



Science Synthesis Report

Tahoe Science Consortium



SCIENCE SYNTHESIS REPORT

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Exploration and Outreach

Lake Tahoe Balloons recovery vessel retrieving passengers east of Emerald Bay

ACKNOWLEDGEMENTS

This report represents the contributions of over 200 researchers, students, and technical experts from academia, private sector organizations, and federal, state, and local agencies who conducted scientific studies for nearly 10 years on projects supported by the SNPLMA Science Program. Their hard work provided the scientific basis to preserve, protect and restore the unique aquatic and terrestrial ecosystems in the Lake Tahoe Basin. Environmental managers from federal, state, and local agencies worked closely with the research community as part of the SNPLMA Science Program. Their leadership and commitment to implementing science-based decision making will ensure that Lake Tahoe is a vibrant, beautiful and unique national treasure for generations to come.

All of the research projects covered in this report were supported through funding provided by the Southern Nevada Public Lands Management Act (SNPLMA), administered by the U.S. Bureau of Land Management in partnership with the U.S. Forest Service Lake Tahoe Basin Management Unit. The SNPLMA Science Program was administered by the U.S. Forest Service, Pacific Southwest Research. The authors and research community gratefully acknowledge their support and commitment to sustaining science funding in the Lake Tahoe Basin. The TSC and research community is also grateful to Jonathan Long and Tiff van Huysen for their diligent work and technical leadership as USFS/PSW SNPLMA Science Program Coordinators.



The Tahoe Science Consortium (TSC) represents a unique public-private partnership among major research organizations working in the Lake Tahoe Basin – Desert Research Institute, University of California, Davis, University of Nevada, Reno, U.S. Forest Service, Pacific Southwest Research Station, U.S. Geological Survey. Many scientists and administrators from these organizations served on the TSC Committee of Scientists and TSC Executive Committee over the years. Their support, guidance, and leadership was essential to building a strong network of technical experts across many disciplines whose research, education and outreach has stimulated a culture of science-supported environmental management in the basin. Representatives from TSC partner agencies in the Lake Tahoe Basin including the California Tahoe Conservancy, California State Parks, Environmental Protection Agency, Lahontan Water Quality Board, Nevada Department of Environmental Protection and the Nevada Division of State Lands, Tahoe Regional Planning Agency, and U.S. Forest Service Lake Tahoe Basin Management Unit, worked with the TSC to prioritize the science themes and research areas, serve as agency experts on the proposal peer-review committee, and actively participate in TSC workshops, conferences and technical meetings.

The SNPLMA Science Program would not have been possible without the strong support of members of Congress who sponsored and championed the Lake Tahoe Restoration Act (LTRA) that authorized restoration and science projects in the basin funded through the SNPLMA Program. Without their strong commitment to restoring and preserving Lake Tahoe, we would not have been able to work together to slow the degradation of lake clarity, restore critical streams and wetlands, protect special species habitats, reduce the risk of catastrophic wildfires, mitigate the impacts of aquatic invasive species and prevent new introductions, improve air visibility, adapt to a changing climate, and many more critical efforts.

I would like to personally thank many colleagues that provided much insight and advice to me during my tenure as TSC Executive Director since 2011 including Zach Hymanson, the first TSC Executive Director who laid the foundation for the TSC to integrate science and management and Shane Romsos from TRPA who helped me build the bridge linking researchers and managers. Many thanks to Alan Heyvaert, Alan Gertler, Marc Pitchford, Geoff Schladow, John Reuter, Mike Collopy, Wally Miller, Sudeep Chandra, Graham Kent, Mike Dettinger, Dale Cox, John Sciacca, Tim Rowe, Matt Busse, Rick Bottoms, and Andrzej Bytnerowicz, for their sage advice as members of the TSC Committee of Scientists for many years. I am also very grateful to the basin agency executives who leant their knowledge and insight and taught me how to navigate through the Tahoe landscape including Patrick Wright, Joanne Marchetta, Jim Lawrence, Patty Kouyoumdjian, and Jeff Marsolais.

Finally, I am very grateful to Chris Knopp and Pete Stine for their heroic efforts in drafting this report over the last year and to Kelsey Fitzgerald and Christina Clack for superb and patient editing and professional manuscript preparation.

July 01, 2016

Dear SNPLMA Science Program Researchers, Managers and Sponsors,

Over the last decade, scientists and managers have partnered to create a strong scientific foundation for protecting and restoring the unique and spectacular national treasure that is Lake Tahoe. Major environmental and land-use planning actions by federal, state and local agencies have been underpinned by science, and this has stimulated the adoption of ecologically sustainable development practices. Congressional sponsors and supporters of the Lake Tahoe Restoration Act (LTRA) and the Southern Nevada Public Lands Management Act (SNPLMA) along with their federal agency partners have demonstrated vision, dedication and commitment in establishing and funding the SNPLMA Science Program. This remarkable program set the building blocks of science-based management in the Lake Tahoe Basin.

The researchers supported by the SNPLMA Science Program have collected and analyzed data, developed models, built tools, shared knowledge, and learned the challenges of managing complex ecological systems, thereby stimulating new scientific discoveries. This rich body of knowledge has been put to work by managers to reverse the decline in lake clarity, slow the degradation of the nearshore, protect communities and ecosystems against catastrophic wildfires, restore stream and wetland functions, protect habitats, and mitigate the impacts of climate change.

Although, the SNPLMA Science Program and the Tahoe Science Consortium (TSC) operations will end in 2016 when the program sunsets, it is important to remember that a strong, vibrant and resourceful scientific community will remain the linchpin of adaptive management in the Tahoe Basin in the future. I am very grateful to have had the opportunity to lead the TSC for the last five years and to be part of building a bridge to a better future for Lake Tahoe.

Sincerely,



Maureen I. McCarthy, PhD
Executive Director



Photograph by Shelbi Whitehead

EXECUTIVE SUMMARY

"At last the Lake burst upon us—a noble sheet of blue water lifted six thousand three hundred feet above the level of the sea, and walled in by a rim of snow-clad mountain peaks that towered aloft full three thousand feet higher still! As it lay there with the shadows of the mountains brilliantly photographed upon its still surface I thought it must surely be the fairest picture the whole earth affords."

*—Mark Twain from **Roughing It***

The Lake Tahoe Basin is a unique and spectacular environment that has been significantly altered since the late 1800s by human activity. Restoring and conserving this area poses a substantial challenge to environmental managers and those responsible for encouraging sustainable development and recreational access. The known effects of past human actions over the last 150 years – from clearcut logging to build the Comstock Mines the 1850s to unconstrained development following the 1960 Olympics – combined with the unique character of the Lake Tahoe Basin have led to broad-based support for substantive conservation and restoration efforts. These efforts have involved close partnerships among government agencies, the private sector, and the science community. Determining the most effective and affordable methods for conserving and restoring Lake Tahoe and its watershed has prompted scientists, managers, planners, developers, regulators, and the public to work together to achieve the goal of restoring this national treasure for generations to come. Many challenges remain that will require a sustained investment in science to understand the impacts of a changing climate, redevelopment of aging infrastructure, and the effectiveness of today's restoration projects.

Conservation and restoration of Lake Tahoe and its unique terrestrial and aquatic ecosystems have involved the sustained and coordinated engagement of federal, state, and local governments, as well as the private sector. These entities have worked together over several decades to plan and take actions aimed at achieving common environmental and social goals. (TRPA 2001, TRPA 2007) A shared desire to protect the natural beauty and accessibility of the Lake Tahoe Basin has led to broad-based support for robust conservation



and restoration efforts over the last four decades (CTC 2006, Elliott-Fisk et. al. 1996, Murphy & Knopp 2000, TRPA 2001, U.S. Public Law 106-506 2000). Attention and funding over the past two decades in particular have resulted in remarkable progress towards improving the spectacular clarity Lake Tahoe, restoring the health and functioning of terrestrial and aquatic ecosystems, and supporting vibrant communities for those who live, visit and recreate in the Lake Tahoe Basin (CTC 2006, Elliott-Fisk et. al. 1996, Murphy & Knopp 2000, TRPA 2002, TRPA 2007). Restoration has not only focused on Lake Tahoe, but also on the entire watershed with special attention given to the highly interdependent nature of air, land, and water environments and the multifaceted socioeconomic conditions that influence the Tahoe Basin. (Elliott-Fisk et. al. 1996, Murphy & Knopp 2000). The Lake Tahoe Basin is recognized as a highly complex physical, biological and social environment, and the challenges posed by its restoration and continued management for multiple benefits are paralleled by few other locations (Hymanson and Collopy, 2010).

Prioritizing restoration, conservation, and protection actions remains a challenge in Lake Tahoe in light of changes in climate, ecological conditions, community development, and resources. Science, particularly applied science, to inform adaptive management, provides critical information to support management decision-making and project implementation. A strong, vibrant and resourceful scientific community will remain the linchpin of adaptive, management of the Tahoe Basin in the future. Research at Lake Tahoe began in 1874, expanded through the 1960s, and has continued to the present. It may be thought of as having two distinct phases: uncoordinated and coordinated. The uncoordinated phase was characterized by the pioneering initiative of individual researchers with curiosity and a desire to protect a unique environment. They produced results that created a scientific foundation that showed unambiguously a decline in the clarity of the Lake and the impacts of unconstrained development in the basin.

LTRA AND SNPLMA

The second “coordinated” phase was initiated in 2000 under the Lake Tahoe Restoration Act of 2000 (LTRA) (Public Law 106-506) and funded through by the Southern Nevada Public Lands Management Act of 1997 (SNPLMA) (“As Amended” in Public Law 105-263). The Southern Nevada Public Land Management Act (SNPLMA) became law in October 1998 and enabled the Bureau of Land Management to sell public land within a specific boundary around Las Vegas, Nevada as part of a large federal conservation program for that region. Proceeds from these sales were made available for certain types of projects to further conservation objectives within Clark County, Nevada. In November 2003, SNPLMA was amended to direct \$300 million over a period of eight years to Lake Tahoe for implementation of the Federal Environmental Improvement Program within the Lake Tahoe Basin. The LTRA legislation succinctly stated the challenges managers and scientists faced in saving Tahoe from further environmental degradation.

