental Research Center
P.O. Box 633
Tahoe City, CA 96145
rptownsend@ucdavis.edu
atparra@ucdavis.edu
cstrasenburgh@ucdavis.edu
jereuter@ucdavis.edu

Alan Heyvaert
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512
alan.heyvaert@dri.edu

Dave Vacarello
Placer County Department of Public Works
10825 Pioneer Trail, Suite 105
Truckee, CA 96161
dvaccare@placer.ca.gov

Ross Wigart
Theresa Loupe
California Tahoe Conservancy
1061 Third Street
South Lake Tahoe, CA 96150
rwigart@tahoecons.ca.gov
tloupe@tahoecons.ca.gov

Constructed wetland systems have been shown effective for treatment of stormwater runoff from commercial, residential and other urban impacted landscapes. Over the long-term, however, these wetlands systems are likely to show diminishing performance as nutrients, vegetation and sediments accumulate. Natural wetlands, for example, often have lower long-term assimilative capacities than the short-term uptake rates typical of younger constructed systems. Most treatment wetlands and basins that receive and reduce pollutants from urban runoff will eventually require some level of maintenance or regeneration to maintain optimal performance. At present, however, it is unknown when this will occur or what practices should be implemented to enhance treatment performance. This study looks at the changes in condition and treatment performance of the Tahoe City Wetland Treatment System (TCWTS) since its construction in 1997.

Extensive water quality monitoring at the TCWTS has demonstrated that this system is effective at removing particulates and dissolved nutrients from stormwater runoff throughout the year, achieving median improvements of 49 percent or greater in effluent concentrations of dissolved phosphorus, nitrate, orthophosphate, and total suspended solids. Net nutrient retention was estimated at 3 g phosphorus (P)/m^2/y and 13 g nitrogen (N)/m^2/y, with about 4000 kg of suspended sediment captured per year. Water storage capacity of the TCWTS has been adjusted periodically with weir boards at the outflow point, yielding typical water depths from about 8-24 inches, depending upon season and event characteristics. Recently, however, vegetation and sediment accumulation within the system has required operation at greater weir board heights, suggesting that water storage capacity may be declining, with long-term consequences on pollutant removal efficiency.

This study looks at the changes in vegetation abundance and distribution, sediment accumulation, stormwater flow paths through the wetland, and water depths to evaluate effects on water quality. These data are then discussed in the context of maintenance options and regeneration strategies that would be appropriate as the treatment wetland matures.

Fire Ecology and Fuels Management

Update on the Effect of a Large Uncontrolled Wildfire on Stream-Nutrient Concentrations within an Undisturbed Watershed in the Lake Tahoe Basin

Kip K. Allander, Hydrologist
U.S. Geological Survey
Nevada Water Science Center
2730 N. Deer Run Road
Carson City, NV 89701
(775) 887-7675
kalland@usgs.gov

The Gondola Fire, the largest wildfire in recent history within the Lake Tahoe Basin, burned the Eagle Rock Creek watershed in July 2002. The fire burned 28 percent (0.18 mi^2) of the watershed, with 8 percent (0.05 mi^2) burned at high severity, including the area of its source-water springs. Eagle Rock Creek is tributary to Edgewood Creek near Stateline, Nevada, and has a drainage area of 0.63 mi^2. Prior to the fire, the Eagle Rock Creek watershed was relatively undisturbed and nutrient concentrations were routinely monitored for 11 years (1990-2001) by the U.S. Geological Survey under the Lake Tahoe Interagency Monitoring Program. Monitoring resumed immediately after the fire to determine what effects the uncontrolled wildfire had on the stream-nutrient concentrations of this previously undisturbed watershed. This monitoring continues and the comparison analysis in this abstract represents data through March of 2006.

Stream-nutrient concentrations in Eagle Rock Creek increased as a result of the Gondola Fire. Median concentrations of soluble reactive phosphorus (SRP) more than doubled, increasing from 0.010 mg/L (n=206) to 0.025 mg/L (n=92). Median concentrations of total phosphorus (TP) nearly doubled, increasing from 0.032 mg/L (n=208) to 0.052 mg/L (n=90). Median concentrations of filtered nitrate plus nitrite (NO_3) had a 6-fold increase from 0.011 mg/L (n=206) to 0.065 mg/L (n=90). Median concentrations of total organic nitrogen plus ammonia (TKN) had a modest increase from 0.120 mg/L (n=208) to 0.180 mg/L (n=93). Median concentrations of filtered ammonia (NH_4) remained at less than the method detection limit of 0.003 mg/L (n=206 before the fire, and n=93 after the fire).

Post-fire trends in concentrations for NO_3 show a continued seasonal variability much greater than pre-fire. However, the post-fire trend in concentrations for SRP indicates that, nearly 4 years after the fire, SRP concentrations have almost returned to pre-fire levels. Overall, the data indicate that uncontrolled wildfires within the Lake Tahoe Basin can greatly increase nutrient concentrations in tributary streams for many years after they have been extinguished.

Effects of Historical Fire Regimes and Fuel Treatments on Nutrient Cycling in the Lake Tahoe Basin

Sarah L. Ganschow
Graduate Student
Natural Resources and Environmental Science
University of Nevada, Reno
1000 Valley Road, MS/186
Reno, NV 89512
(775) 784-6319
ganschow@unr.edu

Peter J. Weisberg, Ph.D.
Dale W. Johnson, Ph.D.
Watkins W. Miller, Ph.D.
Natural Resources and Environmental Science
University of Nevada, Reno

Models of historical ranges of variability for fire regimes and forest structure are increasingly used to inform land management in the Lake Tahoe Basin. However, historical variations in cycling of essential plant nutrients such as nitrogen (N) and phosphorus (P), both of which are important for water quality and forest health, are not generally considered in these models. Altered nutrient cycling dynamics due to land use change and fire suppression may have significant consequences. Fire suppression over the past century likely resulted in greatly increased forest floor biomass, which is rich in N and P and may contribute to lake eutrophication through surface runoff. Because sufficient empirical data to quantify long-term nutrient cycling dynamics are unattainable, a modified version of the Nutrient Cycling Spreadsheet (NuCSS) model was used to examine temporal changes in nutrient contents and fluxes under current conditions, given various thinning and prescribed fire prescriptions, and within the bounds of natural variability in fire regimes and forest structure.

Preliminary results suggest that under pre-settlement conditions forest floor accumulations (and thus nutrient contents) were lower (100 kg N ha^{-1} versus 550 kg N ha^{-1}) and available soil nutrients were consistently higher (55 kg N ha^{-1} versus 26 kg N ha^{-1}) than currently, following 120 years of fire suppression. If fire suppression policies continue and forest biomass and forest floor mass continue to increase, model simulations suggest that available N may decrease to levels limiting to plant growth. This may result from loss of shade-intolerant N-fixing chaparral species as forest canopies close and shrub-dominated patches are invaded by coniferous trees. To clarify the potential interactions between disturbance regime and nutrient cycling, the NuCSS model was made more sensitive to changes in fire severity and site environment, N-fixing species and N fixation were explicitly included, and stochasticity was added to establishment and disturbance processes. We present a modeling framework for linking site-specific nutrient cycling with landscape-level processes of forest disturbance, succession, and management treatments.

Operational Forecasts to Predict the Smoke Impact from Wildfire and Prescribed Burns

Julide Kahyaoglu-Koracin
Division of Atmospheric Sciences
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512
(775) 674-7184
(775) 674-7006
Julide.Koracin@dri.edu

Timothy J. Brown
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512

The California and Nevada Smoke and Air Committee (CANSAC) is a consortium of fire weather and air quality decision-makers, managers, meteorologists, and scientists in partnership to provide operational meteorological support for fire and smoke management, and advance the scientific understanding of atmosphere and fire interactions. CANSAC is one of five regional Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS) established as part of the National Fire Plan, and is dedicated to fire and smoke management in California and Nevada. The Desert Research Institute (DRI) Program for Climate, Ecosystem, and Fire Applications (CEFA) is the operational component of CANSAC and provides operational meteorological, fire behavior, and smoke forecasts as well as conducts research in order to improve fire weather and fire impact predictions. Timely forecast information is provided to the users and public online via a web site (cefa.dri.edu/COFF/coffframe.php) maintained by the CEFA group.

CANSAC provides twice daily (00/12 UTC) meteorological forecasts using the Fifth Generation Penn State/NCAR Mesoscale Model (MM5) on a three-nested domain encapsulating the entire California and Nevada at 4 km grid cell resolution for 60-hr forecast range. The atmospheric fields taken from the MM5 forecasts are used in a smoke prediction system, BlueSky, which is developed by the USDA Forest Service AirFire Team in collaboration with land management and air quality regulator users. BlueSky is a complex smoke prediction system comprised of emissions, meteorology, and dispersion models. Burn information to derive fire emissions are obtained from the wildfire 209 reports and the CANBURN manual web-based prescribed and agricultural burn information system. CANBURN is the web-based manual burn input system available to the CANSAC users. Currently the system predicts surface concentrations of PM2.5 from wildfire and prescribed burns. Combining many sophisticated features, it is an excellent predictive tool for land and air quality managers and decision makers to assess the impact from fire and smoke as well as to aid in short term management plans.

Pre EuroAmerican Fire Regimes and Forest Conditions as a Reference for Forest Resource Management in the Lake Tahoe Basin

Alan H. Taylor
Professor of Geography
The Pennsylvania State University
Department of Geography
302 Walker Building
University Park, PA 16802
814 865-3433
(FAX) 814 863-7943
aht1@psu.edu

Pre Euro-American settlement forest structure and fire regimes for Jeffrey pine-white fir forests were reconstructed from trees cut in the 19th century to establish a baseline reference for ecosystem management in the Lake Tahoe Basin. Contemporary forest have more and smaller trees, more basal area, less structural variability and trees with a more clumped spatial distribution that pre Euro-American forests. The mean pre Euro-American fire return interval for Jeffrey pine-white ri forests was 11.5 years and most (>90%) fires burned in the dormant season after trees stopped growth for the year. No fire was recorded in the study area after 1871. Fire regimes during the 400 year pre Euro-American period with a record of fire were influenced by climate. Widespread fires were associated with drought while wet conditions were associated with non-fire years. Fire activity was related to modes of of the Pacific Decadal Oscillation (PDO) an inter-decadal "El Niño-like" variation in north Pacific seas surface temperatures and associated atmospheric structures. Fire activity was not associated with variation in the El Niño/Southern Oscillation. The sensitivity of fire regimes to shifts in modes of climatic variability suggests that climate was a key regulator or forest ecosystem structure and dynamics before Euro-American settlement. The pre Euro-American reference for forest structure and fire regimes suggests that restoration treatments in Jeffrey pine-white fir forests should include: 1) density and basal area reduction, primarily of small diameter trees; 2) increasing structural heterogeneity by shifting clumped tree distributions to a more random pattern; and 3) reintroduction of frequent fire as a key regulating disturbance process.

Effects of Harvesting System and Prescription Fire on Forest Floor Fuels in Jeffrey Pine: Implications for the Lake Tahoe Basin

Roger F. Walker, Ph.D.
Professor of Forest Resources
University of Nevada, Reno
Department of Natural Resources and Environmental Science
1000 Valley Road
Reno, NV 89512
(775) 784-4039
walker@cabnr.unr.edu

Robert M. Fecko, Graduate Research Assistant
Wesley B. Frederick, Undergraduate Research Technician
Dale W. Johnson, Ph.D., Professor of Forest Soils
Watkins W. Miller, Ph.D., Professor of Soils and Hydrology
Department of Natural Resources and Environmental Science
University of Nevada, Reno
1000 Valley Road
Reno, NV 89512

Thinning using cut-to-length and whole-tree harvesting systems with subsequent prescribed underburning were assessed for their effects on forest floor fuels by timelag category in a second-growth Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) stand on the Tahoe National Forest. Cut-to-length harvesting more than doubled total fuel loading to 113829 kg ha^{-1} compared to 55865 kg ha^{-1} in the unthinned control treatment, with increases of 466% and 354% in the 100-hr and 1000-hr categories, respectively, while 1+10-hr fuels increased by 61%. In contrast, whole-tree harvesting did not significantly alter fuel loading in any timelag category. The 1+10-hr and total fuel accumulations in the cut-to-length treatment and that of 1000-hr fuels in the whole-tree treatment were positively correlated with harvested basal area and harvested foliage, branch, bole, and total tree biomass. Consumption during underburning eliminated 1+10-hr and 100-hr fuel additions from cut-to-length harvesting plus a portion of the natural loading in these categories but resulted in only minor reductions of 1000-hr fuels. For the cut-to-length, whole-tree, and unthinned treatments, consumption of 1+10-hr, 100-hr, and total fuels was positively correlated with the amounts present within each category before underburning. Because second-growth Jeffrey pine stands are prevalent in the eastern portion of the Lake Tahoe Basin, results of this study can be readily extrapolated to these stands, thus facilitating predictions of the fuel modifications that are likely to result from field practices integral to the enhancement of their health and fire resilience.

Social Science

How do Landowner Attitudes effect Policy Adoption? Preliminary Results from an Empirical Study of Best Management Practices (BMPs) and Transferable Development Rights (TDRs) in the Tahoe Basin

Derek Kauneckis, Ph.D.
Assistant Professor, Department of Political Science
University of Nevada, Reno
MS 302
Reno, Nevada 89557
(775) 784-4601, ext. 2804
kauneck@unr.edu

With the increased emphasis in environmental policy on voluntary and market-based instruments targeting private landowners there has been a renew research focus on understanding the incentives of landowners to participate in policy programs. Various researchers have begun to develop rudimentary theories of landowner motivations to participate in public programs that include interactions among economic incentives, political attitudes, and norms. This paper presents preliminary results from an ongoing study of policy participation and attitudes toward two policies (BMPs and TDRs) that target private landowners in the Lake Tahoe basin. A survey questionnaire was administered that focused on landowner's understandings of environmental problems in the basin, beliefs about the impact of land use activities on lake clarity, financial costs and benefits to landowners, attitudes toward the various public agencies active in policy implementation, understandings of policy instruments, personal networks, and general political values. Using discrete choice modeling techniques, the paper examines which factors influence the likelihood of participation in BMP and TDR programs. It concludes with a discussion of the interface between policy instrument design and motivational theories of landowner behavior, as well as tentative recommendations for increasing landowner participation.

Land Cover Change in the Southern Lake Tahoe Basin, 1940-2002

Christian G. Raumann
Geographer
U.S. Geological Survey
Western Geographic Science Center
345 Middlefield Road, MS-531
Menlo Park, CA 94025
(650) 329-5648
craumann@usgs.gov

The Lake Tahoe Basin has been subject to significant landscape-altering human activity since the mid-1850s. Two time periods in particular dramatically changed the basin landscape, first widespread timber harvest from the 1850s to 1920s followed by urban development from the 1950s to the present. The consequences of land-use/cover change such as decreased water quality, degraded biotic communities, and increased fire hazard have prompted rising levels of concern for the ecological integrity of the region as well as calls to action to better understand the mechanisms of impact. We mapped, quantified, and described the historical changes in land use/cover in the southern Lake Tahoe Basin for the period from 1940 to 2002 in an effort to establish a baseline understanding of the type, direction, and magnitude of change in recent history. Our assessment relied on post-classification change detection of multitemporal land-use/cover and impervious surface area data that were derived through visual interpretation, image processing, and GIS data integration for four dates of imagery: 1940, 1969, 1987, and 2002. The most significant changes over the 62-year study period were an increase in urban lands with a corresponding decrease in natural land cover, changes in forest density within the forested areas, overall forest loss, forest encroachment, and tree mortality. The highest rates of change occurred between 1940 and 1969 but the rates of change have since declined through 2002 for all processes except forest-density decrease and tree mortality. Causes of change included regional population growth, tourism demands, timber harvest for local use, fire suppression, and fuels reduction activities. We are currently cooperating with the Lahontan Regional Water Quality Control Board to integrate the multitemporal land-use/cover data with roads and erosion potential data in order to produce historical land-use inputs for a Total Maximum Daily Load (TMDL) watershed model. This analysis of land-use/cover change is part of continuing research to quantify and analyze trends in development, land management, and forest succession during the most intensive urbanization period for the Lake Tahoe Basin.