“Lake Tahoe, one of the largest, deepest, and clearest lakes in the world, has a cobalt blue color, a unique alpine setting, and remarkable water clarity, and is recognized nationally and worldwide as a natural resource of special significance. In addition to being a scenic and ecological treasure, Lake Tahoe is one of the outstanding recreational resources of the United States, offering skiing, water sports, biking, camping, and hiking to millions of visitors each year, and contributing significantly to the economies of California, Nevada, and the United States. The economy in the Lake Tahoe basin is dependent on the protection and restoration of the natural beauty and recreation opportunities in



the area. Lake Tahoe is in the midst of an environmental crisis. The Lake's water clarity has declined from a visibility level of 105 feet in 1967 to only 70 feet in 1999, and scientific estimates indicate that if the water quality at the Lake continues to degrade, Lake Tahoe will lose its famous clarity in only 30 years. Sediment and algae-nourishing phosphorous and nitrogen continue to flow into the Lake from a variety of sources, including land erosion, fertilizers, air pollution, urban runoff, highway drainage, streamside erosion, land disturbance, and ground water flow. Methyl tertiary butyl ether has contaminated and closed more than one-third of the wells in South Tahoe and is advancing on the Lake at a rate of approximately 9 feet per day. Destruction of wetlands, wet meadows, and stream zone habitat has compromised the Lake's ability to cleanse itself of pollutants. Approximately 40 percent of the trees in the Lake Tahoe basin are either dead or dying, and the increased quantity of combustible forest fuels has significantly increased the risk of catastrophic forest fire in the Lake Tahoe basin." ---- **Lake Tahoe Restoration Act of 2000 (PL 106-506)**

Although the majority of the investments authorized by LTRA were intended to address capital projects, program needs, and operations and maintenance needs, there was a specific and important role for research to address key scientific uncertainties. Approximately 10% of the Lake Tahoe SNPLMA budget was allocated to the SNPLMA Science Program. Scientific research has always been considered an integral component to the overall environmental framework for the Lake Tahoe Basin, and has played a key role in the development of the environmental thresholds, in identifying trends in threshold attainment, and more recently for informing policy decisions. Research was considered necessary to address the most pressing management questions facing Tahoe Basin land managers, and to reduce the uncertainty in the effectiveness of capital improvement projects.

The SNPLMA science and management programs supported research that was deliberately focused and coordinated in specific areas necessary to enable policies and management actions to reverse the trends of Lake and ecosystem decline. In this coordinated phase, management agency personnel developed research themes and specific research projects were competitively awarded in response to those themes. Approximately \$3.4M in research funds were annually for nearly 10 years. This strong commitment to science allowed an influx of a wide array of new researchers and a commitment to long-term research that would have been impossible otherwise. It created venues for the rapid exchange of research products to management agencies. In many cases the lines between agency professionals and research scientists blurred as the level of interaction increased.

TAHOE SCIENCE CONSORTIUM

This report summarizes the progress that has been made linking science and management with resources through an applied science program, the SNPLMA Science, and coordinated by the Tahoe Science Consortium (TSC) (<http://tahoescience.org>). The TSC SNPLMA Science Program was as an integral part of the basin-wide Environmental Improvement Program (EIP), led by management agency executives from federal, state, and bi-state agencies including U.S. Forest Service (USFS), Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), U.S. Bureau of Reclamation (USBR), California Tahoe Conservancy (CTC), Lahontan Water Quality Board, and Nevada Department of Environmental Protection (NDEP), Nevada Division of State Lands (NDSL), and the Tahoe Regional Planning Agency (TRPA).



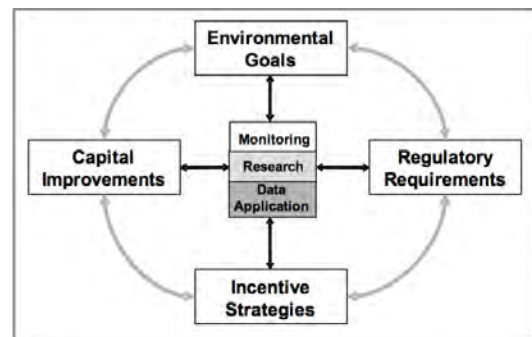
The Tahoe Science Consortium (TSC) was formed through a memorandum of understanding in August 2005 to foster a greater level of collaboration between research organizations and resource management agencies. In 2010 the TSC published the “Integrated science plan for the Lake Tahoe basin: conceptual framework and research strategies” that identified research to address key management needs. (Hymanson & Collopy 2010) Funding to support the operations of the TSC were provided through the SNPLMA Science Program and will sunset in 2016. The research organizations that comprise the TSC include: [Desert Research Institute](#), [University of California, Davis](#), [University of Nevada, Reno](#), [U.S. Geological Survey](#), and the [U.S. Forest Service, Pacific Southwest Research Station](#).

THE PRIMARY FUNCTIONS OF THE TSC ARE TO:

- Promote scientific advancement by providing an organizational capacity to undertake science planning and support ongoing science activities.
- Support adaptive management strategies by contributing to the design and implementation of a Tahoe Basin adaptive management system.
- Promote independent peer review by providing the capacity to conduct and administer peer review processes.
- Provide scientific consultation services by serving as a resource for scientific expertise.

The Tahoe Science Program is partnership between federal and state agencies, local jurisdictions, and the science community to achieve science-based decision-making and restoration of the Lake Tahoe Basin through environmental monitoring, applied research, and data application.

- **Monitoring** establishes baseline conditions and trends over time and tracks the effectiveness of restoration actions.
- **Research** seeks to understand the complex ecosystem of the Basin and generate information to support effective policies, regulations, and management.
- **Data application** analyzes, interprets, organizes, and reports technical information to environmental managers, regulators and the science community.



SNPLMA SCIENCE PROGRAM

The U.S. Forest Service (USFS) Pacific Southwest Research Station (PSW) served as the federal agent to manage research funds of approximately \$3.4 million per year through SNPLMA, beginning in spring 2007 with SNPLMA Round 7 and concluding with the final grants awarded in 2013 through SNPLMA Round 12. Research priorities were identified and projects selected each year. The PSW administered an annual Request For Proposals (RFP) to solicit research proposals for key work in the basin, and in partnership with



the Tahoe Science Consortium (TSC), conducted a scientific and management agency peer review of submitted proposals. The PSW Program Coordinator and the Tahoe Science Consortium, worked each year with the resource management agencies in the Tahoe Basin to identify research priority theme areas within which to solicit proposals. Specific research areas varied from year to year within the eight science themes listed below. These eight themes spanned the research needs identified and prioritized by management agencies in the basin. Summaries of these research areas and the corresponding key management decisions that they support are presented in a series of TSC Fact Sheets in Appendix A.

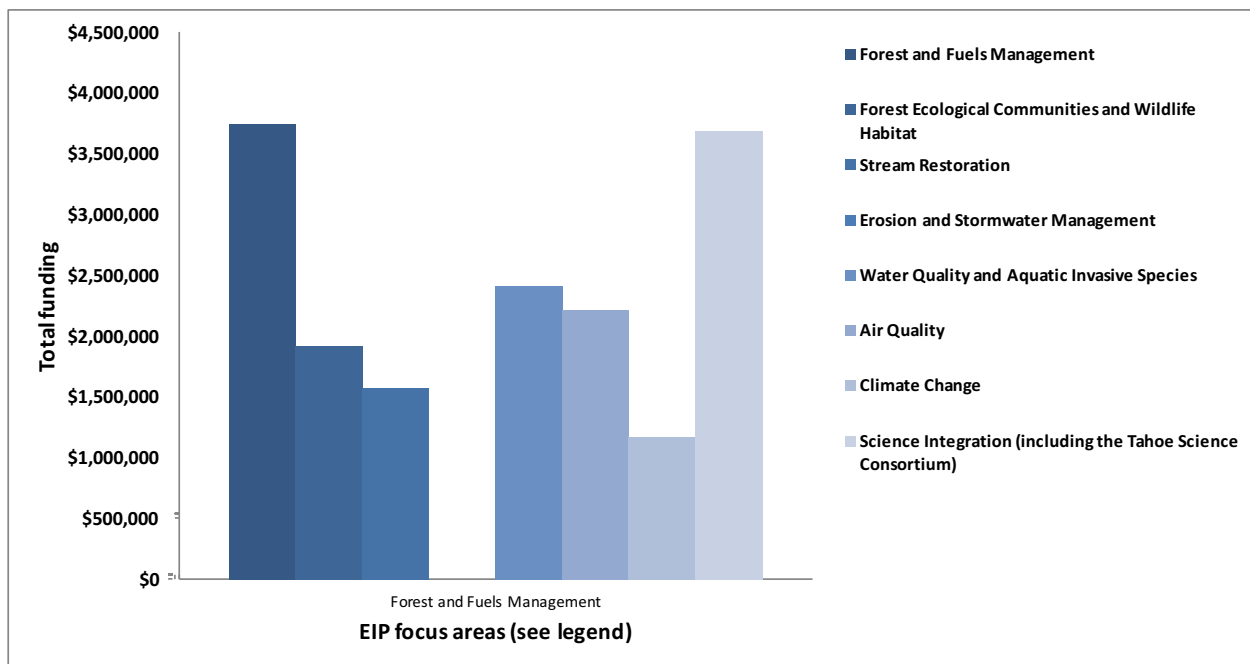
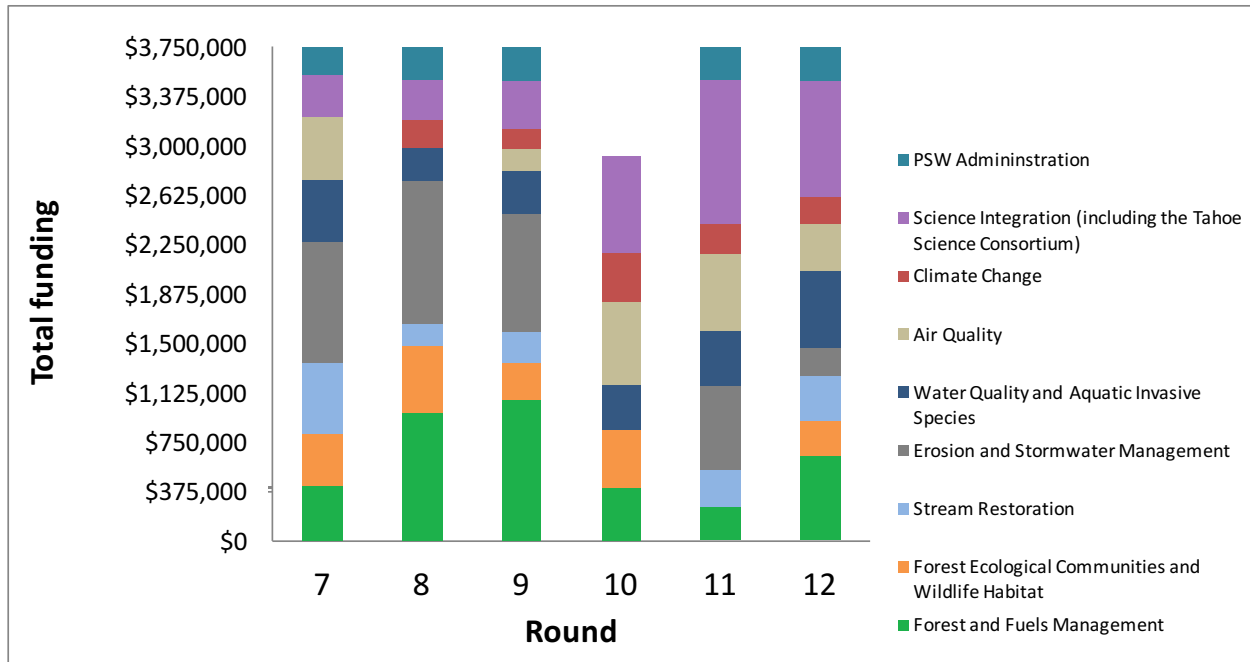
SNPLMA SCIENCE RESEARCH THEMES

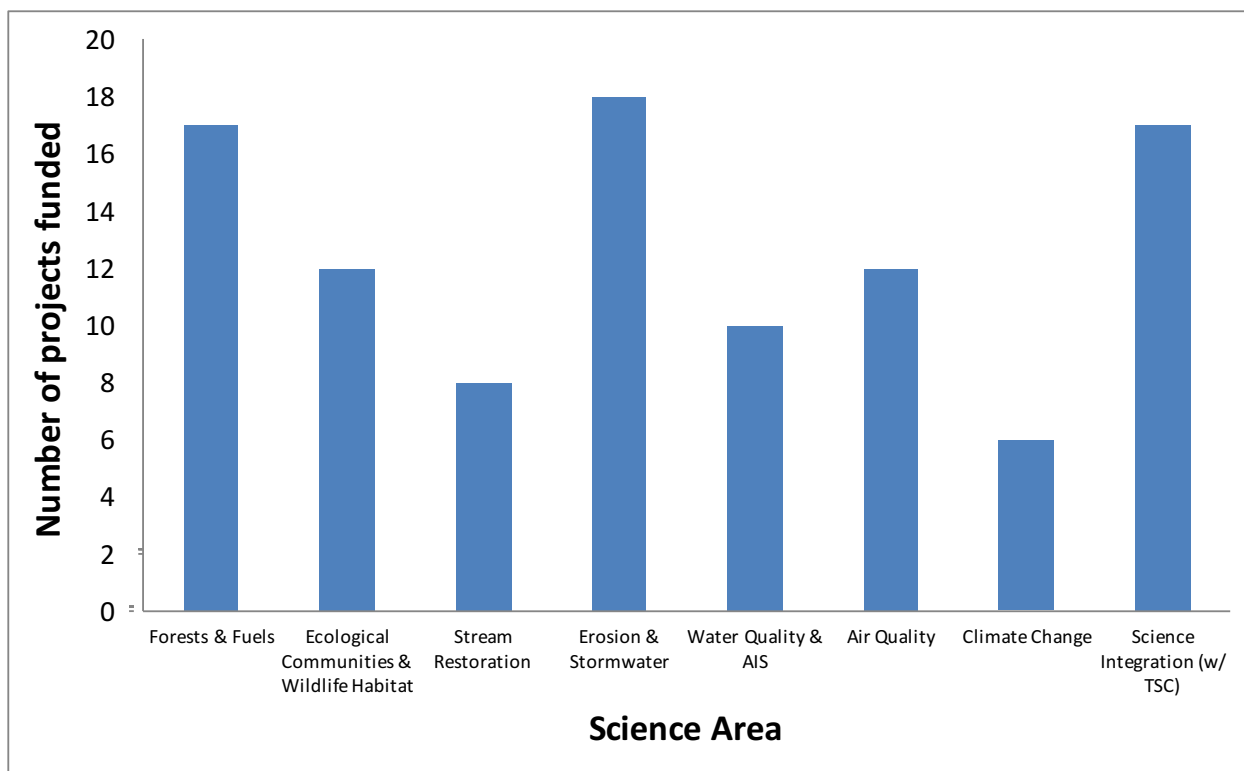
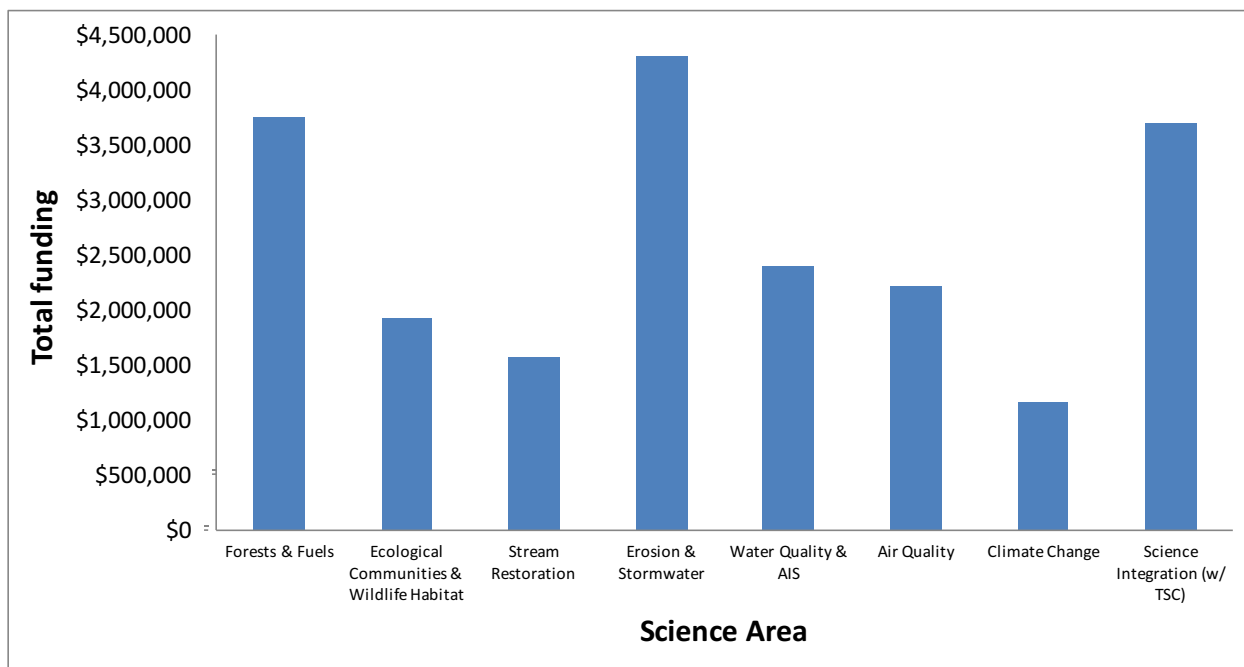
- **Air Quality:** Air pollutants pose threats to health of humans and forests at Lake Tahoe, as well as to the clarity of the lake itself. Research evaluated these impacts and developed appropriate treatments.
- **Climate Change:** Research focused on developing new and expanding tools to inform policymakers about how future climate change will specifically affect the Lake Tahoe Basin and provide information that could lead to proactive policy alternatives.
- **Forest Fuels and Vegetation Management:** Forest treatments, including prescribed burning, help to reduce wildfire hazards in the Tahoe Basin. Research evaluated the effects of treatments and wildfires on values such as air quality, water quality, and wildlife habitat.
- **Habitat Improvement:** Research investigated the special management needs of rare or vulnerable species and ecological communities in the Tahoe Basin.
- **Lake Quality:** To "Keep Tahoe Blue" is a primary goal in the Tahoe Basin. Research focused on methods for reversing the long-term decline in open-water clarity, and impacts to lake quality from the spread of attached algae (*periphyton*) and non-native organisms.
- **Stormwater Management:** Fine sediments, nutrients, and other pollutants, particularly from urban areas and roads, pose major threats to the clarity of Lake Tahoe. Research helped to design best management practices (BMPs) to prevent these pollutants from entering downstream waterways.
- **Stream Restoration:** Research helped to design projects to restore stream geomorphic and ecological functions, including retention of fine sediments and enhancement of habitat for plants and animals.
- **Science Integration:** This category was included to enable work that crossed over multiple theme areas and provided valuable insight from multiple lines of research. The Tahoe Science Consortium also conducted workshops and provided technical assistance to apply current research to challenges facing management agencies within the Tahoe Basin.



SNPLMA SCIENCE INVESTMENTS (2007-2012)

The portfolio of projects supported through the SNPLMA Science Program are illustrated below in the Tables below. A total of 100 projects (95 research and 5 TSC operations) projects were funded in SNPLMA Rounds 7-12.







SCIENCE SYNTHESIS REPORT

The purpose of this Science Synthesis Report is present to SNPLMA sponsors (U.S. Congress and federal agency partners), the science community, and the general public an overview of the key findings from the research projects supported by the SNPLMA Science Program and to illustrate their relevance to management actions in the Lake Tahoe Basin. Synthesizing scientific research with management priorities was accomplished by distilling key findings from the projects across the major theme areas, conducting interviews with Lake Tahoe management agency executives, and conducting a workshop with scientists and managers to discuss lessons learned from the SNPLMA Science Program and future science needs.

THE SCIENCE SYNTHESIS REPORT IS ORGANIZED AS FOLLOWS:

- **Chapter 1** – The Need for Science at Lake Tahoe
- **Chapter 2** – Interviews with Basin Executives
- **Chapter 3** – Synthesis of Findings – Air Quality, Climate Change, Forest Fuels & Vegetation Management, Habitat Improvement, Lake Quality, Stormwater Management, Riparian/Stream Restoration
- **Chapter 4** – Future Science Needs & Delivery
- **Appendix A** – Tahoe Science Consortium Fact Sheets
- **Appendix B** – Project Summaries (for all 95 research projects)

MANAGEMENT AGENCY INTERVIEWS

Six agency executives were interviewed. The agencies participating were the California-Tahoe Conservancy, the U.S. Forest Service, the Lahontan Regional Water Quality Control Board, the Nevada Division of State Lands, the Tahoe Regional Planning Agency, and the Tahoe Transportation District. These agencies represent the majority of the policy and management programs affecting the entire Tahoe region. The discussions were energetic and often strayed from the formal questions. These interviews were designed to capture both formal answers a set of structured questions and the informal thoughts captured during the discussion.

INTERVIEW QUESTIONS AND SUMMARY ANSWERS:

What is your perspective regarding the value of the past five to ten years of research to your agency's planning and regulatory decisions?

The common response to this question was that research has been and will continue to be a cornerstone of agency policy and decision-making. Research literature is used extensively in the development of every new planning or policy document. This is done to ensure that decisions are based on the best available science and because overlooking applicable research will result in appeals and costly delays. There were exceptions, primarily in the transportation sector, where it was noted that very little economic or transportation related research had been accomplished. There was a broader range of responses to the question regarding the value of new research. The work to develop an effective strategy to reverse the decline of lake clarity has been



profoundly affected by targeted research to discover the causes for that decline. It appears likely that the need for research will shift from water quality to other social and terrestrial issues rather than universally decline, and the demand for new research from each agency will be likely to vary based on each agency's need.

How has the research community engaged in research support activities such as environmental monitoring, data analysis, participation in workgroups, and subject matter expert advice for developing environmental policies and regulations? Have these support activities been effective in supporting your agency's decisions? How can the science community better support your agency's mission?