Learning from Lake Tahoe's Transferable Development Right System: Recommendations for New Evaluative Criteria

Sienna Reid, MA Candidate
Department of Political Science
University of Nevada, Reno
MS 302
Reno, Nevada 89557
(775) 287-0440
siennareid@charter.net

Derek Kauneckis, Ph.D.
Assistant Professor, Department of Political Science
University of Nevada, Reno
MS 302
Reno, Nevada 89557
(775) 784-4601, ext. 2804
kauneck@unr.edu

Over the past twenty years, an increasing number of transferable development right (TDR) programs have been implemented to preserve environmentally sensitive lands, conserve farmlands in the face of rapid suburban development, or maintain historic landmarks, without compromising the property rights of private landowners. TDR programs attempt to use market mechanisms rather than zoning ordinances to direct location decisions toward increasing development densities away from sensitive resources. Since its adoption in 1987, the TDR program in the Tahoe Basin has been widely recognized as one of the most successful programs in the country. However, the measure of success has typically been understood as a function of the volume of transfers alone, and an evaluation of the program conducted in 2003 by the Solimar Research Group found only marginal progress towards program goals and specifically noted the lack of explicit measures of success. This paper uses the Tahoe experience to develop a general framework for measuring the success of TDR programs. First, it presents a broad review of the existing literature on TDR systems, with a specific focus on evaluation and analysis methods. Second, it provides a detailed examination of the Tahoe TDR program, highlighting many of the findings of the Solimar report as well as incorporating critiques of that evaluation. Third, the paper proposes a framework for evaluating TDR programs in general, as well as a set of specific evaluative measures for the Tahoe TDR program. These measures include both the direct and indirect effects of the program as understood within the nine environmental threshold carrying capacities outlined by the TRPA.

Soil Conservation

The Gondola fire: Effects on Nutrient Loss, Soil Fertility, and Leaching

Dale W. Johnson, Professor
University of Nevada, Reno
Natural Resources and Environmental Science
Fleischmann Ag, MS 370
Reno, NV 89557
(775) 784-4511
dwj@cabnr.unr.edu

W.W. Miller, Professor
E. Carroll, Professor
R.F. Walker, Professor
University of Nevada, Reno
Natural Resources and Environmental Science
Reno, NV 89557

D.W. Glass, Graduate Student
J.D. Murphy, Graduate Student
University of Nevada, Reno
Natural Resources and Environmental Science
Reno, NV 89557

Because of the availability of pre-fire samples of soils, vegetation, and soil leaching, we were able to very accurately measure the effects of that fire on nutrient losses and transformations both via volatilization (by before and after sampling) as well as by water transport. The fire resulted in near complete combustion of the forest floor and a substantial portion of understory vegetation. Because nitrogen (N) has a low volatilization temperature, we presume that all N in these components was lost, and it constituted a significant fraction of total ecosystem N capital that will not be made up for without post-fire invasion of N-fixing species. Soil N losses were very minimal, indicating that soil heating was not extreme. The fire caused substantial increases in N leaching from soils over the first two years, but by year 3 this had subsided to near pre-fire levels. The total N lost from the system by leaching constituted less than 10% of that lost by direct volatilization during the fire. Phosphorus (P) losses by volatilization during the fire were presumed to be minimal because of the relatively high volatilization temperature of P, and thus the P content of combusted materials was presumed to be left behind in ash. A large post-fire erosion event caused the displacement of ash and some soil to a nearby riparian area; however, soil extractable P pools are naturally very large in this parent material and the losses of P were not considered important to the terrestrial ecosystem. There was some increase in post-fire P leaching, but far less than for N, and it subsided to near background levels by year three also.

Web Soil Survey – A New Tool

William Loftis
Soils Scientist
USDA - Natural Resources Conservation Service
South Lake Tahoe Field Office
870 Emerald Bay Rd, Suite 109, Box 3
South Lake Tahoe, CA 96150
william.loftis@ca.usda.gov
530-543-1501 (104) (v); 530-543-1579 (f)

The USDA has launched a Web Soil Survey site that provides public access to the national Soils Information System. This site is a simple yet powerful way to access and analyze soils data that contributes to every aspect of public and private land use. In the Lake Tahoe Basin, soil survey data is critical to county and city planners, engineering firms, state and Federal agencies, the Tahoe Regional Planning Agency, and the community of scientists to help make informed decisions on land management, project planning, regulatory issues, and scientific advancements. Coupled with the release of the updated ”Soil Survey for the Tahoe Basin Area, California and Nevada” by the NRCS, accessing and fully utilizing the potential of the soils data base will be facilitated. This poster session will present information on accessing the site through TIIMS, defining the area of interest, exploring for specific soils data, downloading data into a GIS system, and building customized reports that address the viewer individual needs

Vegetation Ecology and Management

Underwater Dendrochronology of Sierra Nevada Lakes

Franco Biondi, Ph.D.
Associate Professor, DendroLab
University of Nevada, Reno
Department of Geography
Mailstop 154
Reno, NV 89557
(775) 784-6921
fbiondi@unr.edu

Submerged, apparently rooted trees found in Lake Tahoe, Fallen Leaf Lake, and other Sierra Nevada lakes indicate the possibility of large-magnitude, rapidly-occurring changes in lake level at some point during the last 2000 years. While these changes have usually been attributed to long periods of very dry conditions during the mid and late Holocene, no similar episodes have been recorded to date by instrumental climate observations in western North America, which began about 1-2 centuries ago. It is then necessary to answer the question "Are submerged trees indicators of past mega-droughts, or were they transported into the lakes by past landslides?" This question can be answered using tree-ring records collected directly from the submerged trees, and crossdated against existing and newly developed long chronologies, to obtain a clear map of the historical periods when such trees were alive. A better understanding of the Holocene environmental record of multiple Sierra Nevada watersheds would make it possible to differentiate between true climatic anomalies and past slope movements caused by geomorphic or seismic events.

The immediate societal benefit of this information can include more accurate predictions of short- and long-term variations of water availability in California and Nevada. As wood samples are collected, dated, and entered into the tree-ring chronology, they will also provide a way to construct a continuous, annually resolved record that could span several millennia, because some of these submerged trees, according to already conducted radiocarbon analysis, date back to the mid-Holocene. It is by collating a myriad of wood samples buried in streambeds and lakes that the longest tree-ring chronologies, now going back 12,460 years, have been developed in central Europe.

During 2005, two wood samples from separate submerged trees were retrieved by John Kleppe (an engineering professor at UNR) and brought to the DendroLab for analysis. In order to date those underwater samples, we developed a western juniper (*Juniperus occidentalis*) tree-ring chronology that spans the period from AD 543 to 2003. Additional tree-ring chronologies were available either from our own studies or from public databases. By means of visual and numerical crossdating, we dated one of the two underwater samples, i.e. a cross section of a branch cut from a standing tree. Anatomical features of this specimen were consistent with pine species, and a clearly visible continuous sequence of 69 rings was crossdated with the master chronology for the period AD 1085-1153. This initial result shows that it is feasible to obtain tree mortality dates and continuous tree-ring time series from submerged trees in the Sierra Nevada.

Effects of Harvesting System and Prescription Fire on Jeffrey Pine Stand Development and Growth: Implications for the Lake Tahoe Basin

Robert M. Fecko
Graduate Research Assistant
University of Nevada, Reno
Department of Natural Resources and Environmental Science
1000 Valley Road
Reno, NV 89512
(775) 784-4039
rfecko@unr.nevada.edu

Roger F. Walker, Ph.D., Professor of Forest Resources
Wesley B. Frederick, Undergraduate Research Technician
Watkins W. Miller, Ph.D., Professor of Soils and Hydrology
Dale W. Johnson, Ph.D., Professor of Forest Soils
University of Nevada, Reno
Department of Natural Resources and Environmental Science
1000 Valley Road
Reno, NV 89512

Thinning with cut-to-length and whole-tree harvesting systems followed by prescribed underburning were evaluated for their effects on stand mensurational variables and productivity in uneven-aged, second-growth Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) on the Tahoe National Forest. Mensurational parameters were derived from trees ≥ 17.8 cm DBH on permanent measurement plots, while stand productivity was assessed with increment cores from both intermediate and a combination of dominant and codominant crown class trees selected within each treatment. Stand characteristics were determined for two subdivisions of measured trees: 1) ≥ 17.8 cm DBH, ≤ 19.8 m tall and 2) ≥ 25.4 cm DBH, based on their presumed probability of either becoming or retaining their status as long-term stand constituents, respectively. Post- to preburn comparisons of mortality revealed significant thinning and underburning main treatment effects as well as significant interaction between the two in both tree size classes examined. However, mortality increased most in the smaller of the size categories within the burned portion of the whole-tree treatment, whereas among the larger trees values of this variable rose most sharply in that of the cut-to-length treatment. Shifts in live crown, expressed as a percentage of tree height, were influenced by both thinning and prescribed fire main treatments in the small and large tree categories, while the interaction of these treatments was also significant in the latter. Within each size class, live crown reductions were greatest in the burned portion of the unthinned control plots, with the next highest losses occurring within that of the cut-to-length treatment. Influences of thinning on radial increment were clearly demonstrated in both intermediate and dominant/codominant crown class trees. Portions of the stand devoted to the cut-to-length and whole-tree treatments exhibited responses ranging from negligible change to substantial increases in posttreatment growth. In contrast, considerable declines in this regard compared to pretreatment values were revealed in trees within the unthinned control. Neither underburning nor the interaction between thinning and the latter significantly impacted radial growth. Because of the prevalence of second-growth Jeffrey pine forests on the eastern side of the Lake Tahoe Basin, findings presented here are clearly applicable to stands in this region in which the field practices evaluated are being contemplated to enhance their health and fire resilience.

Quantitative Evaluation of Revegetation/Mulch Erosion Control Measures in the Lake Tahoe Basin

M.E. Grismer, Professor
Hydrologic Sciences
University of California, Davis
Davis, CA 95616
(530) 752-3243
megrismer@ucdavis.edu

M.P. Hogan, President
Integrated Environmental Restoration Services
P.O. Box 7559
Tahoe City, CA 96145
(530) 581-0355
revegetate@earthlink.net

Revegetation, or other erosion control treatments of disturbed soil slopes in forested areas and along highways of the Lake Tahoe Basin are directed at reduction of sediment loading to waterways reaching the Lake. However, following treatment, little vegetation monitoring, or hydrologic evaluation has been conducted to determine if the various treatments are successful and the duration of erosion control anticipated in the field. Here, we build upon results from use of the portable rainfall simulator (RS) described in the previous two papers of this series to evaluate cover and revegetation treatment effects on runoff rates and sediment concentrations and yields from disturbed granitic and volcanic soils at road cuts and ski runs in the Basin. The effects of slope on rainfall runoff, infiltration and erosion rates were determined at several revegetated road cut and ski run sites. Rainfall simulation (~60 mm h^{-1}, approximating a 100-yr, 15-minute storm) had a mean drop size of ~2.1 mm and approximately 70% of "natural" rainfall kinetic energy. Measurements of time to runoff, infiltration, runoff, sediment yield, and average sediment concentration were obtained. Runoff sediment concentrations and yields from sparsely covered volcanic and bare granitic soils could be correlated to slope. Sediment concentrations and yields from nearly bare volcanic soils exceeded those from granitic soils by an order of magnitude across slopes ranging from 30-70%. Revegetation, or application of pine needle mulch covers to both soil types decreased sediment concentrations and yields 30-50%. Incorporation of woodchips or soil rehabilitation that includes tillage, use of amendments (Biosol®, compost) and mulch covers together with plant seeding resulted in little, or no runoff or sediment yield from both soils. Repeated measurements of sediment concentrations and yields in the subsequent two years following woodchip or soil rehabilitation treatments continued to result in little or no runoff. Revegetation treatments involving use of only grasses to cover soils were largely ineffective due to sparse sustainable coverage (<35%) and inadequate infiltration rates.

Keywords: Rainfall simulation; sub-alpine environment; semi-arid; slopes, ski runs; road cuts; volcanic soils; granitic soils

Genetic Monitoring of *Rorippa subumbellata* (Tahoe Yellow Cress): Managing for an endangered plant species growing along the shores of Lake Tahoe

Valerie Hipkins, Robert Saich, and Jennifer DeWoody
USDA Forest Service
National Forest Genetics Laboratory (NFGEL)
Pacific Southwest Research Station
Placerville CA
(530) 622-1609
vhipkins@fs.fed.us

Genetic monitoring through the assessment of molecular variation can often provide the information necessary to aid in management decisions. Genetic information is an essential part of understanding the foundation of ecosystem and species integrity. We undertook a genetic monitoring study of *Rorippa subumbellata* (Tahoe yellow cress) that spanned a 6-year period. *R. subumbellata* is endemic to the sandy shores of Lake Tahoe in California and Nevada and is currently listed as endangered by the California and Nevada state governments and fully protected by the Tahoe Regional Planning Agency. The species is also a candidate species for listing under the federal Endangered Species Act. This monitoring effort characterized genetic variation at 23 isozyme loci in 1,123 plants found at 38 occurrences. Low levels of genetic variation were observed in *R. subumbellata*, and outplanted sites had a greater probability of containing variation than natural populations. Genetic variation was evenly distributed across the metapopulation, and temporal differences in the amount of variation were also observed in occurrences. These findings demonstrate the lack of genetic structure among populations of *R. subumbellata*, support the current design of *ex situ* collections and outplanting efforts, and confirm the potential for migration among populations.

Locating Aspen in the Tahoe Basin Using Remote Sensing and GIS-based Physical Ecology

Charles Levitan, Ph.D., Professor and Kristine Wilbrecht Director, Natural Sciences
Department of Science and Technology
Sierra Nevada College
999 Tahoe Blvd., Incline Village, NV 89451
(775) 831-1314
clevitan@sierranevada.edu, kwilbrecht@sierranevada.edu

Quaking aspen occur throughout the Tahoe Basin. We attempted to create models predicting their distribution, using both topography and remote sensing. The traditional use of infrared photography, which we demonstrate as being typically effective in delineating many riparian plants, is less effective with aspens. We measured the reflectance of aspen, grass, moss, and willows from a riparian area to try to understand its low conspicuousness in infrared bands. We converted these nanometer-wide reflectances into Landsat and IKONOS reflectances, and equivalent image for infrared film. We also mapped aspens and examined them in georeferenced photos and satellite images. We found both the structure of the aspens and their spectral reflectance contribute to their low conspicuousness in infrared images. On the other hand, using discriminant analysis based on measures of water supply, watershed size, and heat load, we did predict the locations of aspens within study areas.

Rainfall Simulation Effects on Different Forest Types in the Lake Tahoe Basin

Joshua Meidav M.S.
Ph.D. Candidate
Graduate Group in Ecology
University of California, Davis
Tahoe Environmental Research Center
P.O.Box 633
Tahoe City, CA 96145
(510) 435-7861
jsmeidav@ucdavis.edu

Michael Barbour Ph.D.
Professor, Department of Plant Sciences
University of California, Davis
Plant Sciences Department MS 1
University of California, Davis
One Shields Avenue,
Davis, CA 95616

A knowledge gap from the Lake Tahoe Watershed Assessment is the baseline contribution of forested watersheds to sediment and nutrient loading. Though human impacts are considered within the current efforts to model the Lake Tahoe Watershed based on landscape inputs and water quality outputs, vegetated land has been considered a uniform descriptor for much of the uplands within the Lake Tahoe Basin. The objective of this study is to assess the effects of different forest types on sediment and nutrient loss using rainfall simulation. Among the four forest types studied (white fir, open and dense red fir, dense white fir-red fir), dense white fir-red fir demonstrated the lowest amounts of sediment in runoff. There were similar percentages of organic matter and fine particles coming off of all forest sites. Open red fir showed a phosphate filtering capacity while dense white fir-red fir displayed a negligible contribution to phosphate runoff. All forest types revealed a nitrate filtering capacity, but dense white fir-red fir was the only forest type that exhibited an ammonium filtering capacity. Further analyses will examine forest and soil/litter parameters and their influence on sediment and nutrient outputs.

Doing Adaptive Management: Experimental Reintroductions of Tahoe Yellow Cress (*Rorippa* subumbellata)

Alison E. Stanton and Bruce M. Pavlik
BMP Ecosciences
2163 Cornelian Drive
South Lake Tahoe, CA 96150
(530) 573-1177
alisonestanton@sbcglobal.net

Tahoe Yellow Cress (TYC), a plant endemic to the sandy shorelines of Lake Tahoe, has been a candidate for listing under the Endangered Species Act since 1999. In 2001, a Conservation Strategy (CS) was developed to direct efforts to restore and manage the species and affect the federal listing decision process. Implementation of the strategy is being carried out by a multi-agency and private interest group task force composed of an Adaptive Management Working Group (AMWG) and an Executive Committee. Successful implementation of the CS may preclude the need to federally list the plant and provide grounds for down listing in California and Nevada. The CS outlines an adaptive management process designed to integrate new information immediately into management direction. A five point "key management question" framework was developed to guide research and fill in critical gaps of our understanding of TYC restoration. Each key management question has both scientific and management implications leading to the development of specific hypotheses that can be tested experimentally.

Experimental reintroduction of container-grown TYC was initiated in 2003. To date, over 7,400 plants have been installed at 11 sites around Lake Tahoe. Plants were installed in replicated blocks in different microhabitats in "transect" configurations extending along a hydrological gradient. Demographic monitoring and physiological monitoring of plant xylem water potentials were conducted to assess the effects of microhabitat and lake elevation on plant performance. Results from a low lake elevation year, 2004, indicated that microhabitats that provide a shallow depth to the water table that are protected from lake level and human disturbances are more likely to allow high survivorship and reproductive output of TYC. This data will be presented and compared with that from 2006, a high lake elevation year. In addition, pilot-scale translocations, which involve moving established plants in the field from one location at a site to another, were conducted in 2005 and 2006 to assess this method as a mitigation option. Apparent high survivorship in 2005 indicated that it is possible to move plants within a site and that pursuing translocation as a potential mitigation strategy is warranted.

Water Quality

Lake Tahoe Interagency Monitoring Program – An Integral Part of Science in the Lake Tahoe Basin

Nancy L. Alvarez and Alan M. Preissler
Hydrologist and Hydrologic Technician
U.S. Geological Survey
Nevada Water Science Center
2730 N. Deer Run Road
Carson City, NV 89701
Nancy Alvarez: (775) 887-7644
nalvarez@usgs.gov, apreiss@usgs.gov

Scott H. Hackley and Patty A. Arneson
Staff Research Associates

Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
shhackley@ucdavis.edu, parneson@ucdavis.edu

The Lake Tahoe Interagency Monitoring Program (LTIMP) is an essential part of integrated science in the Lake Tahoe Basin. LTIMP stream monitoring began in 1979 after interagency and institutional negotiations and collaboration. The current monitoring program began in 1988 as a cooperative program between the U.S. Geological Survey (USGS), Tahoe Regional Planning Agency (TRPA), and University of California, Davis- Tahoe Research Group (UCD-TRG). Since 1988, the USGS and TRPA spent more than $9.1 million dollars on the monitoring program and collected over 10,000 water-quality samples, with in-kind services provided by UCD-TRG.

The primary objective of the monitoring program is to collect long-term water-quality and flow data on streams tributary to Lake Tahoe. These data are used for: 1) estimation of suspended sediment and nutrient loads and trends from major and minor tributary streams from both disturbed and undisturbed basins, 2) assessment of the effects of land use on water quality, and 3) supporting basic research.

The monitoring program has expanded and contracted over the years, and the current program consists of 18 sampling sites on 10 major tributary streams around Lake Tahoe, and one sampling site on the Truckee River near the outlet of Lake Tahoe. Five tributary streams have more than one sampling site. The monitoring program follows three sampling schedules; systematic monthly sampling, storm sampling, and intensive snow-melt runoff sampling. Water samples are collected throughout the year during low, medium and high flows. Water samples are analyzed for nitrogen and phosphorus species and suspended sediment concentration. Continuous streamflow data are collected at all but one of the 19 sampling sites.

The water-quality and streamflow data are stored in the USGS National Water Information System (NWIS) database and published, after quality assurance review, in the USGS annual data report and also are available on the USGS website. The data are used to estimate the annual total-phosphorus, total-nitrogen, and suspended-sediment loads for a subset of the sampling sites. This work is completed by UCD-TRG and provided to TRPA for their annual report. The LTIMP stream data also has been used in several recent studies and was a significant asset to the validation of models used by Lahontan Regional Water Quality Control Board to develop the Lake Tahoe total maximum daily load (TMDL).

Climate Change Impacts in the Tahoe Basin: Snowmelt Timing, Lake Thermal Structure, and Phytoplankton Dynamics

Robert Coats
Department of Environmental Science and Policy
University of California, Davis
Davis, CA 95616
rncoats@ucdavis.edu
Principal, Hydroikos Ltd.
2560 9th St., Ste. 216
Berkeley CA 94710
(510) 845-0435

Monika Winder
Tahoe Environmental Research Center
University of California, Davis
One Shields Ave.
Davis CA 95616-8803
mwinder@ucdavis.edu

Climate change in the Tahoe Basin—an aspect of global warming—is likely to have profound long-term effects on the Basin's terrestrial and aquatic ecosystems. Climate change is modifying both internal lake dynamics and the timing and magnitude of nutrient and sediment loading from tributary watersheds, and in turn these factors are likely to affect phytoplankton dynamics in the lake. Little is known, however, about how processes and mechanisms at the watershed and lake level are responding to climate change in the Tahoe basin. We use a historical data set of lake water temperature and phytoplankton from Lake Tahoe in combination with streamflow records of five major tributaries to investigate phenology patterns over the last four decades. The daily streamflow records indicate a trend toward earlier snowmelt peaks of about one day per three years over the last four decades. This shift is strongly related to an upward trend in night-time air temperature during spring and to the Pacific Decadal Oscillation. Changes in physical processes in the lake are also related to a warming trend in the basin: the timing of stratification onset is shifting slightly forward, the timing of stratification termination is delayed, the thermal stability of the lake is increasing, and the overall growing period has increased by about 16 days since the 1970s. Phenology changes of the phytoplankton however are more complex. While the spring and fall peaks of some phytoplankton taxa remain relatively consistent, interannual variability of the temporal dynamics of other taxa changed in most recent years. This indicates that climate affects physical and biological processes in different ways, which can have important implications for ecosystem functions.

Water Quality, Watershed Characteristics and Land Use in the Tahoe Basin

Robert Coats
Department of Environmental Science and Policy
University of California, Davis
Davis, CA 95616
rncoats@ucdavis.edu
Principal, Hydroikos Ltd.
2560 9th St., Ste. 216
Berkeley CA 94710
(510) 845-0435

Melissa Gunter
El Dorado Irrigation District
Placerville, CA
melissakgunter@gmail.com

Alan Heyvaert
Desert Research Institute
2215 Raggio Parkway
Reno NV 89512
alan.heyvaert@dri.edu

James Thomas
Desert Research Institute
2215 Raggio Parkway
Reno NV 89512
jthomas@dri.edu

Matthew Luck
University of New Mexico
Albuquerque, NM
mluck@unm.edu

John Reuter
Dept. of Environmental Science & Policy
University of California, Davis
Davis, CA 95616
jereuter@ucdavis.edu

Statistical analysis of water quality data plays an important role in development of the Lake Tahoe TMDL. In order to develop relationships between water quality, watershed characteristics and land use in the Basin, we analyzed two water quality data sets: the data from the Lake Tahoe Interagency Monitoring Program (LTIMP), for 20 watesheds (Water Years 1990-2001), and data from the TMDL Stormwater Monitoring Program (SWM), for 19 catchments (Water Years 2003-2004). For both data sets, we calculated discharge-weighted mean concentrations of nitrogen, phosphorus and suspended

sediment; for the LTIMP watersheds, we also calculated mean annual constituent yields. We derived land use and watershed information from a GIS data base, and related concentrations and yields of nutrients to a suite of explanatory variables, using Robust Multiple Regression. The final selected regression models explain 38 to 75 percent of the variance in constituent concentrations in the stormwater monitoring catchments, and 43-89 percent of the variance in mean annual yields in the LTIMPwatersheds. The results emphasize 1) the importance of impervious surface and residential density as factors in water quality degradation; and 2) the role of well-developed soil as a factor in water quality maintenance; 3) the importance of the channel system and distance from the lake in modifying water quality. For the SWM catchments, a negative relationship between slope and constituent concentrations may be explained by socioeconomic factors not included in the statistical analysis.

The Application of In-Situ Optical Measurements for Understanding Dissolved Organic Matter Dynamics and Distribution in Lake Tahoe

Bryan D. Downing, Brian A. Bergamaschi, Brian A. Pellerin
U.S. Geological Survey
California Water Science Center
6000 J Street, Placer Hall
Sacramento CA 95831
bdowning@usgs.gov

Emmanuel Boss
School of Marine Sciences
University of Maine
Orono ME 04473
(916) 278-3292

Measurement of optical properties such as fluorescence and UV absorbance in lake water provide quantitative information about the major determinants of clarity, contaminant transport and biogeochemical cycling. In spring 2004, we used in situ optical measurements of absorbance and fluorescence at several locations within Lake Tahoe to help elucidate the sources and magnitude of colored dissolved organic matter (CDOM) in lake waters. Results indicated that the values of CDOM near the inflow from Ward Creek (a tributary on the west side of the lake) were more than an order of magnitude larger than CDOM values at the center of the lake. While tributaries appear to contribute significant CDOM to Lake Tahoe, the spatial variability and vertical gradients of CDOM near the creek inflow and other sampling locations suggests the need for additional profiling.

In comparison, in situ optical measurements in Crater Lake (Oregon) reveal a major difference between the two alpine lakes. The values of CDOM in rain and snowmelt entering Crater Lake were undetectable, suggesting that the most significant source of colored dissolved organic matter was from metabolic processes within the lake.

In 2006, during a separate field campaign, we observed the values of CDOM within the Ward Creek tributary to vary diurnally, suggesting that the short-term dynamics of snowmelt processes have an important impact on CDOM delivered to the lake. Both observations illustrate the utility of high frequency in-situ sensing of optical properties in resolving spatial and temporal scales which cannot be well resolved by the analysis of grab samples.

The Effects of an Open Space Dog Exercise Area on a Stream Feeding Lake Tahoe

Lynell M. Garfield and Mark Walker, Ph.D.
Ecotoxicology Graduate Research Assistant
Professor and Cooperative Extension Specialist
University of Nevada Reno
College of Agriculture, Biotech, and Natural Resources
FA 132, MS 370
University of Nevada Reno
Reno, NV 89557
(775) 784-4882
lynell@clearmountainstream.com

Waterborne disease outbreaks have been associated with dispersed animal sources, such as cattle and wildlife. It has been estimated that there are over 15,000 domestic dogs in the Lake Tahoe basin. Dogs can be carriers are zoonotic diseases, which may affect public health through drinking water supplies or contact recreation. This poster addresses the question: is the water supply of Lake Tahoe affected by dog exercise areas?

We conducted a fourteen month assessment of fecal loading in a dog exercise area upstream of the intake for a public water supply adjacent to Lake Tahoe, Nevada. Our goal was to assess site use and loading, as well as seasonal risk to the water supply by loading at the recreational area. The study area includes national forest land that is heavily used by visitors and local residents to exercise dogs throughout the year, with paths leading to Lake Tahoe. At two week intervals, we analyzed water samples for the indicator organisms fecal coliform and *E.coli* in samples from a stream that passed through the site. Water sampling sites were located above, within and below a large portion of the dog exercise area, and included a flow-through settling pond on the main stream course. We also collected feces from 14 circular transects and used these to estimate total loads of accumulated dry matter for each time period.

Our results indicate that fecal loading is highly localized within the study area, and that fecal loading varies significantly through time. Despite periods of high seasonal use (for example, major summer holidays) and limited access due to inclement weather, there is no apparent correlation between fecal density on-site and seasonality. Our results do not demonstrate that the study area influences bacterial water quality, perhaps due to the on-site sedimentation pond allowing suspended particles to settle out from the main flow of water.

We did find a correlation between snowmelt events and high concentrations of instream bacteria. This could be explained by live bacterial reservoirs in sediment and upstream soil erosivity during runoff flows, or the release of fecal bacteria from solid waste previously suspended in the snowpack.

The site currently has no facilities to encourage dog owners to collect and dispose of wastes. Our mapping efforts suggest locations for bag dispensing stations and collection barrels and also provide information about the frequency of maintenance that would be needed for each.

Identification of Fine-Grained Sediment Sources in Three Watersheds Draining to Lake Tahoe

Allen.C Gellis
U.S. Geological Survey
Maryland-Deleware-Washington, D.C. Water Science Center
8987 Yellow Brick Road
Baltimore, MD 21237
(410) 238-4281
agellis@usgs.gov

Andrew Simon
USDA-ARS
National Sedimentation Laboratory
P.O. Box 1157
598 McElroy Drive
Oxford, MS 38655
(662)-232-2918
asimon@ars.usda.gov,

Jerry C. Ritchie
USDA-ARS
Hydrology and Remote Sensing Laboratory
Beltsville, MD 20705
(301) 504-8717
jritchie@hydrolab.arsusda.gov

Fine-grained sediment is having an adverse effect on the water clarity of Lake Tahoe. In order to reduce fine-grained sediment inputs to the lake, it is necessary to identify the significant sources of fine-grained sediment. Sediment sources for three watersheds draining to Lake Tahoe, the Upper Truckee River (142 km^2), Third Creek (15.7 km^2), and Blackwood Creek (20.0 km^2), were identified using a sediment-fingerprinting approach. In this approach, the sources of fine-grained suspended sediment in transport can be established by comparing physical and chemical properties of the suspended sediment to potential sources. For this study, suspended sediment (<0.062 mm) samples collected during snowmelt runoff in April and May 2005 were compared to upland sediment sources (roads and slopes) and channel corridor sources (channel banks) using a radionuclide (^{137}Cs), stable isotopes (^{13}C and ^{15}N), and the ratio of total C to total N. Preliminary results indicate that in the Upper Truckee River, slopes are the most significant source followed by roads and channel banks. In Third Creek and Blackwood Creek, bank erosion is the most significant source.