The research community is held in high regard in the Tahoe Basin, and obvious effort has been expended by both groups to maintain and improve the relationship between managers and scientists. Most agency executives believe they have very good relationships with scientists working in the basin. Basin executives reported that they value research based upon: 1) its *relevance* to current management issues; 2) the *understandability* of research outcomes by managers; 3) the *timeliness* of its completion and reporting; 4) the *cost* of the project; and 5) the willingness of the authors to explain the research to staff and concerned publics (*tech transfer*). The context for discussing science delivery is important. In the Lake Tahoe Basin, fundamental environmental processes were not well understood, and research was required to develop effective solutions. As a result, agencies and scientists accepted the need for an accelerated and focused adaptive management strategy.

How can we improve the relevance of research, its focus and delivery to your agency and others in the Tahoe Basin, and how can science further improve the adaptive management process?

As this report was being compiled, there was no single vision from Tahoe Basin executives regarding how to improve the relevance and effective delivery of research. the strongest concept was the one offered by California and Nevada in the Bi-State Science Council (the Council), which was created in response to Nevada's SB 271 and California's SB 630.

SYNTHESIS FINDINGS

Synthesis of findings were organized into seven key areas: Air Quality, Climate Change, Forest Fuels & Vegetation Management, Habitat Improvement, Lake Quality, Stormwater Management, Riparian/Stream Restoration. Highlights of these findings are listed below with references to the SNPLMA Science project numbers listed at the end of this document. Details and final reports for each of these projects is available on the USFS/PSW SNPLMA Science website: <http://www.fs.fed.us/psw/partnerships/tahoescience>

Air Quality - SNPLMA funded 13 air quality-related projects in the Lake Tahoe Basin. Very little was known regarding air quality in the basin in 2000, but excellent progress has been made and it is clear that the atmosphere is an important source of nitrogen, phosphorous, and fine particulates to the lake. The varying complexities of emission sources from vehicles, roadways, fireplaces, prescribed fires and wildfires reveal the need for an equally complex approach to limiting these sources in order to retain the delicate balances within the greater Tahoe ecosystem.



KEY FINDINGS HIGHLIGHTS:

- Gaseous nitrogen pollutants are of ecological concern to the Basin due to their role as ozone precursors as well as their direct impacts on terrestrial biota and aquatic nutrient enrichment leading to increased aquatic biotic productivity and declining lake clarity. (P063)
- The majority of ozone precursors are emitted in the urbanized areas of the Central Valley and possibly the San Francisco Bay Area. (P075)
- The major source of phosphorous is soils. (P013)
- The bulk of airborne emissions will deposit within a few kilometers of the road. (P001)
- Lake Tahoe Total Maximum Daily Load (TMDL) likely underestimates the PM mass deposition fluxes. The contribution of atmospheric deposition to lake clarity degradation may, therefore, be larger than anticipated. (P094)
- Re-suspended paved road dust is the major source of PM10 in the basin. (P013)
- Light extinction coefficient measurements on the haziest days resulted from large wildfires, of which frequency and intensity are expected to increase over time owing to climate change. (P06)
- Biomass burning is a significant emission source of PM2.5. (P062)

Climate Change - Over the last several decades Lake Tahoe Basin has experienced warmer temperatures, changes in winter precipitation (more rain/less snow), extended droughts, and extreme winter storms. These and other related meteorological factors are impacting forest and vegetation health, wildfire risks, invasive species survivability, habitat integrity, air quality, lake levels, and nearshore conditions. Warming air and water temperatures are likely to alter the processes in which water circulates and mixes in the lake; these changes may result in a loss of dissolved oxygen at the bottom of the lake, which may in turn lead increased nutrient levels in the lake.

KEY FINDING HIGHLIGHTS

- Climate change impacts to the Lake Tahoe Basin will likely be dictated by more than just temperature and precipitation. (Dettinger, 2013)
- Beginning and end dates for the snowpack period in the Lake Tahoe Basin are predicted to change significantly by the end of the century. (P030)
- Annual secchi depth measures of lake clarity in the later portion of the 21st Century could be in the range of 15-20 m as compared measured values of 21-22 m since 2000. (P030)
- By the middle of the 21st Century (after about 2050) Lake Tahoe could cease to mix to the bottom. This may in turn result in complete oxygen depletion in the deep waters and an increase in sediment release of nitrogen and phosphorus. (P030)
- Species-specific growth sensitivity to climate and the resultant carbon stock changes vary considerably as a function of the climate projections for a given emission scenario. (P029)



- As drying and warming occurs, an increase in the suitability of conditions to support cheatgrass will follow. As temperatures warm and cheatgrass suitability rises (if and where it does), the threat of enhanced fire activity will also increase. (P028)

Habitat Improvement - The overall understanding of nearly all aspects of Lake Tahoe's habitats and biodiversity—from species found in lakeside meadows, to those on alpine peaks above—is still rudimentary. Scientific research can help us better manage and conserve these special communities and species. Conservation of the native habitats and species of this area is one primary theme for continued scientific discovery.

KEY FINDING HIGHLIGHTS

- Both riparian and upland stands currently appear to be more fire prone than their historic conditions, with riparian areas significantly more so than adjacent upland areas. (P007)
- Riparian forests could be considered a high priority for restoration and fuel reduction treatments, with objectives similar to adjacent upland forests. (P007)
- Abiotic variables (e.g. elevation) within the basin have perhaps a greater influence on species distribution than variability in forest structure. (P050)
- Management actions that are driven by one or a few focal species are not likely to maintain biodiversity if they result in decreased variability in habitat condition. (P050)
- The use of multi-species approaches to inform land management can also enhance biodiversity conservation by identifying habitat conditions that support unique suites of species. (P050)
- Woodpeckers play an important role in post-fire habitats by rapidly colonizing burned areas and creating cavities that are used by many other species that rely upon them for nesting, denning, roosting, and resting. (P053)
- The dispersal of Asian clam larvae by wind-induced currents occurs mainly on small spatial scales. The risk of new Asian clam infestation outside the existing beds in Marla Bay on account of transport of Marla Bay juveniles is close to zero. (P092)
- Researchers strongly recommend the establishment of a long-term monitoring and surveillance program to improve the likelihood of detection of Asian clams and other harmful introduced species to Lake Tahoe's nearshore. (P057)

Lake Quality - Leading up to and following President Clinton's visit in 1997, efforts for resolving the decline in Lake Tahoe's clarity were focused on eutrophication, and primarily on the buildup of nitrogen and phosphorous that resulted in algal growth. Despite improvements to deep water clarity (measured as secchi depth), water quality in the nearshore of Lake Tahoe has shown signs of continued degradation in the form of algal growth and invasive species. As a result, the focus of recent research has shifted to the nearshore.

KEY FINDINGS HIGHLIGHTS

- Suspended sediment concentrations show pronounced fluctuations in the nearshore zone around the lake and at the same locations over time. (P002)



- Turbidity was identified as a reliable proxy to predict Fine Sediment Particle concentrations at urban stormwater sites. (P084)
- Burning of wood piles and slash piles did not produce a detrimental change in soil fertility indices such as total soil carbon, nitrogen, phosphorus, pH, inorganic nutrients, or visual observations of fine roots production. (P035)
- Warm water fish move out of the Tahoe Keys during summer and late fall, suggesting that the Tahoe Keys may be an important source population for the rest of the lake. (P002)
- Release rates of ammonium and phosphate estimated at summer temperatures were 10 to 1000 times higher than release rates from sediment reported in Lake Tahoe, suggesting that dead Asian clams were possible sources. (P056)
- A nearshore conceptual model was developed to reflect the measurable health of Lake Tahoe's nearshore zone. (P048)

Stormwater Management - Researchers and environmental managers have just begun to use models for water quality planning at Lake Tahoe as evidenced by the current Lake Tahoe TMDL effort (http://www.waterboards.ca.gov/lahontan/water_issues/programs/tmdl/lake_tahoe/). Universal challenges for any assemblage of management models is to maximize their utility by having them correctly applied to a given problem, to be able to utilize existing data sets and generate new compatible data, and to consistently and accurately analyze the results they produce.

KEY FINDING HIGHLIGHTS

- Poor road condition in the late winter/early spring can result in a substantial downslope water quality risk when rains efficiently transport these pollutants into the stormwater system, requiring treatment and/or retention to prevent fine sediment particles from reaching the Lake. (P038)
- Total phosphorus delivered is likely to be the highest during the peak flow times associated with snow melt in April and May. (P052)
- Observations support previous assumptions that increased sweeping frequency during winter months removes coarse material delivered to road surface prior to pulverization. (P038)
- Despite a robust statistical separation by discriminant analysis, source samples of road sediments from different areas are quite similar and discrimination between them is based upon very small differences in their composition. (P026)
- Wetland retention basins efficiently combine the physical properties of a retention basin with the biological characteristics of wetlands. (P054)

Riparian/Stream Restoration - Sixty-three streams drain into Lake Tahoe, carrying rain and snow melt, sediments, and nutrients. Riparian corridors throughout the basin provide vital connections between the surrounding watershed and the lake. Inputs of nutrients such as nitrogen and phosphorus and fine sediment particles, coming from the surrounding watersheds, are suspended in the flowing water that eventually enter the lake. It is largely through this connection that the water quality of Lake Tahoe is regulated.



Degraded streams can be a troublesome source of sediments and nutrients to downstream locations, including Lake Tahoe.

KEY FINDINGS HIGHLIGHTS

- Results of model simulations show that failing to account for the erosion resistance of riparian roots resulted in over-estimation of bank erosion. (P003)
- Resource managers need tools to quantify the water quality benefits of SEZ restoration efforts in a manner comparable to and consistent with the stormwater quality load reduction tools that have been developed. (P004)
- Significant temporal and financial requirements make the quantification of the actual long-term water quality benefit of a restored SEZ extremely challenging. (P042 and P074)
- While the cost effectiveness of SEZ restoration actions to achieve pollutant load reductions varied across projects, this analysis does suggest that SEZ restoration is another valid and cost-effective tool in the pollutant load reduction opportunity toolbox for Tahoe Basin managers to reduce pollutant loads to Lake Tahoe. (P089)

FUTURE RESEARCH & DELIVERY

On May 31, 2016, over forty representatives from the science community and Lake Tahoe Basin management agencies met to discuss the role science has played in supporting management actions and to suggest future research needed to sustain science-based decision-making. The group was asked to share their insight on the role the SNPLMA Science Program has had informing management actions, identify gaps in our current knowledge, and suggest ways to enhance information sharing among scientists, managers and the public.

WORKSHOP HIGHLIGHTS

- Understanding the impacts of climate change on hydrology in the Tahoe Basin is still a pressing research need. At present, more is known about the climate impacts on water quality than on water quantity. As more winter precipitation comes as rain instead of snow, the impact of changing hydrologic conditions on streamflows, groundwater supplies, and restoration projects needs to be examined.
- Managers in the Tahoe Basin are aware that long-term climate impacts are likely, but aren't sure what to do with climate change information, or how to apply and incorporate it into near-term management practices.
- Unanswered questions remain about how climate change may impact the ability of basin agencies to meet their goals under the Total Maximum Daily Load (TMDL) program. In particular, more information is needed to understand how/when changes in deep mixing may occur and the resultant potential impacts from the release of nutrients stored in bottom sediment on lake clarity and TMDL targets.



- A lake-wide program for monitoring the introduction, spread and impacts of aquatic invasive species (AIS) is needed. Project-level AIS monitoring studies are not sufficient to validate the impact of AIS lake-wide. Surveillance, monitoring and modeling are needed to map the nearshore areas at the highest risk for AIS invasions.
- More robust basin-wide datasets and baseline data are needed to enable managers to prioritize ecosystem restoration and protection projects and to justify funding requests for landscape scale restoration efforts.
- Reevaluating and improving air transport models is essential to understanding the relative contribution of airborne deposition of nitrogen compounds on the lake surface and how this impacts nutrient loading. New models are currently available that could refine the estimates of airborne nitrogen loading on the lake. These data could help inform future TMDL targets and compliance goals.
- Resolving (or reaffirming) the current models of nitrogen loading on the lake is essential to ensuring the current TMDL targets are obtainable.
- Research into alternative roadway composition such as new mixes of asphalt, changes in grading and maintenance, and improvements in driveway sealers could help state and local agencies prioritize investments and rules/regulations designed to reduce the impact of the built environment on lake clarity.
- Quantifying the potential impacts that changes in temperature and precipitation will have on roadways and paved surfaces would help agencies and jurisdictions prioritize resource investments in road infrastructure maintenance and improvements.
- Engaging the socioeconomic research community in the Tahoe Basin would provide the agencies with more rigorous data to support the development and implementation of policies, regulations, and programs to protect the unique natural resources and community development of the Lake Tahoe Basin. Socioeconomic studies could help inform the development and implementation of policies and programs to maximize both ecological preservation and the quality recreational experiences
- Advancing the education of the general public is an area that could be expanded in future science programs in the basin.
- With the end of SNPLMA Science Program, alternative funding sources need to be identified to support landscape-scale, basin-wide studies such as a Tahoe Basin Climate Assessment.
- A major, ongoing challenge for management agencies and scientists is the lack of funding for long-term, persistent environmental monitoring, especially for measuring environmental change over times that extend beyond the scope of project effectiveness evaluation.



IN CONCLUSION

The Lake Tahoe basin has served as a proving ground to demonstrate how focused research can be integrated into management actions to address complex ecological problems. With the sunset of the SNPLMA Science Program, it is critical that the scientists and managers do not lose this momentum and continue to build on the strong partnerships that have developed over the last decade. The breadth and pace of ecological change in the Tahoe Basin suggests that an engaged scientific community in partnership with active, energetic, and informed managers will continue to be the linchpin for preserving Lake Tahoe as a national treasure for all to experience for generations to come.



CHAPTER 1: INTRODUCTION

THE NEED FOR SCIENCE AT LAKE TAHOE

The known effects of past actions and the unique character of the Lake Tahoe Basin have led to broad-based support for substantive conservation and restoration efforts over the last four decades (CTC 2006, Elliott-Fisk et al. 1996, Murphy and Knopp 2000, TRPA 2001, U.S. Public Law 106-506 2000). Increased attention and funding over the past two decades in particular have resulted in remarkable progress towards restoration goals, along with considerable information on the strengths and weaknesses of different approaches to addressing the substantial restoration challenges (CTC 2006, Elliott-Fisk et al. 1996, Murphy and Knopp 2000, TRPA 2002, TRPA 2007). Restoration has focused not only on Lake Tahoe, but on the entire watershed. Special attention has been given to the highly interdependent nature of terrestrial and aquatic habitats and the multifaceted socioeconomic conditions that influence the Tahoe Basin ecosystem (Elliott-Fisk et al. 1996, Murphy and Knopp 2000). The Lake Tahoe Basin is now recognized as a highly complex physical, biological and social environment, and the challenges posed by its restoration and continued management for multiple benefits are paralleled by few other locations (Hymanson and Collopy 2010).

Conservation and restoration of the Lake Tahoe Basin ecosystem have required the sustained engagement of federal, state, and local governments, as well as the private sector. These entities have worked together to develop and implement a variety of programs and activities aimed at achieving common environmental and social goals (TRPA 2001, TRPA 2007). Despite recent progress, determining how to proceed with conservation and restoration efforts in the face of limited information remains a central challenge. Science (e.g., monitoring, research, and modeling), particularly applied science completed to inform adaptive management, provides a promising set of tools to address information limitations that affect our ability to select and implement effective management strategies. The coordination of scientific activities with



management actions is the core of an effective adaptive management approach (Manley, et al. 2000). However, effort is required to organize and describe the science activities needed to inform an adaptive management system focusing on the conservation and restoration of a complex system.

One risk to the continued progress of conservation and restoration efforts in the Lake Tahoe Basin is the ill-advised notion that we know enough to solve the problems we are faced with; that no new research is necessary. Agencies in the basin have begun informed efforts to correct the problems they face, but even the Tahoe Total Maximum Daily Load (TMDL) program (<https://www.enviroaccounting.com/TahoeTMDL/Program/Display/LakeTahoeTMDL>), perhaps the best example of our rapid ascent to knowledge, will not succeed without a continued, diligent effort to adjust its controls based on the outcome of new research and monitoring.

Our knowledge of the terrestrial systems in the basin is in its infancy. Our understanding of the complex social systems and their interaction with the environment has made little progress since it was identified in earlier assessments. Effective regulations intended to conserve and restore these complex systems require an understanding that is commensurate with the complexity and depth of the problem. Dr. Jared Verner, when discussing the complexity of old growth forests, said, “These systems are much more complicated than we think. In fact, they’re more complicated than we can think.” We may believe we know what the solution to a problem is, but only continued investigation can verify that. Learning as we manage will light the path to improved solutions. With the conclusion of the Southern Nevada Public Lands Management Act (SNPLMA) management and research programs, we face a challenging question: what new synergistic mix of science and management will be required to resolve the next generation’s needs for conservation and restoration activities, or to realize our own?

HISTORY AND THE ROLE OF SNPLMA SCIENCE IN LAKE TAHOE

Research at Lake Tahoe began in 1874 and has continued to the present. It may be thought of as having two distinct phases: uncoordinated and coordinated. The uncoordinated phase was characterized by the initiative of individual researchers who produced excellent results and were responsible for creating the scientific foundation that identified the declining clarity of the Lake and the need for further research to uncover potential remedies. SNPLMA solidified the second phase where research was deliberately focused and coordinated in specific areas necessary to enable policy and management changes needed to reverse the trends of Lake and ecosystem decline. In the recent coordinated phase management agency personnel developed research themes while funds for projects responsive to those themes were allocated on a competitive basis. Funds were provided on a predictable schedule at predictable levels for nearly 10 years. This allowed an influx of a wide array of new researchers and a commitment to long-term research that would have been impossible otherwise. It created venues for the rapid exchange of research products to management agencies. In many cases the lines between agency professionals and research scientists blurred as the level of interaction increased. The consequence was focused and timely research that resulted in leaps of understanding and consequent policy, making the Lake Tahoe TMDL program, for example, possible. It may be impossible to quantify the benefits of this research directly, but we hope that by presenting an overview of the research results here and discussing its implications that we can achieve an appreciation for its value and a perspective for the efficacy of the scientific infrastructure created to deliver it.



The need for coordination of research did not happen overnight. Scientific research at Lake Tahoe has been ongoing since 1874. Early work was engendered mostly by the initiative of individuals pursuing their own scientific curiosity, who often produced excellent research, but without an overriding purpose. According to the first research assessment at the Lake, *Research Needs for the Tahoe Basin* (1974), the result was “a general feeling that research efforts and their end product were not specifically directed nor given proper priority to deal with development pressures in the Lake Tahoe basin.” This first assessment identified information shortfalls that compromised management of the Tahoe Basin’s air, water, vegetation, fish and wildlife, social sciences, as well as identifying resource systems. More than 80 separate research needs were identified.

In 1979, the *Lake Tahoe Environmental Assessment* (WFRC IRTF 1979) presented a second compilation of information, an interagency product of a “federal partnership” between the U.S. Environmental Protection Agency, the U.S. Forest Service, the U.S. Department of Housing and Urban Development, the U.S. Department of Transportation and the U.S. Department of Energy, and numerous state and regional agencies. The assessment summarized data on air quality, water resources, vegetation, fish and wildlife, land use, visual quality, transportation, noise, energy use, and social, economic, and demographic features of the basin. The assessment aggregated data into a model, which then was used to evaluate “effects accumulated through webs of interactions,” concluding that during the 1970s “the basin’s environmental quality had depreciated in a measurable, cumulative way.” It introduced formal concepts of carrying capacities (intrinsic limits to land development and certain other activities in the Tahoe Basin) and thresholds (quantitative standards to set these limits). The 1979 report greatly influenced the establishment of the nine environmental threshold categories that are now guiding conservation efforts under the most recent Regional Plan (2012).

The third effort to organize Tahoe’s research needs, the *Lake Tahoe Case Study* (http://pubs.usgs.gov/dds/dds-43/ADDEND/A_C07.PDF; Elliot-Fisk et. al. 1996), took a science-based approach to provide an ecosystem and policy assessment of the Lake Tahoe Basin. The study synthesized information from these assessments to inform the Sierra Nevada Ecosystem Project (USDA-Forest Service) and identified future science-based management needs for the Lake Tahoe Basin.

The Environmental Improvement Program (EIP) (<http://www.trpa.org/about-trpa/how-we-operate/environmental-improvement-program/>; TRPA 2001) was the fourth effort. While primarily a management tool for regulating development in the basin, it included a section that identified thresholds and related research and monitoring projects intended to (1) advance scientific understanding of ecosystem processes and threshold attainment, (2) refine planning and restoration strategies, and (3) improve and quantify the effectiveness of capital improvement projects.

The fifth project, the *Lake Tahoe Watershed Assessment* (<http://www.fs.fed.us/psw/publications/documents/gtr-175/>; Murphy and Knopp 2000), provided a comprehensive “State of the Basin” synthesis of 20 years of research publications and reports dealing with atmospheric, aquatic and terrestrial environments, the living resources associated with these environments, and cultural and socioeconomic conditions. Like the documents that preceded it, this assessment included recommendations for research and monitoring. The assessment also presented an adaptive strategy for moving management actions forward, given the reality of incomplete information, by continuously updating those actions as informed



by the emerging science. It also required that the science be focused to expeditiously serve the needs of basin managers while providing a foundation for future research. This process of mutual scientific and management development has been a cornerstone of much of the progress that agencies have made over the past decade.