Lake Tahoe : Four Decades of Change and the World Water Crisis

Charles R. Goldman
Distinguished Professor of Limnology
Department of Environmental Science and Policy
University of California, Davis
Davis, CA 95616
crgoldman@ucdavis.edu

Freshwater and marine ecosystem integrity is now threatened on a global scale. The decline in water quality is rapidly becoming one of the most important environmental problems to be faced in the 21st Century. It is closely linked with global warming and the resulting climatic change. China and India with there large populations have the world's most serious water quantity and quality problems followed by, Africa and the desert nations. The conservation of lakes and streams as well as the protection of drinking water sources from pollution and possible terrorist attack are of great international concern The enormously importance to life on our planet of lake waters such as Biwa in Japan , the North American Great Lakes and Baikal in Russia as well as the of lakes, reservoirs and streams in the Southern Hemisphere can not be exaggerated. Lake Tahoe which continues to lose transparency as algal growth and fine particulates cloud the water column, and both exotic aquatic weed and fish introductions further threaten the lake. Like many of the world's lakes it has significantly warmed over the last two decades and has been a focal point of environmental concern. Long-term data collection and analysis together with paleolimnology have been important for better managing Tahoe and its air- and watersheds. Regulatory policy decisions worldwide are unfortunately often based on scanty or poorly interpreted data. Limnologists, Oceanographers, Hydrologists and Environmental Engineers together with more effective public education must help meet this growing global challenge for restoration and preservation of natural and altered ecosystems that support our increasingly limited water supplies. Strong environmental science must be at the forefront in developing improved adaptive management practices. To help address the increasing global water shortages influenced by the climatic changes that can no longer be denied for political or industrial advantage, the World Water and Climate Network (WWCN) was established in Kyoto Japan in 2003. Data is now being assembled to assess the impact of climatic change and global warming on surface waters of the world with the hope of improving strategies to meet the world water crisis.

ASLO-Savannah 2004

Trends in Wet Deposition of Nitrogen and Phosphorus at Lake Tahoe

Scott H. Hackley, John E. Reuter, Mark D. Palmer
Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
shhackley@ucdavais.edu, jereuter@ucdavis.edu, mdpalmer@ucdavis.edu
(530) 304.1473 (John Reuter), (530) 583-3279 (Scott Hackley), 530.583-3279 (Mark Palmer)

In this presentation we summarize some results from an analysis of Lake Tahoe atmospheric deposition data collected by TERC as part of the Lake Tahoe Interagency Monitoring Program. The focus is on wet deposition estimates for nitrogen and phosphorus. Wet deposition completely separated from dry deposition has not yet been collected directly from the lake surface due to technical constraints. Therefore, we present data from the Ward Lake Level station (west shore) where an Aerochem Metrics Wet/Dry sampler has been operational since 1981. In this analysis, we attempted to assess what trends were apparent from the long-term wet deposition data record at Ward Lake Level with respect to loading and average concentrations for each Water Year compared with precipitation.

Nutrient data for nitrate, ammonium, soluble reactive-P (SRP) and precipitation are available from 1981 to the present. Total Kjeldahl-N and total dissolved-P are available through 2003.Total-P data is available for periods 1992-94 and 2000-2003. Data through 2003 was used in this analysis. Regression analyses between precipitation amount (rain and snow) and nutrient loading (g/hectare/year) showed that in general load increased with higher levels of precipitation; however, as suggested by the moderate 'r-values' that typically ranged from 0.5-0.8 (r^2 = 0.3-0.7), annual precipitation alone was not the best predictor of wet N and P deposition. This was largely because the nutrient concentration in precipitation does not remain uniform either within a storm (e.g. wash-out effect) or between frontal systems (changing source contributions). To compensate, loading was expressed on the basis of the number of days precipitation per year that exceeded 0.10 inches. Between 1992 and 2003 the mean annual load (± s.d.) for wet deposition based on precipitation days was 13.3±3.5 g NO_3^--N/hectare/precip/day and 10.7±2.9 for NH_4^+-N, 21.8±4.8 for TKN, 0.58±0.21 for SRP, 1.23±0.51 for TDP and 1.48±0.43 for TP. Sample size was 1—12 years except for TP where n=7 years.

A spatial study of wet deposition at Ward Lake Level, Meyers, Incline Village and Glenbrook in 1982 showed that during that year variation in annual concentration around the lake for both NO_3^-N+ NH_4^+-N and SRP was low at 81±13 µg/L and 2±1 µg/L, respectively. Graphs of the long-term data for load and concentration for dissolved inorganic-N (NO_3^- and NH_4^+) and SRP show that while interannual variability is high, there are no readily discernable long-term trends.

Periphyton Biomass Monitoring in the Near Shore Zone of Lake Tahoe

Scott H. Hackley, Brant C. Allen and John E. Reuter
Tahoe Environmental Research Center
University of California, Davis
Davis, CA. 95616
shhackley@ucdavis.edu, bcallen@ucdavis.edu, jereuter@ucdavis.edu
530-583-3279 (SH, BA), 530-304-1473 (JR)

The accumulation of periphyton (attached algae) on rocks, piers, boats and other hard-bottomed substrates is a striking indicator of Lake Tahoe's declining water quality for the largely shore-bound population. Thick, green or white expanses of periphyton biomass often coat the shoreline in portions of the lake during the spring. When this material dies and breaks free, beaches can be fouled. Slippage by humans walking on the periphyton-covered surfaces is a nuisance and can be a safety concern. The near shore periphyton can significantly impact on the aesthetic, beneficial use of the shore zone.

In 2000, the Tahoe Environmental Research Center (TERC) re-initiated regular monitoring of periphyton abundance around the lake for the Lake Tahoe Interagency Monitoring Program (LTIMP). This monitoring is ongoing. As part of the current program, we are monitoring algae growth at ten stations (five each in CA and NV), nine of which have historical data on periphyton biomass. Samples of natural periphyton are collected directly from rocks at 0.5 m depths, approximately monthly during the peak growth season (Jan-Jun) and less frequently Jul-Dec. Chlorophyll *a* content of the samples is measured in the lab to estimate the amount of living algae (biomass) present.

Some results from monitoring done during 2000-2003 are presented here. Measures of annual maximum, average annual and baseline chlorophyll *a* were determined for each year 2000-2003 and these values were compared with our historical data collected for similar data in 1982-85. The average annual maximum biomass measured as chlorophyll *a* concentration was clearly higher in areas of high development in the north-west portion of the lake during both periods, ranging from 70-140 mg/m^2 (Pineland, Tahoe City and Dollar Pt., 2000-2003) (Pineland and Dollar Pt., 1982-85, Tahoe City was not monitored). In contrast to this, the average maximum biomass was consistently low at Incline West, Sand Point, Deadman Pt. and Zephyr Pt., was less than 40 mg/m^2. Data for average annual biomass and annual baseline biomass also show generally higher values for the more developed sites in the northwest portion of the lake during the two periods.

The lack of sufficient data limits our ability to statistically analyze this data with respect to temporal trends; however, some general observations are meaningful for future discussions: 1) Annual baseline chlorophyll *a* suggests that while values at Deadman Pt. and Sand Pt. on the undeveloped east shore, increased, all other locations appeared unchanged for baseline concentrations, 2) the relative relationships between the sampling locations appeared generally consistent over the 20-year period. Locations that were low in 1982-85 were generally low in 2000-03 and sites with elevated chlorophyll *a* in 1982-85 also showed elevated chlorophyll in 2000-03, and 3) if periphyton growth is related directly to flow and nutrient load, it may be noteworthy that many of the sites in 2000-03 were comparable to 1982-85. Based on this, one could hypothesize that locations such as Pineland and Dollar Point will have much higher periphyton during years when flow is comparable to 1982-85. Continued monitoring is needed.

Meta-Analysis of Stream Bioassessment Data in the Tahoe Basin: Aquatic Invertebrate Responses to Local and Watershed-Scale Disturbance

David B. Herbst, Ph.D.
Research Biologist
Sierra Nevada Aquatic Research Laboratory
University of California, Santa Barbara
HCR 79, Box 198
Mammoth Lakes, CA 93546
(760) 935-4536
herbst@lifesci.ucsb.edu

The development of threshold standards and indicators for water quality in the Tahoe Basin have emphasized water chemistry, physical habitat features, and fish populations as measures for attainment of acceptable environmental quality in stream environment zones. Independent efforts to characterize the biological integrity of streams using macroinvertebrate bioassessment provide another approach for developing criteria of stream health. The main goal of this project was to compile and integrate bioassessment information from different programs for use in defining standards, associating biotic thresholds with chemical/physical stressor levels, and design long-term monitoring strategies. The approach taken was to define the reference condition and evaluate the level at which target stressors (especially sediment) impair measures of biological integrity. Sites with minimal upstream road crossings defined the reference condition, and varied exposures to differing reach-scale and watershed disturbance factors were used to evaluate dose-response relationships for establishing threshold levels for impairment of biological integrity. Streams with local bank erosion in excess of 20-30% were typically associated with channels having greater than 60% of the bed substrates composed of small particle classes of fines, sand and gravel (FSG), with a median particle size of less than 50 mm. Biological indicators examined with data from within the Tahoe Basin or the greater eastern Sierra region showed consistent loss of biological integrity where substrates were >60% FSG or <50 mm D-50 median size. This suggests that a provisional acceptable standard for maintaining ecological integrity of streams would be to keep bank erosion at less than 20-30%, or improve degraded channels to at least this level. Combined data showed watershed-scale influences of land use and atmospheric pollutant loads on biological indicators. Diversity declined as watershed area covered by impervious or disturbed land surface increased or as natural vegetation cover decreased, but increased as dry nitrogen deposition increased. The decline in stream biological diversity with land disturbance in watersheds was consistent with the reach-scale observation of sediment-impaired habitats. Nitrogen deposition, driven by interception and uptake of forest canopy cover, appeared to enhance stream biodiversity, suggesting that within the range observed, nitrogen and/or forested terrain may serve as a subsidy to stream biota. These data may guide land use management and local-scale stream environment zone riparian and bank protection in maintaining and improving the biological health of streams. Inconsistency within some programs emphasizes the importance of using standardized high-resolution field and laboratory protocols for collecting data on the physical habitat and biological community of streams.

Further analysis:

1. Significant differences between reference and test populations, wrt biological indicators and measures of local/watershed disturbance?? Statistical tests?
2. Restoration of Trout Crk via improved substrate quality, shown in watershed disturbance plots
3. Do reference group sites with few road crossings have less sediment deposition and larger particle sizes, greater riparian cover, etc? And do these sites have overall lower levels of watershed disturbance?
4. Calculate IBI-10 scores for the SNARL data set?

Preliminary Results from a Watershed Source Apportionment Study of Fine Sediment Loadings into Lake Tahoe

Alan Heyvaert, Jim Thomas, Ross Edwards,
[1]Desert Research Institute
2215 Raggio Parkway,
Reno, NV 89512
alan.heyvaert@dri.edu, jim.thomas@dri.edu, ross.edwards@dri.edu.

Collin Stasenburgh, John Reuter, Charles Goldman
Tahoe Environmental Research Center
University of California, Davis
P.O. Box 633
Tahoe City, CA 96145
cstrasenburgh@ucdavis.edu, jereuter@ucdavis.edu, crgoldman@ucdavis.edu

An accumulation of fine suspended sediments in Lake Tahoe has contributed to the decline of its renowned water clarity. Yet historical patterns of watershed contributions and the accumulation of sediments and associated pollutants have not been well evaluated for the lake. This study looks at the distribution of fine sediments from cores in the pelagic lake bed, from lake sediment traps, and from stream water quality sampling to evaluate likely sources based on particle biogeochemical characteristics.

Undisturbed sediment cores were collected from the lake at profundal depths and sectioned at centimeter intervals over a length representing about 200 years of historic sediment accumulation. These samples were first analyzed for particle size distribution, then sieved into <63 micron and <10 micron fractions. Each fraction was analyzed for macro and trace element content. The same analyses were applied to samples collected from sediment traps suspended in mid-lake, and to samples collected from LTIMP streams.

Samples were also collected from various watershed sources, including street sweepings, watershed parent materials (andesite, granodiorite), and streambank soils. Each of these were analyzed for elemental composition to develop a source characteristic classification system. The results are presented in terms of historical accumulation patterns relative to modern profiles, with a discussion of source apportionment for fine particle loadings to the lake from the Tahoe Basin. We also discuss the apparent nutrient (N and P) accumulation profiles in Lake Tahoe sediments, and its relevance to changes in watershed and lake conditions over time.

Modeling and Microscopy – an Attempt to Model the Particle Size Distribution of Lake Tahoe Particles

David Jassby and Geoff Schladow
Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
(530) 752-3942 (GS)
davidjassby@gmail.com, gschladow@ucdavais.edu

Lake Tahoe, located on the border between California and Nevada, is famous for its beautiful scenery and clear water. Declining water clarity in the lake has prompted researchers with the Davis - Tahoe Environmental Research Center to investigate the reasons for this decline as well as the mechanisms by which the decline can be reversed. This present study attempted to add to the current body of knowledge pertaining to aquatic particles that directly affect clarity. In this work, a particle aggregation model that characterizes particles by their mass and fractal length was used to predict the particle size distribution in the lake. This model will ultimately be incorporated into the Dynamic Lake Model, a 1-D water clarity model. Also, this study involved microscopy work to shed light on the spatial structure of aquatic particles found in the lake. The results of this work show that particle aggregation is indeed an important mechanism for the removal of particles from the water column, and that beam attenuation is closely linked to the number of particles of a particular size. Also, this study shows that the spatial structure of aquatic particles found in the lake is not uniform, and that when attempting to model the behavior of these particles, it is essential to allow for the large variability of particle characteristics.

Additionally, to determine how the particle size distribution (PSD) changes with depth, we chose three reference depths to correspond with depths above, in, and below the thermocline; 8 m, 38 m, and 70 m. Sampling was done during June of 2005. Fitting a linear trendline through these PSD for log particle size versus log particle numbers yielded a characteristic slope for each PSD measurement. Comparing the slopes generated at each depth indicates that as depth increases, the slope of the fitted trendline becomes flatter. This indicates that as the depth increases, the ratio between the number of small particles and large particles decreases. This phenomenon is observed on both days measurements were taken, and at every time of day. We hypothesize that the flattening of the PSD slope likely occurs due to the fact that atmospheric depositions increase the numbers of small particles at the surface, but as these small particles coagulate they become larger and sink, increasing the number of larger particles at greater depths and changing the PSD. Additional field work is needed investigate this further.

Modeling sediment and phosphorus transport at Ward Creek watershed, Lake Tahoe: 1. Hydrologic Module

M.L.Kavvas, Professor VII and Director
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616
(530) 220-2402
mlkavvas@ucdavis.edu

J.Yoon, Assistant Professor
Dept. of Environmental System Engineering
Korea University, Korea

Z.Q.Chen, Sr. Dev.Engr. and Mgr.,
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616

L.Liang, Assist. Dev. Engineer
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616

E.C. Dogrul
California Department of Water Resources

N. Ohara, Assist. Dev. Engineer
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616

H.Aksoy, Associate Professor
Dept. of Civil Engineering
Istanbul Tech. Univ.

J. Reuter,
Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
jereuter@ucdavis.edu

S. Hackley,
Tahoe Environmental Research Center
University of California, Davis
P.O. Box 633
Tahoe City, CA 96145

The Watershed Environmental Hydrology (WEHY) model is a newly developed numerical computer model of watershed hydrologic and nonpoint source environmental (NPS) processes. It is a physically-based, process-oriented model that describes the hydrologic flow and sediment and nutrient transport processes in time and space at any location within a watershed. It is unique in that it is based upon upscaled conservation equations that enable its calibration directly from the existing land databases, and not from rainfall-runoff fitting, for its hydrologic module. As such, it is also applicable to ungauged or sparsely gauged watersheds. Also, the upscaled conservation equations, used in the model are consistent with any selected computational grid resolution while accounting for subgrid scale heterogeneities within a watershed through upscaled model parameters. The model was tested at the Ward Creek watershed, Lake Tahoe, for its performance in simulating hydrologic and NPS processes at watershed scale. Since the production, transport and deposition of non-point source substances are fundamentally linked to the underlying hydrologic state of a watershed, in this first part of a two-part presentation the hydrologic module of WEHY model and its application to the hydrologic processes at Ward Creek watershed, Lake Tahoe will be discussed. In this presentation, the delineation of the local alluvial aquifer will be shown along with the hydrologic parameter maps. Also, in the application of the model to some historical rainfall-runoff events, the change in the hydrologic response depending on the nature of the rainfall process, will be shown, and the contribution to each of the runoff hydrographs from various media of the watershed will be identified.

Modeling sediment and phosphorus transport at Ward Creek watershed, Lake Tahoe: 2. NPS Module

M.L.Kavvas, Professor VII and Director
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616
(530) 220-2402
mlkavvas@ucdavis.edu

J.Yoon, Assistant Professor
Dept. of Environmental System Engineering
Korea University, Korea

Z.Q.Chen, Sr. Dev.Engr. and Mgr.,
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616

L.Liang, Assist. Dev. Engineer
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616

E.C. Dogrul
California Department of Water Resources

N. Ohara, Assist. Dev. Engineer
Hydrologic Research Lab.
Dept. of Civil & Environmental Engineering
University of California, Davis
Davis, CA 95616

H.Aksoy, Associate Professor
Dept. of Civil Engineering
Istanbul Tech. Univ.

J. Reuter,
Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
jereuter@ucdavis.edu

S. Hackley,
Tahoe Environmental Research Center
University of California, Davis
P.O. Box 633
Tahoe City, CA 96145

The Watershed Environmental Hydrology (WEHY) model is a newly developed numerical computer model of watershed hydrologic and non-point source environmental (NPS) processes that can be used for the prediction of sediment and nutrient loads from the various watersheds of Lake Tahoe to the lake. It is a process-oriented, spatially-distributed model that can simulate sediment and nutrient production, transport and deposition processes at any spatial location and time within a watershed. As such, it can also be used to identify the source areas for non-point source substance production within a watershed. Since WEHY is a physically-based model, it can also quantify the impact of land use/land cover (eg. vegetation) changes within any Lake Tahoe watershed on that watershed's sediment and nutrient loads to the lake as well as in its water balances. The application of WEHY model to the Ward Creek watershed, Lake Tahoe has shown that it can reproduce the pattern of historical sediment and phosphorus loads with reasonable accuracy. Both the calibration of the model with some historical data, and its validation by a different historical data set showed the model's consistently satisfactory performance in predicting sediment and phosphorus loads at Ward Creek watershed. Also, WEHY performed quite well in identifying the source areas of erosion/sediment production at Ward Creek watershed. Accordingly, the application results showed promise for the potential use of WEHY model for quantifying the effects of different land management practices on the nutrient and sediment balances within Lake Tahoe watersheds. In this second part of a two-part series, the above-mentioned application of WEHY to the modeling of sediment and phosphorus at Ward Creek watershed will be presented.

Mechanical Harvest and Prescribed Fire Effects on Sierran Watershed Runoff Water Quality

W. Wally Miller, Professor
Department of Natural Resources and Environmental Science
College of Agriculture, Biotechnology, and Natural Resources
University of Nevada, Reno
1000 Valley Rd., Mail Stop 186
Reno, NV 89512
(775) 784-4072
wilymalr@cabnr.unr.edu

Theresa M. Loupe, Graduate Student, MS awarded
Dale W. Johnson, Professor
Erin M. Carroll, Graduate Student
James D. Murphy, Graduate Student, MS awarded
Chad M. Stein, Graduate Student
Roger F. Walker, Professor
Department of Natural Resources and Environmental Science
College of Agriculture, Biotechnology, and Natural Resources
University of Nevada, Reno
Reno, NV 89512

Fire suppression and the lack of mechanical harvest in many areas of the eastern Sierra Nevada has left forested areas with dense trees, high fuel loads, and a thick layer of organic litter. Furthermore, recent research has recorded extremely high concentrations of inorganic nitrogen (ammonium, nitrate), phosphorus (ortho-phosphate), and sulfur (sulfate) in surface runoff from these Sierran watersheds. The effects biomass reduction using controlled burning and cut-to-length mechanical harvest followed by chip mastication on surface runoff water quality (N, P, and S) were evaluated. In both unburned treatments (unburned/unharvested, unburned/harvested) there was a clear temporal effect between years 1 (pre-burn) and 2 (post-burn), with higher runoff nutrient loads measured during year 2 of the study. Only SO_4^{2-}-S loading was found to increase significantly following mechanical harvest alone. Total nutrient discharge loading of NH_4^{+}-N, NO_3^{-}-N, PO_4^{3-}-P, and SO_4^{2-}-S was increased by burning, but more so for the burned unharvested than the burn harvested treatments. The combined effects of mechanical harvest and burning were less than burning alone. This suggests that in the absence of biomass reduction, wildfire has the potential to dramatically increase the nutrient content in surface runoff.

AM and EMS at the Lake Tahoe Basin Management Unit

Susan Norman
Adaptive Management Group Leader
USDA Forest Service
Lake Tahoe Basin Management Unit
35 College Dr.
South Lake Tahoe, CA 96151
(530) 543-2662
snorman@fs.fed.us

Joseph F. Keely, Ph.D.
Ecosystem Conservation Staff Officer
USDA Forest Service
Lake Tahoe Basin Management Unit
35 College Dr.
South Lake Tahoe, CA 96151
(530) 543-2661
jkeely@fs.fed.us

We present the evolution of the adaptive management (AM) program at the Lake Tahoe Basin Management Unit, from its origin as the Monitoring and Inventory Program, through its expansion into special studies that address select Key Management Questions of the Environmental Improvement Program within an adaptive management framework, to its imminent pivotal role in our development and implementation of LTBMU's Environmental Management System (EMS). We provide examples of how we have modernized our monitoring program to provide the most useful information for management purposes, including how our Five-Year Adaptive Management Monitoring Plan integrates our many monitoring efforts. We discuss the current development and projected implementation of our EMS, including how it is being coordinated with LTBMU's Forest Plan Revision and Pathway 2007. We recommend a stepwise approach to identifying and integrating the needs of management, regulatory, and planning agencies into the Tahoe Science Consortium's efforts to develop a Basin Science Plan that recognizes science as a tool in Lake Tahoe Basin management. We suggest "reality" checklists for the identification and prioritization of science and research projects that seek to inform management decisions, from the points of view of both management and research.

Development of a Long-Term Stormwater Monitoring Network for the Lake Tahoe Basin

Andrea Parra, Collin Strasenburgh, Ralph Townsend, Charles Goldman
University of California, Davis
Tahoe Environmental Research Center
P.O. Box 633
Tahoe City, CA 96145
atparra@ucdavis.edu, cstrasenburgh@ucdavis.edu, rptownsend@ucdavis.edu, crgoldman@ucdavis.edu

Alan Heyvaert, Todd Mihevc, Jim Thomas
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512
alan.heyvaert@dri.edu, todd.mihevc@dri.edu, jim.thomas@dri.edu

Preliminary data from pilot studies and from the Tahoe TMDL program have shown that stormwater runoff contributes a significant portion of total nutrient and suspended sediment loading into Lake Tahoe. As the Tahoe TMDL program continues, there will be increasing need to refine basin estimates of stormwater pollutant loading from diverse land use sources and to evaluate the long-term trends in loading associated with implementation of various Best Management Practices (BMPs) and the TMDL.

The primary goal of this project has been to develop a strategy for implementing an efficient, basin-wide, statistically-based stormwater monitoring program. This includes identifying crucial resource management decision-making needs, developing an appropriate monitoring design to address those needs, and providing the data analysis and data presentation tools necessary for effective stormwater management in the Tahoe Basin. The results of these efforts to date are provided along with an assessment of existing deficiencies in current monitoring design and an evaluation of critical information gaps relevant to stormwater management.

One of the specific objectives of this project was to establish a series of long-term stormwater monitoring sites within the Tahoe Basin that would provide calibration data for the evaluation of results from localized shorter term studies. The framework of this long-term monitoring system has been established, and consists of sites distributed around the Tahoe Basin. The current data analysis shows characteristics of different event types, site runoff coefficients, particle size distributions and nutrient concentrations associated with different land use features and with BMP efficiency assessments around the lake. An extensive analysis of fine sediment loadings in stormwater runoff from diverse areas in the Tahoe Basin is presented. Appropriate protocols for comparative analysis using the data from long-term calibration monitoring sites are also demonstrated.

Water Quality Improvement by Cultured Periphyton: Preliminary Results of a Tahoe Basin Pilot System

Steven Patterson
Restoration Ecologist
Biological x Design
10820 Olson Drive Ste. C262
Rancho Cordova, CA 95670
(916) 524-9039
spatterson5000@earthlink.net

Alan Heyvaert
Desert Research Institute
2215 Raggio Parkway
Reno, NV 89512
alan.heyvaert@dri.edu

Collin Strasenburgh
Tahoe Environmental Research Center
University of California, Davis
P.O. Box 633
Tahoe City, CA 96145
cstrasenburgh@ucdavis.edu

Structural Best Management Practices (BMPs) commonly used around the country to reduce nonpoint source pollution may not be sufficient to achieve the water quality characteristics needed for reduced inputs of nutrients and fine sediments to Lake Tahoe. The Tahoe Science Plan and the Tahoe TMDL both recognize that new and innovative techniques may be necessary to reverse the declining clarity of the lake. Reported here are conceptual motivations behind the design of a periphyton-based cultured ecology system and some preliminary test results.

It has long been known that periphyton in natural systems can reduce the rate of nutrient transfer from wetlands to associated lakes. Pioneering attempts to utilize periphyton for nutrient removal date back at least 20 years. One advantage of a periphyton-based treatment system is that it could function well in the cool subalpine air and water conditions that prevail during spring runoff in the Tahoe Basin. Research data available from the littoral zone of Lake Tahoe, for example, demonstrate high periphyton growth rates in the spring. Another potential advantage of a cultured ecology system is that periphyton excrete a sticky mucilaginous material that can adsorb fine particulates from the water column. It has been shown also that periphyton can rapidly remove phosphorus to very low concentrations in laboratory mesocosms, suggesting that low soluble phosphorus concentrations could be achieved by similar systems at the BMP scale.

A Tahoe cultured ecology test system was constructed in the summer of 2006 at the TERC field facility in Tahoe City, CA. It consists of two cylindrical tanks made from a photosynthetic-wavelength translucent fiberglass, each containing a cylindrical screen that serves as substrate for periphyton growth. Both tanks were seeded with propagules of Tahoe periphyton species. Once established, the

accumulated periphyton was harvested every 21 to 30 days to remove the nutrients as well as suspended sediment trapped in periphyton biomass. Regular harvesting kept the periphyton in an active growth phase. Influent and effluent concentrations of phosphorus and nitrogen were sampled every 14 days. The total N and total P concentrations of harvested periphyton biomass were analyzed. Preliminary results from these analyses are compared to the nutrient and fine particle concentrations typical of Tahoe Basin streams, stormwater runoff, and BMP discharges. Estimates are then provided for the surface area and other conditions that would be needed if this system were scaled up to treat urban runoff at a typical BMP site.

Spatial and Temporal Distribution of Fine Particles and Elemental Concentrations in Suspended Sediments in Lake Tahoe Streams

Alexander A. Rabidoux[1] and Geoff Schladow
Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
[1]Current address: Solano County Water Agency
arabidoux@scwa2.com
(530) 752-3942 (GS)
gschladow@ucdavais.edu

This study investigated the spatial and temporal variation of both fine particle and elemental concentrations in Lake Tahoe streams. Stream samples were collected approximately bimonthly for water years 2002 and 2003. Both particle size and elemental size measurements were made. The results show that the west and south shore streams have the highest fine particle inputs, while the east shore streams have considerably smaller inputs. Regression estimates also show that fine particles in the range of 0.5 - 20 μm make up almost 25 % of the total suspended sediment load. The streams with the highest fine particle inputs include the Upper Truckee River, Blackwood, Trout, Ward, and Meeks Creeks. Furthermore, in 2002 and 2003 the west shore streams contributed over 80 % and the Upper Truckee River over 70 % of their yearly particle loads during the spring snowmelt. Conversely, the east shore streams contributed only 32 - 62 % of their yearly load during the spring snowmelt. A preliminary study was done to investigate the depth of insertion for stream particles (discharge) into Lake Tahoe. Based on modeling results it was observed that the depth of insertion varied on both seasonal and diel scales, with input found both above and below the thermocline depending on time and date.

The most abundant elements in Lake Tahoe streams include silicon, calcium, magnesium, sodium, potassium, aluminum, phosphorus, and manganese, with calcium having predominantly the highest concentration. Additionally the alkali and alkali earth metals along with silicon and scandium are predominantly found in the dissolved state while transitional metals like titanium and manganese, heavy metals, and the rare earth elements are all primarily dominated by particulate sized particles in Lake Tahoe streams. For the elemental mass flux rates, the west shore streams of Blackwood, Ward, and General Creeks along with the Upper Truckee River fluctuate widely over the water year, with significantly higher rates during the spring snowmelt as compared to the other streams. The north and south-east shore streams of Incline, Third, Trout, Edgewood, and Eagle Rock Creeks all have relatively stable mass flux rates, with a small increase during the spring snowmelt. The east shore streams of Logan House and Glenbrook Creeks experience larger fluctuations than the south-east and north shore streams, but not as much as the west shore streams. During the spring snowmelt the west shore streams along with the Upper Truckee River dominate in both the filter and dissolved flux rates, while during the late summer and early fall months, the south-east and north shore streams have comparable and sometimes higher flux rates than the west shore streams.

The Lake Tahoe Clarity Model – A Tool for Guiding Basin Management Decisions

Geoff Schladow, Goloka Sahoo and John Reuter
Tahoe Environmental Research Center
University of California, Davis
Davis, CA 95616
(530) 752-3942 (GS)
gschladow@ucdavais.edu , gbsahoo@ucdavis.edu , jereuter@ucdavis.edu

The Lake Tahoe Clarity Model is a coupled hydrodynamic, ecological and optical model, developed to provide deterministic prediction of water clarity, to understand the root causes of its decline and to explore management options for reversing this trend. The model is quasi two-dimensional, and based on DLM-WQ. Inputs to the model consist of daily values of meteorological variables, as well as nutrient and fine particle loading from stream-flow (for all 63 streams), 10 intervening zones, groundwater, and the atmosphere. The model predicts the vertical distribution of nutrient concentration, algal concentration and suspended particle concentration at hourly time scales. Water clarity, a function of light absorption and scattering, is in turn calculated from algal concentration and the size distribution and concentration of inorganic particles.

The model has been calibrated and validated using measured data collected for the period 1999 - 2004. In order to run the model to explore future changes, it is necessary to have estimates of future meteorological, hydrological and atmospheric loadings. These were obtained from the results of the basin hydrologic model LSPC. By assuming that the historical precipitation patterns are maintained in the future, a 30 year “business as usual” base case scenario has been developed. This shows clarity continuing to decline albeit it at a slower pace.

By selectively reducing either or both the loads of fine particle or nutrients, it is possible to quantitatively estimate the impact of load reduction on lake clarity in the future. These hypothetical load reductions can be applied at varying rates so as to simulate the effect of different rates of capital investment in BMPs. Similarly, by varying the hydrologic forcing distribution, the impact of climate change is being explored. Results to date indicate that attaining the target mid-lake clarity target is indeed possible. The time taken to attain the target depends both on the level and type of load reduction, as well as the rate at which load reductions are implemented.

Estimates of Fine-Sediment Loadings to Lake Tahoe from Channel Sources

Andrew Simon
USDA-ARS
National Sedimentation Laboratory
P.O. Box 1157
Oxford MS 38655
(662) 232-2918; (662) 281-5706 (fax)
asimon@ars.usda.gov

The delivery of fine-grained sediment from tributary basins is listed as a major cause of water-clarity deterioration in Lake Tahoe. Efforts to control the discharge of fine sediment to the lake and to predict future clarity conditions with a lake-clarity model require knowledge of the volumes, rates and sources of this material. Combinations of field-based observations of channel and bank stability with measured and simulated data on fine-sediment loadings were used to estimate fine-sediment loadings from un-monitored basins throughout the Lake Tahoe Basin.