In another project, Key Management Questions (SAG 2001) were developed by scientists and managers to direct new research and monitoring in the Lake Tahoe Basin. Some were periodically revised and updated (2002-2004) to reflect the most important questions that land managers, project implementers, and regulators had about land use and methods to improve ecosystem health in the basin. Tahoe Basin executives prioritized these questions, which were subsequently used by federal and state agencies for budget preparation, and later used by the Tahoe Science Consortium and the U.S. Forest Service's Pacific Southwest Research Station (PSW) through the Committee of Scientists to allocate SNPLMA research funds.

The most recent effort was *An Integrated Science Plan for Lake Tahoe Basin: Conceptual Framework and Research Strategies* (PSW-GTR-226, May 2010). The main purpose of the plan was to develop a set of research strategies addressing key uncertainties and information gaps that challenge resource management and regulatory agencies. This plan was developed through the Tahoe Science Consortium (TSC), itself the product of an effort to put more order into the future science at Lake Tahoe. The plan updated a broad range of research questions, based in part on the original Key Management Questions, whose purpose was to establish priorities for SNPLMA research funding. The TSC's intent for this science plan was to periodically update the questions or funding categories and hence the research emphasis. The revised funding process that was developed was then used to select research projects, which account for about half of the projects summarized in this document.

SNPLMA SCIENCE FUNDING AND PROJECT SELECTION PROCESS

The Southern Nevada Public Land Management Act (SNPLMA) became law in October 1998 and enabled the Bureau of Land Management to sell public land within a specific boundary around Las Vegas, Nevada as part of a large federal conservation program for that region. Proceeds from these sales were made available for certain types of projects to further conservation objectives within Clark County, Nevada. In November 2003, SNPLMA was amended to direct \$300 million over a period of eight years to Lake Tahoe for implementation of the Federal Environmental Improvement Program within the Lake Tahoe Basin.

Although the majority of these investments in the Lake Tahoe Basin were intended to address capital projects, program needs, and operations and maintenance needs, there was a specific and important role for research to address key scientific uncertainties. Scientific research has always been considered an integral component to the overall environmental framework for the Lake Tahoe Basin, and has played a key role in the development of the environmental thresholds, in identifying trends in threshold attainment, and more recently for informing policy decisions. Research was considered necessary to address the most pressing management questions facing Tahoe Basin land managers, and to reduce the uncertainty in the effectiveness of capital improvement projects.

The U.S. Forest Service's Pacific Southwest Research Station (PSW) served as the federal agent managing the research funds of approximately \$3.4 million per year through SNPLMA, beginning in Spring 2007 with



Round 7. Research priorities were identified by the management agency partners and projects were selected during SNPLMA Rounds 7-12 with the final research projects awarded in 2013. The PSW administered an annual Request For Proposals (RFP) to solicit research proposals for key work in the basin. The PSW, in partnership with the Tahoe Science Consortium and representatives from the management agencies, conducted scientific peer reviews to evaluate the proposals (submitted annually) for technical merit and management relevancy.

PSW, through the Tahoe Science Consortium, worked each year with the resource management agencies in the Tahoe Basin to identify research priority theme areas within which to solicit proposals. The themes varied somewhat from year to year, but were generally divided among eight general science themes, in response to needs expressed by the management and policy officials within the basin. These eight themes captured the research needs identified by managers in the basin:

PRIORITY RESEARCH THEMES

- **Air Quality:** Air pollutants pose threats to health of humans and forests at Lake Tahoe, as well as to the clarity of the lake itself. Research evaluated these impacts and developed appropriate treatments.
- **Climate Change:** Research focused on developing new and expanding tools to inform policymakers about how future climate change will specifically affect the Lake Tahoe Basin and provide information that could lead to proactive policy alternatives.
- **Forest Fuels and Vegetation Management:** Forest treatments, including prescribed burning, help to reduce wildfire hazards in the Tahoe Basin. Research evaluated the effects of treatments and wildfires on values such as air quality, water quality, and wildlife habitat.
- **Habitat Improvement:** Research investigated the special management needs of rare or vulnerable species and ecological communities in the Tahoe Basin.
- **Lake Quality:** To "Keep Tahoe Blue" is a primary goal in the Tahoe Basin. Research focused on methods for reversing the long-term decline in open-water clarity, and impacts to lake quality from the spread of attached algae (*periphyton*) and non-native organisms.
- **Stormwater Management:** Fine sediments, nutrients, and other pollutants, particularly from urban areas and roads, pose major threats to the clarity of Lake Tahoe. Research helped to design best management practices (BMPs) to prevent these pollutants from entering downstream waterways.
- **Stream Restoration:** Research helped to design projects to restore stream geomorphic and ecological functions, including retention of fine sediments and enhancement of habitat for plants and animals.
- **Science Integration:** This category was included to enable synthetic work that crossed over multiple theme areas and provided valuable insight from multiple lines of research. The Tahoe



Science Consortium also conducted workshops and provided technical assistance to apply current research to challenges facing management agencies within the Tahoe Basin.

The annual RFP process typically included specific subthemes within a theme area that identified more specialized topic areas for research proposals. The RFP allowed for multi-year, collaborative projects, but funding requests had to either support multi-year projects with one increment of funding or consider that availability of funds in subsequent years must be contingent on future competition. A peer review panel comprised of the Executive Director of the Tahoe Science Consortium and two members from TSC institutions who performed the initial screening of proposals for relevance to research needs. All accepted proposals were circulated to an independent technical peer review panel with three reviewers for each proposal. The reviews evaluated the scientific approach and quality, and probability of timely success for each proposal. The scientific/technical merit of each proposal was assessed based on a set of Technical Review Criteria:

- **Goals:** Are the goals, objectives, and hypotheses clearly stated and internally consistent? Is the idea timely and important?
- **Justification:** Is the study justified relative to existing knowledge? Is the conceptual basis clearly stated in the proposal and does it explain the underlying basis for the proposed work?
- **Approach:** Is the approach well designed and appropriate for meeting the objectives of the project? Are the results likely to add to the base of knowledge? Is the project likely to generate novel information, methodologies, or approaches?
- **Feasibility:** Is the approach fully documented and technically feasible? Are the underlying assumptions reasonable? What is the likelihood of success? Are the scale, budget, and timeline of the project consistent with the goals and objectives and within the grasp of the authors?
- **Products:** Is the project likely to yield products of value? Are interpretative (or interpretable) outcomes likely from this project? Will the information ultimately be useful to decision makers?
- **Capabilities:** What is the track record of the authors in terms of their past work? Is the project team qualified to efficiently and effectively implement the proposed project? Do they have the infrastructure and other aspects of support necessary to accomplish the project?

Based on these criteria, the proposals were rated as superior, good, average, below average, or inferior. Research conducted in the basin and supported by funds from the SNPLMA program was also required to be policy relevant. The TSC developed a process to conduct peer reviews of the scientific merit of each proposals in conjunction with management relevancy reviews provided by agency representatives. This “relevancy review” rated proposals for their policy/management relevance as superior, good, or average.

Each RFP Round received approximately 50-100 proposals from a wide variety of research institutions, including universities, government agencies, non-governmental organizations and private consulting firms. The proposals with the highest combination of technical and relevancy merit were submitted to the Lake Tahoe Federal Advisory Committee for official approval. The number of research projects selected each year varied from 14 to 18, based on the availability of funds, which was typically about \$3.4 million per year. Over the seven-year period a total of 100 projects were funded.



The intent of this synthesis is to distill the hundreds of research publications and reports derived from this program into succinct findings that provide relevant knowledge for resource managers in the basin. We know that it is challenging for managers and policy-makers to keep abreast of the many scientific publications. It is our hope that this summary will provide a first contact to the important scientific findings and enable further, deeper investigation into the relevance of the work completed through the SNPLMA Science Program. The following chapters provide a synthesis, with highlights of key findings, of what has been learned from each of these 100 research projects. We trust this will be of immense value to subsequent efforts to manage and restore ecological health of the basin.



CHAPTER 2: INTERVIEWS WITH BASIN EXECUTIVES

INTRODUCTION

The purpose of the SNPLMA research program was to broaden our understanding of Lake Tahoe's ecosystem processes and functions, thereby enabling Tahoe Basin managers to create more effective policies and management programs to restore the lake. This chapter reports Tahoe Basin executives' perspectives regarding the relevance of the SNPLMA research program and the value of the research results for their respective agencies. We hope that by asking these questions, the execution and delivery of science can be improved in the future.

Six agency executives were interviewed. The agencies participating were the California-Tahoe Conservancy, the U.S. Forest Service, the Lahontan Regional Water Quality Control Board, the Nevada Division of State Lands, the Tahoe Regional Planning Agency, and the Tahoe Transportation District. These agencies represent the majority of the policy and management programs affecting the entire Tahoe region. The discussions were energetic and often strayed from the formal questions. The notes below capture both answers to the formal answers and informal feedback provided during the course of the discussions.

INTERVIEW QUESTIONS AND RESPONSES

What is your perspective regarding the value of the past five to ten years of research to your agency's planning and regulatory decisions?

The common response to this question was that research has been and will continue to be a cornerstone of agency policy and decision-making. Research literature is used extensively in the development of every new planning or policy document. This is done to ensure that decisions are based on the best available science and because overlooking applicable research will result in appeals and costly delays.



There were exceptions, primarily in the transportation sector, where it was noted that very little economic or transportation related research had been accomplished. Nonetheless, basic road design and maintenance have been directly influenced by recent research, which has resulted in updated road Best Management Practices (BMPs). The paucity of basic transportation information affects interregional and in-basin planning, and consequently affects the basin's competitiveness for state and federal transportation project funding. Basin transportation leadership believes that without the ability to demonstrate credible use of the basin from nearby metropolitan users, interregional planners will miss an opportunity to resolve significant issues that otherwise would be addressed. While basin managers do acquire their own data, its credibility is diminished compared to independent investigations.

There was a broader range of responses to the question regarding the value of new research. The work to develop an effective strategy to reverse the decline of lake clarity has been profoundly affected by targeted research to discover the causes for that decline. Without that research, it seems likely that little substantive progress would have been made in terms of understanding the science of the decline. The regulatory environment has likewise been directly shaped by targeted research. The Lake Tahoe Total Maximum Daily Load (TMDL) program, which is the cornerstone and embodiment of the strategy to restore clarity to the lake, is based upon research that allows quantification of source loads, affects design of restoration projects, and has created models that can identify specific sources of real improvements amidst the normal noise of variable climates and measurement imprecision.

By any measure, understanding why the lake's clarity has been declining and how to establish an effective regulatory process to reverse that decline would not have occurred without the recent research contributions. Do basin managers see the need to continue new research? The answer varied among agencies, but basically the answer was "not as much as before." Several basin executives felt that we need to shift into an implementation mode, while others felt that we should concentrate on monitoring and fine-tuning policies and project designs. Fundamental research should continue to the extent dictated by available funding, with a focus sharpened by specific management needs. In all fairness, the differences in opinion are likely reflecting the urgency that unknowns impose upon the potential effectiveness of current management strategies and the vulnerability to litigation that uncertainty engenders. Each agency has a different emphasis, each emphasis has a different level of certainty depending on the thoroughness of existing science, and hence each agency has a different level of comfort with proposing new research. Comfort is usually inversely related to the volatility of an issue, so it seems likely that as basin managers begin the task of revising Tahoe Regional Planning Agency (TRPA) basin thresholds, for example, many of the upland and social aspects of the basin's ecology embodied in those standards will rise to a heightened sensitivity. Since quantifiable and defensible thresholds are the "Holy Grail", research directed at that goal will become increasingly more urgent. It appears likely that the need for research will shift from water quality to other social and terrestrial issues rather than universally decline, and the demand for new research from each agency will be likely to vary based on each agency's need.



How has the research community engaged in research support activities such as environmental monitoring, data analysis, participation in workgroups, and subject matter expert advice for developing environmental policies and regulations? Have these support activities been effective in supporting your agencies decisions? How can the science community better support your agency's mission?

The research community is held in high regard in the Tahoe Basin, and obvious effort has been expended by both groups to maintain and improve the relationship between managers and scientists. Most agency executives believe they have very good relationships with scientists working in the basin. Most acknowledge that as the work has changed over time, their list of scientists to work with has changed as well. Scientists who are successful in maintaining those relationships make a point of devoting time to consistently be present at appropriate meetings and contribute to project planning and implementation. As a result, agency professionals are comfortable candidly discussing their concerns with scientists, and both parties view these discussions as productive. During the late 1990s, this camaraderie was not always present, but it evolved during the SNPLMA Science Program. Agency executives and scientists appear to share an understanding of the challenging nature of conducting research and the difficulty of translating scientific information into effective and timely policies.

Basin executives reported that they value research based upon: 1) its *relevance* to current management issues; 2) the *understandability* of research outcomes by managers; 3) the *timeliness* of its completion and reporting; 4) the *cost* of the project; and 5) the willingness of the authors to explain the research to staff and concerned publics (*information transfer*). Details about each are discussed in subsequent paragraphs.

The context for discussing science delivery is important. In the Lake Tahoe Basin, fundamental environmental processes were not well understood, and research was required to develop effective solutions¹. When critical natural resources are in jeopardy and the time to conduct research and implement solutions is limited. As a result, agencies and scientists accepted the need for accelerated and focused applied science and adaptive management strategies.

1. Relevance

Relevance of research to current management issues was of key importance to Tahoe Basin executives. The general focus for science investigation in the Lake Tahoe Basin has developed over several decades and has been discussed in at least seven publications². It has been supported by a variety of entities, notably the Science Advisory Group (SAG) that operated from 2000 until about 2002, and more recently by the Tahoe Science Consortium (TSC), created in 2005. The TSC is a partnership among five research organizations and operates independently of the management and regulatory agencies working in the Lake Tahoe Basin. The TSC provided the majority of the science coordination since its inception, but its role is diminishing with the close of the Tahoe SNPLMA Program funding. The allocation of SNPLMA Science project funds was based on an RFP process that grouped the research into eight categories. Those categories were developed in response to Key Management Questions authored by the SAG in 2001, which were developed collaboratively by a group of staff members representing each agency. Each year the available funding was allocated between categories based on technical merit and agency-relevancy reviews of each. This process was managed by the TSC Executive Director.



Basin executives give the science process described above mixed reviews regarding the relevance of the science projects accomplished when discussing specific projects, but overall believe the science was well targeted to management needs. The process itself was criticized as sometimes not representing management's perspective adequately, and/or needing more commitment from managers to ensure that the most compelling issues were addressed first. One executive said, "We had good interaction with scientists, just not enough." Agencies not directly tied with the outcome of the TMDL process also felt that there was too much emphasis on water quality and not enough on landscape-level processes and wildlife. The transportation discussion pointed out that no transportation research or economic research was conducted, which has hurt that group's competitiveness for project funding. The frustration over these issues was not laid solely on the scientist's shoulders. One executive said, "We just don't sit around thinking about what research is needed." Another offered that after the initial rush to get the science projects started, many executives simply bowed out of the process. Selection of projects was then left to those managers or their staff who stayed involved and members of the TSC Committee of Scientists. There was clear agreement between executives that overall, the water quality work was well focused. One specific area of disagreement reflected a multi-agency view that too much time was spent proving that BMPs developed outside the basin, also worked in the basin. This may have reflected a difference of perspective between agencies regarding the role of BMPs in the regulatory process, however, several managers felt it was a distraction, that consumed resources that could have been used elsewhere.

Basin managers indicated that SNPLMA-funded research that effectively addressed management concerns largely came from researchers who spent a lot of time meeting with managers and had a strong grasp of the managerial issues. The extreme examples were scientists who specifically wrote proposals in response to issues managers asked them to address. Often these proposals included work that academic researchers might not have pursued. Having scientists and managers working closely together is critical to making adaptive management work. One agency preferred to work with private contractors and consultants over academic researchers because the former tended to be more responsive to near-term management needs.

2. Understandability

Basin executives described understandability as an important element in what made scientific research useful to their organizations, citing two main aspects of what made research understandable: First was the language that was used in published papers and/or technical reports. Was it comprehensible to the average executive or staff professional? Were scientific terms explained? Did the paper get to the point, or did the reader have to wade through methodology and background that was only of interest to other researchers? Some executives expressed the view that the need for academic researchers to conduct scholarly work did not always produce information that was accessible and understood by a broader audience of managers and the public. Regarding the question of did the research papers and technical reports adequately address the issue and was the relevance of the research explained; several executives stressed the need for more attention to be paid by the science community on translating and presenting the scientific findings in the context of policy and management decisions. More focus was needed on communicating scientific uncertainties and the broader impacts of the research.

3. Timeliness



According to basin executives, the time required to deliver research products matters to their organizations because there has been a perception that if effective action is not taken to reverse ecosystem declines, a threshold may be crossed from which recovery is difficult or impossible. Research projects with long timelines (multiple years) may be out of sync with management project timelines and hence, be less relevant to agency managers. Managers in the Tahoe Basin are often under pressure to resolve environmental issues quickly. Long (multi-year) timelines for applied research projects also may not keep pace with changes in agency leadership, budgets and direction. Lastly, if the science is needed to inform project execution contracts then unanticipated delays in the research schedule can be costly to the management agencies. There was a perception among some agencies that private consultants were more likely than academic researchers to deliver products on time. The distinction between research and professional services has been blurred at times in the basin, with some agencies needing more prompt and concise studies and others relying on more in-depth and thorough research. It is imperative that researchers operating in an adaptive management environment recognize and be responsive to the time constraints of their management partners. Not publishing (or sharing) research data during the execution of a research study is a common academic practice, which can be problematic when the research is expected to support time urgent adaptive management decision-making. More frequent communications and sharing of preliminary results by scientists with managers would go a long way to reducing some of these issues and perceptions. Setting and adhering to tight time schedules largely resolves this potential source of conflict.

4. Cost

Basin executives accept that research often is expensive and that the expenditures often yield positive and essential results. This understanding includes an element of frustration that seems tied to the basic uncertainty inherent in a discovery process. While there was a recognition that breakthrough results are not predictable, more focused answers to specific questions may be. A better balance between in-depth research and more limited and focused studies may be needed in the future to better support Tahoe basin adaptive management. Overall, basin executives were satisfied that research costs were reasonable and necessary.

5. Information Transfer

Basin executives were appreciative of what they perceived as excellent sharing of research results with managers (described as “information transfer”). This was highly valued by agency staff and executives, and was perceived as an essential component to incorporating research findings into remediation project design and implementation. Two executives voiced a desire for researchers to engage even more closely with managers to help design and evaluate projects. In both cases the discussion revolved around the complexity of implementing very large-scale landscape treatments. Managers expressed a need for technical experts that are independent, unbiased and authoritative, to provide project teams with advice so issues that arise during project execution can be addressed quickly. Executing landscape-scale projects will require more coordination among agencies and clear delineations of the roles and responsibilities for scientists involved in providing technical advice for project planning and evaluation and those involved in project execution.



How can we improve the relevance of research, its focus and delivery to your agency and others in the Tahoe Basin, and how can science further improve the adaptive management process?

As this report was being compiled, there was no single vision from Tahoe Basin executives regarding how to improve the relevance and effective delivery of research. There was a recognition among the agencies that maintaining strong partnerships between the science community and basin agencies will be essential in the future. One option may be through the newly created California and Nevada in the Bi-State Science Council (the Council), which was created in response to Nevada's SB 271 and California's SB 630. The Council was established, in part, to address issues between the two states regarding regional planning by the Tahoe Regional Planning Agency (TRPA). The basin executives believe that one role of the Council should be to independently assess TRPA's threshold indicator program and recommend changes to the threshold monitoring and reporting framework based on a scientific review of the relevancy, effectiveness, and robustness of the current threshold program.



Exploration and Outreach
Kokanee Salmon traveling up Taylor Creek to spawn

Other items, suggestions and needs discussed by basin executives included:

- Provide better focus for research by: a) more accountability for funding expenditures, and adherence to timelines, and b) more dialogue with researchers to ensure proposals address management questions. Note: this point was also mentioned as a strength of basin scientists, so we interpret this not as a criticism, but as an area that could be further strengthened.



- Improve the credibility of management projects by including more scientific expertise during planning and evaluation.
- Maintain the credibility of basin science by maintaining independent expertise and oversight. Provide more scientific reviews of basin regulations and oversight of agency monitoring programs.
- Maintain the excellent information transfer that basin scientists currently provide. Information transfer was evidenced in individual presentations by scientists to staff, the availability of scientists for personal meetings and phone calls from agency staff, science participation in numerous basin workgroups, development and oversight of annual workshops, and maintenance of web sites.
- Basin executives should be more involved with the selection of future research projects to better ensure their interests are addressed.
- Create the capability in the basin to accept private sector philanthropic funding for research.
- Strengthen the basin's adaptive management process to include short, focused scientific reviews of proposed regulations to ensure that they are based on the latest scientific data.
- Provide scientific oversight of agency monitoring programs to ensure they're coordinated, and that their objectives are realistic and appropriate to the scale of the problem being addressed. While much coordination is already in place, there is a perception that disproportionate resources are often allocated on monitoring low priority needs, while some high priority monitoring needs remain unfunded.
- Provide better implementation and effectiveness monitoring and analysis and the funding to support both. Since this is viewed as the cornerstone of adaptive management, more attention needs to be placed on funding monitoring programs beyond project implementation timelines.
- With the close of the SNPLMA Science Program, a new more efficient (and less costly) system for maintaining science-based management is needed.