Fine-sediment (<0.063) loadings in tonnes per year for each un-monitored watershed were based on extrapolating relations between distributions of a combined-stability index and measured fine yields ($T/y/km^2$) within each basin quadrant. The greatest contributors happened to be those with measured data. In descending order they are: Upper Truckee River (1010 T/y), Blackwood Creek (846 T/y), Trout Creek (462 T/y) and Ward Creek (412 T/y). Summing the values from the contributing watersheds provided an average, annual estimate of fine-sediment loadings to the lake of 5,206 T/y.

Fine-sediment loadings (in T/y) were converted to number of particles per year finer than 0.020 mm for by establishing relations between total, suspended-sediment concentration (in mg/l) and the concentration of the 5-20 μm fraction in number per milliliter. Resulting data were converted to mean-daily and then annual values using suspended-sediment rating relations. A total of 7.79E+19 particles in the 5-20 μm fraction were calculated to enter Lake Tahoe in an average year with the Upper Truckee River accounting for almost 25% of the total. Contributions from Blackwood, Ward, Trout, and Third Creeks account for another 23% of these very fine particles. Thus, these five streams making up about 40% of the basin area, account for almost 50% of all fine-sediment loadings to the lake.

Contributions of fine sediment from streambank erosion were estimated by developing empirical relations between measured or simulated bank-erosion rates with a field-based measure of the extent of bank instability along given reaches. Measured, unit values of fine sediment erosion ranged from to 0.002 $m^3/y/km$ for Logan House Creek to 12.2 $m^3/y/km$ for Blackwood Creek. Multiplying by the length of main channels in the watershed produced estimates of fine-sediment streambank erosion for each of the watersheds in T/y. Summing the values for 57 contributing watersheds provided an average, annual fine-sediment loading from streambank erosion of 1,305 T/y. This represents about 25% of the average, annual fine-sediment load delivered to the lake from all sources. The two largest contributors, the Upper Truckee River (639 T/y) and Blackwood Creek (431 T/y), account for slightly more than 80% of all fines emanating from streambanks. Extrapolations of fine-sediment loadings from streambanks to the un-monitored watersheds contain a significant amount of uncertainty results, therefore, should be considered as estimates.

Wind-Driven Upwelling at Lake Tahoe: Satellite and *In Situ* Measurements

Todd E. Steissberg, M.S.
Graduate Student Researcher, Civil and Environmental Engineering
University of California, Davis
Civil and Environmental Engineering
One Shields Avenue
University of California, Davis
Davis, CA 95616
(530) 754-6425
tsteissberg@ucdavis.edu

Thermal infrared images acquired by high-resolution and moderate-resolution satellite instruments can be used to observe wind-driven upwelling in lakes and can provide a measure of their spatial variability and horizontal distribution, information that conventional field-based measurements cannot provide. The surface temperature maps derived from these images enabled the identification of wind-driven partial upwellings and the horizontal transport associated with them as important and persistent features at Lake Tahoe. The satellite images, paired with *in situ* buoy-mounted surface thermistor and meteorological data, have shown that upwellings occur at least twice monthly, on average, throughout the spring and summer stratified period, transporting water from the metalimnion to the surface layer. They commonly display a jet-like appearance, traveling from the upwind to the downwind side of the lake, typically at current speeds of 15 – 25 cm/s. Partial upwellings were found to generally decrease lake clarity, although deeper upwelling events can increase clarity. Sinking zones, other convergence areas, and divergence areas can also be observed in the thermal patterns of the satellite images. These are important events that contribute to the patchiness and heterogeneity that characterize natural aquatic systems. The spatial variability evident in the thermal infrared satellite images illustrates the advantages of synoptic thermal infrared satellite measurements over *in situ* point measurements alone to characterize upwelling events since, depending on location, *in situ* temperature sensors and other field measurements might not even capture an upwelling event. Satellite imagery used in conjunction with *in situ* lake measurements can provide a spatial context for the in-lake data, describing the spatial extent and variability of lake processes. The spatial information conveyed by the synoptic satellite measurements can help improve monitoring of the clarity and general water quality of Lake Tahoe and other lakes.

Turbidity Measurements for Determination of Sediment Source and Retention in River and Marsh Environments

A.P. Stubblefield, Professor
Dept Forestry and Watershed Management
Humboldt State University
Arcata, CA
apstubblefield@gmail.com

E.W. Larsen, Research Faculty
Dept. Landscape Architecture
University of California, Davis
Davis, CA 95616
ewlarsen@ucdavis.edu

M.I. Escobar, Student
Dept. Hydrology
University of California, Davis
Davis, CA 95616
mescobar@ucdavis.edu

J.E. Reuter, Research Faculty and C.R. Goldman, Professor
Dept. Env. Sci. & Policy
University of California, Davis
Davis, CA 95616
jereuter@ucdavis.edu, crgoldman@ucdavis.edu

Deployment of networks of turbidity sensors can be effective for determining sediment and phosphorus sources, recording transport dynamics, and quantifying sediment retention characteristics in aquatic systems. This paper presents the use of continuously recording optical backscatter turbidometers in two subalpine watersheds of Lake Tahoe and the delta floodplain of the Upper Truckee Marsh, South Lake Tahoe. Excellent correlations were found between turbidity and suspended sediment and total phosphorus. Sediment budgets created from turbidity measurement indicate 20-40% of spring snowmelt sediment loads came from badlands created on volcanic breccia mudflows in Ward and Blackwood Creeks, comprising only 1% of the watershed area. In inaccessible mountain watersheds, the greatly increased temporal coverage provided by turbidity measurement compensates for inaccuracies introduced by the use of the technique as a proxy for other variables. Similarly, in an equally inaccessible and frequently indurated marsh environments, turbidity measurement made possible the quantification of sediment retention for marsh segments with different levels of anthropogenic disturbance. Intact portions of the delta floodplain had 68-90% retention of suspended sediment load entering from Trout Creek. Channelized and deeply incised portions of the delta flowing from the Upper Truckee River had 13-41% retention. Total phosphorus retention had similar trends. Examination of continuous turbidity record shows evidence of clockwise hysteresis in the relationship of suspended sediment and discharge. Comparison of turbidity and sediment rating curve method suggests that rating curve method overestimated sediment load during low flow and underestimated during peak flow events.

Retention of Suspended Sediment and Phosphorus on a Freshwater Delta, South Lake Tahoe, California.

Andrew P. Stubblefield
Department of Geological Sciences,
Case Western Reserve University,
andrew.stubblefield@case.edu

Marisa I. Escobar
Hydrologic Sciences Graduate Program,
University of California, Davis USA

Eric W. Larsen
Department of Landscape Architecture,
University of California, Davis, USA

The Upper Truckee River and Trout Creek, two major tributaries inflowing to Lake Tahoe, join to form what was historically the largest wetland in the Sierra Nevada mountain range that separates California and Nevada (USA). In the 1950s the delta floodplain of the Upper Truckee River was greatly reduced in area (38%) by urban development and the diversion of the river into a single excavated channel. Conversely, Trout Creek still flows through a wide marsh system with significant overbank flooding before entering Lake Tahoe. This study hypothesized that river channel reaches that are not incised within the delta floodplain retain more sediment and nutrients as a result of greater floodplain connectivity, compared to more incised and excavated reaches. Suspended sediment (SS) and total phosphorus (TP) load data from the delta formed by the Upper Truckee River and Trout Creek were collected using flow stage sensors, turbidometers and depth-integrated samples. During the spring snowmelt flow events monitored in 2003, SS load was reduced by 13–41% for the Upper Truckee River and by 68–90% for Trout Creek. Similar reductions in TP load were observed: 13–32% for the Upper Truckee River and 61–84% for Trout Creek. Monitoring of Trout Creek indicated a reduction in load per unit volume of 20–34% in a moderately incised reach versus a reduction of 51–77% in a non-incised marsh reach containing lagoons, braided channels and backwater areas created by a beaver dam. Smaller particle sizes, <10 lm, were retained in the lower marsh reach with similar efficiencies as larger particle sizes. If retention rates from the Trout Creek portion of the marsh are applied to the Upper Truckee River, sediment loading to Lake Tahoe for 2003.

Water Clarity Modeling in Lake Tahoe: Linking suspended matter characteristics to Secchi Depth

Theodore J. Swift
Department of L&, Air & Water Resources
University of California, Davis
1 Shields Avenue
Davis, California 95616
Present address: California Department of Water Resources
901 P Street
Sacramento CA 94236
(916) 651-9694
tswift@water.ca.gov

Joaquim Perez-Losada
Department of Civil & Environmental Engineering
University of California, Davis
1 Shields Avenue, Davis, CA 95616
Present address: Departament de Fisica, Universitat de Girona, Campus de Montilivi, 17071 Girona, Catalonia, Spain

S. Geoffrey Schladow
Department of Civil & Environmental Engineering
University of California, Davis
1 Shields Avenue, Davis, CA 95616

John E. Reuter
Alan D. Jassby
Charles R. Goldman
Department of Environmental Sciences & Policy
University of California, Davis
1 Shields Avenue,
Davis, CA 95616

Lake Tahoe is world-famous for its clarity and color. Long-term monitoring by the University of California, Davis, has documented several mechanisms affecting water clarity on seasonal, annual, and interannaul time scales. An additive semi-analytic model of water clarity for the forward problem of calculating apparent optical properties (AOPs) of diffuse attenuation and Secchi depth from the inherent optical properties (IOPs) due to suspended matter in oligotrophic waters is presented. The model is general in form, taking into account algal concentration, suspended inorganic sediment concentration, particle size distribution, and dissolved organic matter to predict Secchi depth and diffuse light attenuation. The model is being applied to ultra-oligotrophic Lake Tahoe, California-Nevada to quantify the relative effects of phytoplankton or phytoplankton-derived organic materials, other particles such as suspended mineral sediment, and dissolved organic matter on the lake's clarity. We conclude that suspended inorganic sediments and phytoplanktonic algae both contribute significantly to the reduction in clarity, and that suspended particulate matter, rather than dissolved organic matter, are the dominant

causes of clarity loss. Fine inorganic suspended sediments are carried into the lake by snowmelt, increasing light attenuation due to scattering. Algae and detritus from the deep chlorophyll layer (40-60 m depth) are brought up to the near-surface during winter deep mixing, where they absorb and scatter light. These findings provide input to the ongoing scientific research and watershed management efforts in the Tahoe basin. Cumulative contribution to the scattering coefficient for inorganic particles for each of the particle size ranges used in the clarity model. Size classes correspond to 0.5–1, 1–2, 2–4, 4–8, 8–16, and 16–32 μm.

Rosewood Creek: A Seasonal Analysis of Water Quality in the Tahoe Basin

Emma Tolley
Student, Homestead High School
1447 Richardson Avenue, Los Altos, CA 94024
(650) 961-4804
Meow23x@aol.com

Lesley Higgins, PhD
Conservation Assistant, Tahoe Resource Conservation District
870 Emerald Bay Road, South Lake Tahoe, CA 96150
(530) 543-1501 ext.121
Lvhiggins@aol.com

This study analyzed the water quality of Rosewood Creek from source to mouth over four seasons: summer, fall, winter and spring during 2004-2005. Measurements were conducted every other month in order to compare seasonal changes in water quality. The purpose of this study was to discover where major changes in water quality occurred and to learn whether the Rosewood Creek Restoration Area effectively lowered turbidity.
The creek was mapped with a GPS receiver and eight measurement sites were chosen to represent different terrain and possible sources of sediment loading. Site 1, located slightly below the source and above any developed areas, served as the control sample. A variety of measurements were taken at each site, including conductivity, parts hydrogen (pH), dissolved oxygen, total dissolved solids (TDS), and turbidity. Dr. Rick Susfalk and staff at the Desert Research Institute conducted additional turbidity readings of some of the water samples.

This study found that summer and winter turbidity measurements were reduced after the water had traveled though the Rosewood Creek Restoration Area, while the turbidity levels in the fall remained fairly constant. In the spring the restoration area appeared to have no effect in lowering turbidity. Contributing to high turbidity during the winter and spring might be Highway 28 runoff and snow that was plowed into the creek. Conductivity and TDS were greater farther down the creek in the summer through winter. The pH levels at the source were remarkably basic, but became more acidic lower down the stream. Dissolved oxygen followed no discernable trend.

The seasonal turbidity trends demonstrate that the Rosewood Creek Restoration Area has the greatest impact on water quality but fails to reduce the high sediment loads of spring runoff before the water reaches Lake Tahoe.

Inter-annual Variability of the Tahoe Basin Water Balance, 1901-2004

James C. Trask, PhD candidate
Hydrologic Sciences Program, Veihmeyer Hall
University of California at Davis
Davis, CA 95616
(530) 756-3244
jctrask@ucdavis.edu

Graham E. Fogg, Professor
Land Air and Water Resources Dept.
Hydrologic Sciences Program, Veihmeyer Hall
University of California at Davis
gefogg@ucdavis.edu

Patterns in annual Tahoe Basin water balance components for 1901-2004 are presented. A clear trend of increasing inter-annual variability over the period of record is present for both annual precipitation data (1915-2004) and annual basin water yield data (Lower Truckee outflow + Lake Tahoe storage changes; 1901-2004). No overall trend in the mean annual magnitude of any of the major water balance components (precipitation, watershed runoff, basin water yield, Lake Tahoe evaporation, or watershed ET) are statistically discernable, although decadal-scale fluctuations are present. Decadal-scale quasi-periodic fluctuations in precipitation data are distinct, and paralleled by fluctuations in both watershed runoff and basin water yield data. Lake Tahoe evaporation and watershed ET have fluctuated on a time scale of several decades. Basin water yield is more perfectly correlated with gaged watershed runoff over the period of record (1958-present) than with basin precipitation.

Annual watershed runoff data and basin water yield are highly correlated with precipitation data for both the current and previous water-years. A novel statistical application to water balances reduces the random error 'noise' in precipitation and runoff data. The resulting noise-filtered data show clear correlation of annual watershed runoff (& basin yield) with precipitation over the previous 2 water-years. This demonstrates significant watershed 'memory' for annual precipitation extending back 2 water-years.

Very low stream baseflow observed in late summer and early fall indicates the amount of steady groundwater flow into Lake Tahoe is small (>1,000 to <~12,000 acre-ft/yr). The amount of nonsteady annual groundwater discharge, which fluctuates in response to annual precipitation, likely averages >4,000 acre-ft/yr (from nearshore areas), with a water balance residual upper bound of ~85,000 acre-ft/yr. However hydrogeologic considerations suggest that this relatively 'rapid-response' component of groundwater flow into Lake Tahoe is also small (mean <~20,000 acre-ft/yr), and that total groundwater discharge directly into Lake Tahoe is smaller than recently reported estimates, with most of watershed groundwater discharging into streams as baseflow.

Finally, inter-annual variance of normalized precipitation data attenuates rapidly with increasing elevation in the Tahoe Basin. This indicates that use of an isohyetal map and reference stations to estimate precipitation at ungaged sites should be supplemented with a simple elevation-dependent correction factor, to accurately account for the dependence of normalized precipitation variance on surface elevation.

Reduced Mixing Causes Reorganization of the Phytoplankton Community Structure in Lake Tahoe

Monika Winder, Ph.D.
Tahoe Environmental Research Center
University of California, Davis
One Shields Ave.
Davis CA 95616-8803
(530) 754 9354
mwinder@ucdavis.edu

Phytoplankton communities consist of many different species and the performance of individual taxa is to a large extent governed by nutrient availability and physical mixing processes. Climate warming strongly affects the extent of vertical mixing and nutrient redistribution from the deep-water layer in lakes, and thus it is expected that a changing thermal regime will affect phytoplankton composition and ultimately the energy production and flux to higher trophic levels. In this study I use a historical phytoplankton data set from Lake Tahoe to understand the response of phytoplankton dynamics and community composition to reduced vertical mixing. Lake Tahoe experienced a warming trend over the last four decades with an increasing stability in the upper water column. While phytoplankton biovolume remained relatively constant since the early 1980s, the community composition was highly variable among years and a temporal separation of the phytoplankton community structure is evident. The reorganization of the phytoplankton community is associated with altering nutrient ratios and mixing processes. Mixing processes indirectly affected the temporal dynamics of chrysophytes through its effect on nutrient redistribution, while other phytoplankton taxa showed a direct response to reduced vertical mixing: in diatoms species with low sinking velocities are able to expand and species turnover rate decreased and the community became more stable. In contrast, species turnover rate in chlorophytes increased with increasing water-column stability, indicating that reduced mixing will generate rapid restructuring within this community. Overall small-sized cells were strongest associated with a more stable water column and are therefore better competitors under a more stable environment with low nutrient availability. This study illustrates that phytoplankton community reorganization is likely under reduced vertical mixing; however responses to climate change are complex because changes in other ecosystem components act simultaneously on phytoplankton populations.

Sediment Retention on a Deltaic Floodplain in Response to Climate and Land-Use Changes

Steven Matthew Winter
Adolfson Associates, Inc.
5309 Shilshole Ave. NW, Ste. 200
Seattle, Washington 98107
swinter@adolfson.com

Eric W. Larsen
Department of Environmental Design,
University of California, Davis,
USA 95616
ewlarsen@ucdavis.edu

The Lake Tahoe basin on the borders of California and Nevada, USA, has been subjected to two major phases of anthropogenic disturbances to sediment and nutrient transport processes: the construction of roads and timber harvesting in the 1860's and urbanization in the 1950's and 1960's. The Upper Truckee Marsh is located on a delta formed where the basin's two largest drainages flow into the southern end of Lake Tahoe. The marsh system – through its sedimentation record - provides an integrated record of the geomorphic effects of watershed disturbances. This study determined that sedimentation on the Upper Truckee Marsh is primarily a function of climate and land-use changes, and only secondarily of lacustrine processes. ^{14}C and ^{137}Cs dating procedures were used to investigate sedimentation rates on the marsh in the pre-disturbance era (10^3 yr scale), and in the post-urbanization era (the past 50 yrs). Mass sedimentation rates range from 0.025 to 0.075 g cm^{-2} yr^{-1}, and from 0.14 to 1.12 g cm^{-2} yr^{-1} for long term and short term (ie, post-urbanization) periods, respectively. While the mid- to late-Holocene sedimentation record incorporates significant shifts in climate, the increase in sedimentation rate from 1950 to the present indicates that land-use changes have had an impact on the geomorphology of the Upper Truckee Marsh with increased overbank sedimentation rates. These results suggest that the Upper Truckee Marsh has the potential for future sediment and nutrient retention, which makes the site a good candidate for restoration efforts to reconnect a degraded (incised) channel, the Upper Truckee River, and floodplain systems to reduce impacts to Lake Tahoe's water quality.

Wildlife and Fish Ecology

The Effects of Cultural Eutrophication on the Coupling between Pelagic Primary Producers and Benthic Consumers in Lake Tahoe

Sudeep Chandra
Department of Natural Resources and Environmental Science
1000 Valley Road
Mail Stop 186
University of Nevada, Reno
Reno, Nevada, USA 89512
(775) 784-6221, (775) 784-4583 (FAX)
sudeep@cabnr.unr.edu

M. Jake Vander Zanden
Center for Limnology
University of Wisconsin at Madison
Madison, WI 89509

Alan C. Heyvaert, Bob C. Richards, Brant C. Allen, and Charles R. Goldman
Department of Environmental Science and Policy
University of California at Davis
Davis, CA 95617

We investigated the effects of cultural eutrophication on the coupling between pelagic primary producers and benthic consumers in Lake Tahoe. Spatial and temporal changes in zoobenthos energetics were documented by measuring >40 years change in pelagic primary production through ^{14}C incubations, reduction in clarity by Secchi and light measurements, and sedimentation rates. Effects on zoobenthic primary consumers (oligochaete and chironomidae) and an obligate benthic secondary consumer (*Catostomus tahoensis*) were determined by comparing $\delta^{13}C$ values of historical and contemporary samples. A model that considers primary production (benthic or pelagic) contributions and their respective $\delta^{13}C$ signals was used to examine the factors contributing to zoobenthic energy shifts. Spatially, zoobenthos exhibited a strong positive relationship between lake depth and pelagic isotopic signals. At depths where ambient 1% light levels have shifted with time (50-85 meters), pelagic primary producer and zoobenthic consumer coupling was positive. Historically, zoobenthos from this depth zone obtained 32% of their energy from phytoplankton sources. After 43 years of eutrophication they obtained 62% from pelagic sources. A simple model indicated increased pelagic production and resultant export of matter, combined with the loss of benthic primary production contributed to the change in zoobenthos energetics. This change was passed to higher consumers, with the benthic fish, Tahoe sucker, now deriving ~14% of their energy from pelagic primary production sources (Figure 1).

Currently most research on Lake Tahoe has focuses on pelagic habitats. This study is the first to demonstrate how lake eutrophication shifts ecosystem dynamics at multiple habitats through increases the coupling between pelagic and benthic habitats. Research programs needs to quantify changes to benthic habitats if we are going to pursue programs restoring the lake.

Evaluation of the Re-Introduction of Native Lahontan Cutthroat Trout in Fallen Leaf Lake (California) and Development of Management Strategies for Recovery

Sudeep Chandra and Lisa Atwell
Department of Natural Resources and Environmental Science
1000 Valley Road
Mail Stop 186
University of Nevada, Reno
Reno, Nevada, USA 89512
(775) 784-6221, (775) 784-4583 (FAX)
sudeep@cabnr.unr.edu

Brant C. Allen and John Reuter
Department of Environmental Science and Policy
University of California at Davis
Davis, CA 95617

M. Jake Vander Zanden
Center for Limnology
University of Wisconsin at Madison
Madison, WI 89509

The historic range of Lahontan cutthroat trout (LCT), *Oncorhynchus clarki henshawi*, covered much of northern Nevada, southern Oregon, and the eastern slope of the Sierra Nevada mountain range in California including the Truckee-Pyramid watershed. Human impacts from the mid 1800's silver rush and the rapid increase in development within the Truckee River watershed eventually led to the extirpation of LCT by the 1930's. Within the Lake Tahoe basin, there have been several attempts to reestablish both fluvial (resident stream form) and lacustrine (resident lake form) LCT populations however none have scientifically evaluated the impediments to restoration in large lakes within the basin. In 2001, a collaborative interagency effort was undertaken to foster LCT recovery in Fallen Leaf Lake. With funding from the US Fish and Wildlife Service and support from the California Department of Fish and Game, US Forest Service, California Trout Unlimited, Fallen Leaf Lake Homeowners Association, University of California- Davis, University of Nevada- Reno, and University of Wisconsin-Madison, a study was initiated to evaluate the LCT reintroduction and develop management strategies for their recovery in a lacustrine environment.

The Fallen Leaf Lake LCT reintroduction project was designed to evaluate ecological shifts that may occur as a result of reintroducing the native species into an environment dramatically altered from its historic condition. With an understanding of previous attempts to reintroduce cutthroat trout in the western United States, attention was given to key stumbling blocks that have prevented the establishment of self-sustaining populations. During this project (2001-2005), work focused on determining the following:

- evaluate the food and habitat resource availability in the lake for introduced LCT
- measure the annual growth rates of LCT in the lake
- evaluate the annual harvest of LCT by recreational anglers

- survey Glen Alpine Creek for the presence of spawning LCT and competing rainbow trout
- observe the impact of non-native predators on the different life stages of LCT
- model the pre- and post-introduction energetic alterations to predators (if any) as a result of the reintroduction
- develop adaptive management strategies that favor the survival of LCT

Cumulatively, the objectives of the study were designed to provide an understanding of ecological shifts resulting from the LCT reintroduction. These included predator-prey interactions with nonnative species and resource utilization by the introduced species. Additionally, special attention was given to potential impediments to the life history characteristics of the LCT after stocking, in order to develop management strategies that would enhance the recovery potential of LCT and thus promote natural growth and survival of the population.

Controlling the Proliferation of Invasive Warm Water Fish Species in the Lake Tahoe Basin

Sudeep Chandra
Department of Natural Resources and Environmental Science
1000 Valley Road
Mail Stop 186
University of Nevada, Reno
Reno, Nevada, USA 89512
(775) 784-6221, (775) 784-4583 (FAX)
sudeep@cabnr.unr.edu

Brant C. Allen
Department of Environmental Science and Policy
University of California at Davis

Brian Shuter and Christine Ngai
University of Toronto, Toronto, Ontario, Canada

Nonnative species introductions into aquatic ecosystems are of growing concern worldwide due to their economic and ecological impacts. In the last 125 years numerous nonnative species already have been introduced into Lake Tahoe. In recent years however there has been an increase in warmwater invaders (e.g. bass, bluegill species, etc.) which will likely affect nearshore productivity and clarity through the recycling of nutrients. These nonnative species will also affect how we manage and restore native fishes within the basin. This project is developing and implement best management practices for the containment and reduction of at least 5 invasive warm water species in the Lake Tahoe basin. The management program is based on a scientific understanding of invasive species habitat requirements (e.g. temperature, spawning requirements, food resources) and the overlap there in. To minimize economic costs for controlling these species, we are determining the locations of current and future hot spots within the lake resulting from the gradual warming of Tahoe waters due to climate change.

Community, food web, and ecosystem consequences of *Mysis relicta* introduction in Lake Tahoe

Sudeep Chandra
Department of Natural Resources and Environmental Science
1000 Valley Road
Mail Stop 186
University of Nevada, Reno
Reno, Nevada, USA 89512
(775) 784-6221, (775) 784-4583 (FAX)
sudeep@cabnr.unr.edu

M. Jake Vander Zanden
Center for Limnology
University of Wisconsin at Madison
Madison, WI 89509

Brant C. Allen and Charles Goldman
Department of Environmental Science and Policy
University of California at Davis

Jason Van Tassell
Aquatic Ecology Laboratory
Ohio State University
Columbus, OH, 43212-1156

Chuck Levitan
Department of Science and Technology
Sierra Nevada College
999 Lake Tahoe Blvd
Incline Village, NV 89451

The importance of species and their impacts on various levels of ecological organization (population, community, and ecosystem) is increasingly recognized. Certain species, in particular those labeled keystone species, have been shown to be important in regulating population and community level dynamics (Paine 1966). In contrast, understanding the importance of species on ecosystem-level processes reduces the emphasis on species identity and classifies species according to their contribution to overall ecosystem functioning. Regardless of the ecological level, the emphasis has been on biodiversity and conservation. An alternative approach is to evaluate the impact of species invasions across several levels of ecological organization. Species invasions can represent dynamic natural experiments that allow an assessment of the importance of species interactions and their impacts on ecosystems.

Some studies have evaluated the impact of a species invader across many levels of ecological organization within one particular system. Plant invasions can alter nutrient availability by either increasing or decreasing nutrients available to other organisms thereby competing with or providing

food resources to other biota in an ecosystem. The establishment of nonnative fish in streams may not only replace native predators but alter the distribution of invertebrates, thereby increasing algal biomass. Furthermore, the removal of invertebrates in some streams due to strong top down control can increase algal productivity and thus increase flux of nutrients through the benthos.

The objective of this study is to determine the long-term impacts of a nonnative invertebrate introduction across community and ecosystem levels. Currently, most investigations of community and ecosystem impacts in natural environments are on shorter time scales (2-5 years). Due to its unique limnological characteristics, nutrient loading and biotic production in Lake Tahoe have been intensively studied during the latter half of the 20th century. As a result the long-term evaluation of community and ecosystem scale impacts from an introduced invertebrate grazer is possible. Mysid shrimp (*Mysis relicta*) were introduced into Lake Tahoe in the mid 1960's as forage for introduced gamefish. This species undergoes daily vertical migrations from pelagic to profundal environments, with the largest individuals in Lake Tahoe migrating up to 400-500 meters per day. Thus, this species has the potential to couple these two different habitats. In this study, we examine long-term trends in pelagic primary production, carbon sedimentation rates, zooplankton densities, and *Mysis* feeding behavior to examine the impact of *Mysis* on Lake Tahoe at community, food web, and ecosystem levels.

An Evaluation of Indicators to Determine Biological Condition of Lake Tahoe Streams

Leska Fore, MS
Environmental Statistician, Statistical Design, Inc.
136 NW 40th St.
Seattle, WA 98107
(206) 632-4635
leska@seanet.com

James R. Karr, Ph.D.
Professor Emeritus
University of Washington, Seattle, WA
190 Cascadia Loop,
Sequim, WA 98382
(360) 681-3163
jrkarr@u.washington.edu

Ian Chan, MS
Aquatic Ecologist
Garcia & Associates (GANDA)
P.O. Box 1268
Tahoe City, CA 96145
(530) 363-2008
ichan@garciaandassociates.com

J. Shane Romsos, MS
Wildlife Biologist, Forest Plan Revision Team
Lake Tahoe Basin Management Unit
USDA Forest Service
35 College Dr.
South Lake Tahoe, CA 96151
(530) 543-2745
sromsos@fs.fed.us

Currently, indicators to assess the quality of Lake Tahoe's streams to support native biological activity are insufficient. Land use regulators and land managers need better indicators of biological condition in order to improve decision-making, prioritize and measure stream restoration projects, and assess stream condition trends. Benthic macroinvertebrate (aquatic insects) data were systematically collected from 10 streams with similar flow characteristics in order to assess their ability to serve as indicators of stream biological integrity. A multimetric index was derived from aquatic insect community metrics that were shown to be most responsive to varying intensities of human influences. Results from this evaluation and potential management and monitoring implications will be presented.

Lahontan Cutthroat Trout Recovery in the Tahoe Basin: A Partnership Between Management and Research for Refined Conservation Planning and Management of Lahontan Cutthroat Trout

Lisa Heki
Manager
Lahontan NFH Complex
U.S. Fish and Wildlife Service

Mary Peacock, PhD
Professor
University of Nevada

Lahontan cutthroat trout (LCT), a cutthroat trout subspecies endemic to the Lahontan hydrographic basin of northern Nevada, eastern California and southeastern Oregon, has been listed as threatened since the early 1970's. The historic distribution of this subspecies included large interconnected stream systems and stream and lake systems. Fragmentation of these interconnected habitats has lead to extensive population extirpation. Population level phylogenetic analyses has allowed us to identify evolutionary relationships among extant populations of LCT and therefore suitable donor populations for use in appropriate recovery waters. One of the primary recovery goals for this subspecies is to reestablish naturally reproducing lacustrine populations, the majority of which are currently maintained by hatchery production. Results of this ongoing partnership between conservation research and management provide the use of cutting edge population monitoring and genetic tools to continue refinement of our approach to population management, broodstock development, and population re-establishment. We have moved into an era in LCT recovery where management actions are based upon peer-reviewed scientific publications that result from partnerships between management and research.

Occurrence of Native Amphibian and Reptile Species in Lakes and Ponds of the Lake Tahoe Basin

Patricia N. Manley, Ph.D. , Amy J. Lind, Ph.D.
U.S. Forest Service
Sierra Nevada Research Center
2121 Second St., Suite A-101,
Davis, CA 95616
(530) 759-1719
pmanley@fs.fed.us

Aquatic ecosystems, including associated riparian habitat, support many dependent and closely associated wildlife species, thus making a substantial contribution to the biological diversity of any area, particularly drier landscapes such as the Lake Tahoe basin. Lentic ecosystems are particularly vulnerable to degradation because of sensitive physical and chemical balance required to sustain their biological integrity, and when altered they require lengthy recovery periods. The *Lake Tahoe Watershed Assessment* (Manley et al. 2000) concluded that lentic ecosystems (standing water, including lakes, wet meadows, and bogs) were at risk of degradation and loss based on their condition and levels of protection compared to lotic ecosystems. Conservation of aquatic ecosystems and populations of associated biota hinges on the ability to identify key stressors and associated thresholds for population persistence. The primary objective of study was to characterize the distribution, status, and change of aquatic amphibian and reptile species in their primary habitat (lentic ecosystems) in the Lake Tahoe Basin. We evaluated three species of amphibians (Pacific tree frog, long-toed salamander, and western toad) and two species of garter snakes (western terrestrial and Sierra), which have populations primarily associated with lakes and ponds in the basin. We surveyed a total of 148 sites throughout the basin (nearly 50% of all sites) and described their habitat conditions over a 7-year period, with over half the sites sampled in multiple years. The most commonly detected amphibian species was Pacific treefrog, which was detected at nearly 60% of the sample sites, followed by long-toed salamander and western toad at 21.1 % and 8.6 % of the sample sites, respectively. Western terrestrial garter snake was detected at approximately 30% of the sites, while the Sierra garter snake was not as well distributed, detected at only 10% of the sample sites. Consistency in site occupancy across years mirrored the relative proportion of sites occupied – consistency in occupancy was lower for species with the lower proportion of sites occupied. These results suggest that all but the Pacific treefrog have small populations in the basin and are vulnerable to population decline and extirpation. Our preliminary analysis of biotic interactions indicated that fish, especially introduced non-native trout, may be having a negative influence on the distribution of both long-toed salamanders and Pacific treefrogs. Western toad was detected too infrequently to evaluate their co-occurrence relative to fish.

Multi-taxonomic Patterns and Thresholds of Biological Diversity along a Gradient of Human Development

Patricia N. Manley, Ph.D.
U.S. Forest Service
Sierra Nevada Research Center
2121 Second St., Suite A-101,
Davis, CA 95616
(530) 759-1719
pmanley@fs.fed.us

Dennis D. Murphy, Ph.D.
Department of Ecology, Evolution, and Conservation Biology
University of Nevada, Reno, NV 89557

Lori A. Campbell, Ph.D.
U.S. Forest Service
Sierra Nevada Research Center
2121 Second St., Suite A-101,
Davis, CA 95616

Kirsten E. Heckmann
Department of Environmental Science and Policy
University of California
Davis, CA 95616

Susan Merideth
Monte Sanford
Department of Ecology, Evolution, and Conservation Biology
University of Nevada, Reno, NV 89557

Matthew D. Schlesinger
U.S. Forest Service
Sierra Nevada Research Center
2121 Second St., Suite A-101,
Davis, CA 95616
Department of Environmental Science and Policy
University of California
Davis, CA 95616

Urbanizing environments offer promise and peril in conserving local biological diversity. Human development negatively impacts the capacity of native ecosystems to support indigenous species through multiple mechanisms. Conversely, interspersions of native ecosystems in developed areas have the potential to enhance the ability of urbanizing areas to maintain some complement of native species diversity, thereby reducing the fragmentation of local populations. We studied changes in the

composition and structure of a diversity of species, including landbirds, small and large mammals, ants, and vascular plants, along a development gradient in the forested landscape of the Lake Tahoe basin. We sampled 72 to 124 sites ranging from 0 to over 70% developed. All taxonomic groups exhibited erosion in biological diversity at higher levels of development, but the type and magnitude of response varied widely among groups. Bird and ant species richness declined with development, whereas small mammal, large mammal and plant species richness did not show a directional change along the development gradient. Abundance patterns did not follow richness patterns for each taxonomic group, owing largely to the varied responses of individual species. Thresholds of development and key environmental parameters appeared to have a pronounced influence on community composition and structure.

Indicators of Biological Diversity in Lake Tahoe Forests

Patricia N. Manley, Ph.D.
U.S. Forest Service
Sierra Nevada Research Center
2121 Second St., Suite A-101,
Davis, CA 95616
(530) 759-1719
pmanley@fs.fed.us

Kristian K. McIntyre
U.S. Forest Service
Sierra Nevada Research Center
2121 Second St., Suite A-101,
Davis, CA 95616

Matthew D. Schlesinger
U.S. Forest Service
Sierra Nevada Research Center
2121 Second St., Suite A-101,
Davis, CA 95616
Department of Environmental Science and Policy
University of California
Davis, CA 95616

Susan Merideth
Department of Ecology, Evolution, and Conservation Biology
University of Nevada, Reno
Reno, NV 89557

Urbanization can have a myriad of effects on biota, typically manifesting in a loss of biological diversity. Responses to human development and disturbance occur at the level of individual species, but also coalesce into changes in community structure and function. Our understanding of how species and communities respond to urbanization is still rudimentary, as is our ability to characterize these responses in a manner that planners and land managers can readily understand and apply to decision making. In many instances, land managers are daunted by the potential cost of funding research or monitoring to improve our understanding of the effects of human disturbance on biological diversity. We used basic survey data on birds and small mammals at 254 sites in the Lake Tahoe basin to demonstrate how such data can be used to characterize changes in species occurrence and abundance along development gradient (0 to 80% developed within a 50 ha analysis unit), and to identify the most sensitive species and species groups associated with these communities using a simple ordinal scale of association. We used a combination of multivariate analyses and Indicator Species Analysis to identify the direction and magnitude of response of species and species groups to development in the montane zone (< 2300 m elevation). We classified species into one of five categories of response based on a Relative Strength of Association (RSA) index: intolerants, avoiders, interlopers, exploiters, and associates. Approximately half of the 103 birds (52%) and 26 small mammal (58%) species showed a patterned response along the

development gradient. Few species were highly intolerant of or only associated with development, with the majority of the remaining species identified as avoiders (23 birds, 8 small mammals) or exploiters (16 birds, 5 small mammals) of development. The remaining species (10 birds, 2 small mammals) were categorized as interlopers – exhibiting maximum occurrence and abundance at intermediate levels of abundance. Species negatively affected by development spanned an array of ecological characteristics, including tree, shrub and ground associates. Species positively affected by development were primarily generalists and exotic species. The RSA index was an effective method of summarizing species associations with development.

Microbial Life in Lake Tahoe

Alison Murray
Earth and Ecosystem Sciences
Desert Research Institute
Reno NV 89512
Alison.Murray@dri.edu

Despite the recognition that the microbial compliment of a lake play central roles in water quality, nutrient cycling and plankton dynamics (which are critical to issues such as lake clarity), little is known regarding the distribution, processes, activities and identities of the bacteria and archaea in extremely oligotrophic lakes. Lake Tahoe, traditionally regarded as a hyperoligotrophic lake, is currently undergoing eutrophication, in part, due to development in the Tahoe Basin. We have made initial efforts to address microbial community structure and diversity through sampling at several times and depths in Lake Tahoe. Molecular ecological investigations including DGGE and cloning of SSU rDNA genes have been used to characterize the prokaryotic populations at MidLake Station. The diversity found in Lake Tahoe is higher than most freshwater systems, with unusual distribution of phylogenetic groups that appear to be very abundant, though have been little-studied. For example, Verrucomicrobia represent over 30% of SSU rDNA clones sampled in surface waters, while green non-sulfur bacteria represent 18% and the planktomycetes represent 12%, of the phylogenetic groups found at 75m. The biogeochemical roles that these bacteria play in Lake Tahoe are currently unknown. Comparisons of the Lake Tahoe bacterial assemblage to 15 other lakes suggests that the community composition is most similar to that found in Crater Lake at depth, and is more similar to a moderately eutrophied lake in surface waters. Further studies to characterize the microbial diversity across the zone of human impact in the lake and to understand the role that these unique and poorly characterized bacteria and archaea play, will help to better understand the ecosystem ecology and health of Lake Tahoe.

Multi Species Monitoring: A Foundation for Comprehensive Status and Trend Monitoring in the Lake Tahoe Basin

Julie K. Roth
Wildlife Biologist, Adaptive Management Group
Lake Tahoe Basin Management Unit
USDA Forest Service
35 College Dr.
South Lake Tahoe, CA 96150
(530) 543-2628
jroth@fs.fed.us

Shane Romsos
Planning Team
Lake Tahoe Basin Management Unit
USDA Forest Service
(530) 543-2745
sromsos@fs.fed.us

The Multi Species Inventory and Monitoring (MSIM) protocol is a comprehensive, multiple taxonomic group sampling protocol for assessing large scale status and trends of vertebrates and their habitats. It was developed as part of the Sierra Nevada Forest Plan Amendment Adaptive Management Strategy as an efficient way to meet legal requirements by monitoring large suites of vertebrates and their habitats region-wide. During 2002-2005, the Lake Tahoe Basin Management Unit (LTBMU) implemented the MSIM protocol in order to 1) test the functionality of the region-wide MSIM protocol, 2) to initiate baseline forest-wide status and trend monitoring for wildlife and their habitats on LTBMU, and 3) to assist in the development of a comprehensive biological resources monitoring and evaluation program for the Lake Tahoe Basin as part of the P7 planning process.

Based on results of MSIM data collection efforts at 105 monitoring sites established throughout LTMBU, 2002-2005, we will briefly summarize current status of a broad suite of wildlife and their habitats in the Lake Tahoe Basin. We will highlight the utility of this protocol and its associated monitoring metrics for meeting future monitoring and evaluation needs at both the region wide (e.g., Sierran) and forest wide (e.g., Lake Tahoe Basin) scales. We will also discuss elements of the MSIM protocol and sampling design which give it flexibility and allow for scientifically sound inferences, making it a strong candidate for forming the foundation of a future Lake Tahoe Basin collaborative monitoring strategy. This will be the first time results and analysis from this effort are presented to the scientific community for discussion and collaboration.

Natural Hazards

Seismically-Induced Landslides, Debris Flows, and Turbidites in Lake Tahoe

Shane B. Smith, Robert Karlin, Ph.D.
University of Nevada, Reno
Department of Geological Sciences
Mail Stop 172
Reno, NV 89557
(775)-784-6723
sbsmith@unr.nevada.edu, karlin@mines.unr.edu

Gordon Seitz, Ph.D.
San Diego State University
Department of Geological Sciences
MC-1020
5500 Campanile Dr.
San Diego, CA 92182-1020
seitz3@mail.earthlink.net

Graham Kent, Ph.D.
Scripps Institute of Oceanography
University of California San Diego
9500 Gilman Drive
La Jolla, CA 92093-0225
gkent@ucsd.edu

Holocene sedimentation and water quality in the Lake Tahoe basin are dramatically affected by large, episodic landslides with associated lacustrine debris flows and turbidity currents. Landslide deposits, line the basin walls. The largest of the landslide complexes is in McKinney Bay, along the southeastern lake margin, and along the northern margin. The landslides redistribute lacustrine sediments throughout the basin via debris flows and turbidity currents, which have been identified correlated and dated in a suite of ~3-m piston cores and ~1-m gravity cores. Debris flow deposits consist of reworked lacustrine sediments including tilted blocks of previously flat-lying sediment, clay and silt balls, and other rip-up clasts. The upper contact of the debris flow deposits is gradational with a turbidite, indicating close association of landslides and turbidites.. The turbidites often lie on an erosional unconformity and grade upward from coarse sand to clayey silt and are capped by a thin diatom layer . The turbidites vary from proximal to distal and account for greater than 50% of sedimentation recorded in the cores. Turbidites can be correlated across the lake based on lithologies, visual characteristics, magnetic susceptibility signatures, and stratigraphic position. Several lines of evidence suggest a seismic origin for the turbidites. The turbidites have greatest thicknesses and the largest grain sizes in proximity to landslides rather than stream inputs. Many turbidites have multiple source areas, suggesting landsliding at multiple locations at similar times. SEM photography suggests that the turbidites contain highly fractured diatoms, indicative of transport as opposed to a diatom bloom. Lacustrine material is reworked in the debris flows, and radiocarbon dates within turbidites are anomalously old as a result of the reworking, while non-turbidite radiocarbon dates provide a consistent age-depth curve. The radiocarbon dating of

one core, when combined with the turbidite correlations, suggests that landslides, lacustrine debris flows, and turbidity currents have redistributed sediment in the lake on the order of every ~1000 years. Strong earthquake shaking on Tahoe basin faults and the Genoa Fault to the east likely caused the massive landsliding and major lake disruption (possibly including seiches) throughout the Holocene. Strong ground shaking, landsliding, and seiching in Lake Tahoe have the potential to catastrophically affect residents and visitors to the area and should impact emergency planning in the basin.

Assessment of natural hazards of Lake Tahoe from underwater geologic studies

R. A. Schweickert
University Nevada, Reno
Reno, NV 89557
richschw@unr.edu

J.G. Moore
U.S. Geological Survey
345 Middlefield Rd, MS 910
Menlo Park, CA 94025
jmoore@usgs.gov

J.F. Howle, M.M. Lahren, and C. Lopez,
University Nevada, Reno
Reno, NV 89557

C. Kitts
Santa Clara University
Santa Clara, CA 95053

Lake Tahoe basin is an active tectonic basin located at the Sierra Nevada-Basin and Range boundary, and is characterized by numerous active faults and by very steep subaqueous topography. Bathymetric mapping (Gardner et al., 1998) has outlined a large debris avalanche on the lake bottom formed from the collapse of a large shoreline area in present-day McKinney Bay. As one part of our efforts to assess the natural hazards of the Lake Tahoe basin, investigations are underway to determine the nature of materials and structure along the steep sidewalls of the lake, and to clarify the geologic history of the basin.

The remotely operated submersible vehicle (ROV Triton) developed and piloted by faculty and students at Santa Clara University and deployed from the UC Davis RV LeConte, is being used to investigate the bottom and sidewall geologic features. Video observations have been supplemented by sampling via dredges and scuba dives.

Detailed video images have been taken on nineteen dives with ROV Triton, including one in Rubicon Bay, 4 in Meeks Bay, 3 near Sugar Pine Point, 5 in McKinney Bay, 4 on Tahoe City shelf, and 2 in Agate Bay. These images reveal the presence of thick sequences of old bedded lacustrine sediments along the western and northern sidewalls from Rubicon Bay to Agate Bay. These deposits, which have been uplifted along faults from their original site of deposition on the floor of the lake, are moderately to weakly consolidated, fractured and tilted, and subject to gravitational collapse. Cliffs of this material show recent failures by submarine mass wasting. The Tahoe City shelf is an extensive, smooth, shallow, wave-bevelled surface cut into the old lacustrine sediments. Scattered boulders of volcanic rock lie upon the surface. Ten to fifteen boulder ridges, 2-3m high, 10-15m wide, and >1 km in length, and generally trending east-west, rest upon this surface.

These data indicate that the McKinney Bay collapse involved ~10 km^3 of lacustrine sediments and overlying glacial deposits. The collapse and ensuing debris avalanche generated large waves which swept northward across the Tahoe City shelf and generated the boulder ridges as gigantic megaripples (Moore et al., 2006).

Our studies show that parts of the sidewalls of Lake Tahoe are potentially unstable and that future collapse events could pose additional tsunami hazards. Ground shaking from earthquakes caused by slip on faults in or near the basin may trigger these and other events. These hazards are underappreciated, and additional research on these topics is needed and should be supported by management agencies within the Lake Tahoe basin.