Forest Health and Fuel Reduction

Aerial view of Angora Fire and Tahoe Keys, November 2010

CHAPTER 3: SYNTHESIS

INTRODUCTION

From 2007 to 2013, the SNPLMA Science Program supported approximately \$3.4 million per year in funding to researchers in the Lake Tahoe Basin. This chapter describes the research and key findings that came out of more than 100 SNPLMA-funded projects, in the eight major science theme areas. Summaries of each of the projects and their respective findings are contained in in Appendix B. Additional details including the final technical reports and (in some cases) research publication for each project is available on the PSW website <http://www.fs.fed.us/psw/partnerships/tahoescience>. In this chapter each project is identified with its assigned project number (e.g. P007), which will enable the reader to locate the project summary in Appendix B and the full report on the PSW website. Research findings are presented for the following topic areas:

- AIR QUALITY
- CLIMATE CHANGE
- FOREST FUELS AND VEGETATION MANAGEMENT
- HABITAT IMPROVEMENT
- LAKE QUALITY
- STORMWATER MANAGEMENT
- RIPARIAN / STREAM RESTORATION



1. AIR QUALITY

A statement from chapter three of the 2000 Lake Tahoe Watershed Assessment (<http://www.fs.fed.us/psw/publications/documents/gtr-175/>) captures the essential interaction between air quality and every aspect of the Lake Tahoe ecosystem:

Air quality is a critical concern for Lake Tahoe watershed management because it is linked in either a major or minor way to nearly every valued resource within the basin. Thus, for management of the watershed and airshed of the basin, there is a need for comprehensively understanding hydrologic, atmospheric, and ecological processes and their interactions, for assessing current environmental conditions (e.g., air quality, water quality, and forest health), for responding to anthropogenic and natural disturbance, and for predicting environmental improvement based on various management strategies.

SNPLMA funded 13 air quality-related projects in the Lake Tahoe Basin. Very little was known regarding air quality in the basin in 2000 but excellent progress has been made and it is clear that the atmosphere is an important source of nitrogen, phosphorous, and fine particulates to the lake. The varying complexities of emission sources from vehicles, roadways, fireplaces, prescribed fires and wildfires reveal the need for an equally complex approach to limiting these sources in order to retain the delicate balances within the greater Tahoe ecosystem.

Lake clarity and air quality are inherently linked with three sources being primarily responsible for the decline in lake clarity over the decades since the original measurements were taken in the 1960s – nitrogen, phosphorus, and fine sediments. Atmospheric deposition is credited with accounting for 55% of the nitrogen, 15% of the phosphorus (Cliff & Cahill, 2000) and 15% of the fine sediments (CWB & NDEP, 2008).



NITROGEN (N)

Normally, for plants to utilize nitrogen for growth, the nitrogen must take the form of either nitrate (NO_3^-) or ammonia (NH_3). Bacteria and lightening can convert atmospheric nitrogen (N_2) into oxides and then into nitrates. Ammonia is usually produced by decomposition, either through biologic decomposition or combustion of wood or petrochemicals. Atmospheric nitrogen as a pollutant normally occurs in three forms: nitrogen oxides (NO_x), Ammonia (NH_3), or nitric acid (HNO_3). These are important as primary pollutants and as a precursor to ozone (O_3) formation. Improving our knowledge of atmospheric N deposition for the entire Lake Tahoe watershed is essential for understanding the causes of the deteriorating clarity of the Lake as well as the ecological sustainability of forests and other ecosystems in the Tahoe Basin. Research has been contradictory regarding the quantity of nitrogen added to the lake above normal saturation concentrations through direct deposition and through deposition on the watershed or snowpack and then by streamflow. (P063).

In project P063, Bytnerowicz et al. (2013) investigated the effects of atmospheric nitrogen deposition at 34 sites located in and around the Lake Tahoe Basin, using passive samplers to monitor O_3 , nitric oxide (NO), nitrogen dioxide (NO_2), ammonia (NH_3), nitric acid (HNO_3) and volatile organic compounds (VOCs). At ten of these sites (called “megsites”), the team also measured N deposition with ion exchange resin (IER) collectors placed in forest clearings (bulk precipitation) and under tree canopies (throughfall).

KEY FINDINGS:

- Gaseous nitrogen pollutants are of ecological concern to the Basin due to their role as ozone precursors as well as their direct impacts on terrestrial biota and aquatic nutrient enrichment leading to increased aquatic biotic productivity and declining lake clarity. (P063)
- Among the N reactive species, NH_3 and NO dominated, comprising 38.2 and 35.4 percent, respectively, of the atmospheric reactive N. However, from the perspective of atmospheric N deposition, NH_3 and HNO_3 were most important due to their high deposition velocities. The highest NH_3 concentrations were measured west of the Lake Tahoe Basin on the western slope of the Sierra Nevada, indicating the effects of mobile and stationary pollution sources in the Central Valley of California. However, local NH_3 emissions seem to contribute to elevated levels of the pollutant on the southwestern side of the Basin. The highest concentrations of total reactive N gases were measured near the western shore of the Lake indicating effects of local emissions from motor vehicles and other pollution sources. (P063)
- Nitrogen deposition in throughfall was low (1-2 kg/ha/yr) at megasites located to the north or west of the lake, but was moderately elevated (> 5 kg/ha/yr) at three sites located south or east of the lake. (P063)
- Nitrogen concentrations in lichen tissue were above the ‘clean-site threshold’ at five of the ten megasites, and throughfall N deposition at three sites was above the critical load at which epiphytic lichen communities become dominated by eutrophic species (P063).



AMMONIA (NH₃)

Ammonia is a concern since it is one of the basic chemicals that deliver biologically available nitrogen to Lake Tahoe. Investigations of N deposition and O₃ transport as part of the Lake Tahoe Atmospheric Deposition Study (Dolislager et al., 2012), observed that three-fourths of the deposited N directly to the lake surface is due to NH₃ with a smaller contribution from HNO₃. As with ozone, a significant amount of the ammonia in the basin comes from outside the basin (P063). Ammonia is a highly reactive (biologically) form of nitrogen and is likely to be one of the primary forms that stimulate algae growth.

KEY FINDINGS:

- The highest NH₃ concentrations were measured west of the Lake Tahoe Basin indicating the influence of mobile and stationary pollution sources in the Central Valley of California. However, local NH₃ emissions seem to contribute to enhanced concentrations of the pollutant on the southwestern side of the basin. (P063)
- The highest concentrations of reactive gaseous inorganic N were determined near the western shore of the Lake, indicating the effects of local emissions of NH₃ from vehicle emissions. (P063)

OZONE (O₃)

Ozone is a pollutant produced largely in metropolitan areas. Much of the ozone measured at Lake Tahoe sites results from the transport of polluted background air into the Tahoe Basin from upwind pollution source regions (e.g., Sacramento, San Joaquin Valley and possibly San Francisco Bay Area). (P075). Overall ozone concentrations in Tahoe are below federal air standards except for short periods at high elevations. Control of peak concentrations of ozone may be accomplished by limiting one of its in-basin precursors, volatile organic compounds (VOC). (P095)

KEY FINDINGS:

- The majority of O₃ precursors (VOC and NO_x) are emitted in the urbanized areas of the Central Valley and possibly the San Francisco Bay Area. (P075)
- Model simulations indicate the majority of secondary organic aerosol (SOA) precursors are emitted upwind of the Lake Tahoe Basin. Ozone is transported from aloft upwind as well, influencing ozone levels in-basin significantly. In-basin contribution to observed O₃ and SOA level is limited. (P075)
- In-basin NO_x concentrations are very low; therefore, in-basin O₃ control strategies may not be warranted or effective. (P075)
- High O₃ concentrations were found in the middle of Lake Tahoe, accompanied by high toluene/benzene and NO/NO₂ ratios, and high anthropogenic volatile organic compounds (VOC) concentrations (especially the higher molecular weight hydrocarbons n-decane and n-undecane).



These results may indicate the influence of local spark ignition and diesel engine emissions from large boats. (P063)

- Ozone transport from the southwest (i.e., from San Francisco, Sacramento and the Central Valley) into the basin may occur at higher elevation (i.e., 500mb). (P063)
- All monitored sites had similar O₃ concentrations in a range of 55-60 ppb during the daytime. At night, the low elevation sites showed much lower concentrations due to their proximity to major traffic routes and possible titration of O₃ by the NO emissions from local traffic. Concentrations were possibly also influenced by fires in local campgrounds. As site elevations increased, the nighttime O₃ concentrations also increased. The Angora Lookout and Genoa Summit 9000 sites show a small increase in average O₃ values during night time hours. (P063)
- The only sites where the daily maximum 8-hour concentrations exceeded 70 ppb were the remote sites with the shortest distance to 'busy' roads being greater than 4 km. Those exceedances were observed when the ozone passive 2-week averages values were greater than 50 ppb. (P063)
- Eight-hour O₃ concentrations >75 ppb (greater than the federal primary O₃ standard) only occurred on a few occasions at high elevation locations. (P063)
- A general conclusion from the sensitivity tests is that the main features of the ozone episode in the Tahoe area have to be considered within the regional pool of ozone and ozone pre-cursors and that the local effects might have a minor role. It appears that the efficient method in this urban area is not to reduce mobile emissions, but to reduce VOCs, while in the Lake Tahoe area, reductions in both mobile and biogenic emissions can lead to reductions of ozone concentration peaks. However, the reductions in ozone peaks were quite small for large reductions of the emissions. (P095)
- Control measures should focus on on-road emissions and biogenic sources as the major components impacting ozone concentrations in the Tahoe area. (P095)
- Reduction ozone precursors outside the basin should be focused on VOCs, while in the Tahoe area, reduction of both mobile (primary) and VOCs (secondary effect) should be considered. (P095)

AIRBORNE PARTICULATES

Airborne deposition of phosphorous (P) is estimated to constitute approximately 27% of the phosphorous delivered to Lake Tahoe and deposition of nitrogen is approximately 50% (Cliff & Cahill, 2000). Deposition of fine particles (<16 um) (FSP) is also important to lake clarity. Frequent wintertime street sweeping is effective in limiting phosphorous and fine particles from both waterborne and atmospheric sources. Domestic wood burning does not contribute much phosphorous, but is a source of PM_{2.5}. (P013)



KEY FINDINGS:

- Phosphorous (a nutrient that contributes to algal growth in the lake) airborne concentrations in re-suspended road dust were greatest in fine particles. Phosphorus did not appear to be associated with most of the road dust mass since 85% of roadside phosphorus was in PM_{2.5} size fraction compared to only 20% of the crustal species (P001).
- The major source of phosphorous is soils. Phosphorous was highly correlated with all soil species in PM₁₀. Chemical source profiles of wood burning contain below detection limit amounts of phosphorous, and the contribution from wood burning can therefore be disregarded (P013).
- The bulk of airborne emissions will deposit within a few kilometers of the road. (P001)
- Nearshore activities contributed significantly to ambient PM concentration. (P094)
- Wood burning is an important source of PM_{2.5} during the winter months. Residential wood combustion, with possible contributions from wildfires and controlled burns, are the major PM_{2.5} sources of pollution during the fall and winter months. Motor vehicle tailpipe emissions contributed only about 23-33% of PM_{2.5}. Secondary pollutants from outside the basin are minor contributors to PM_{2.5} and PM₁₀. (P013)
- Lake Tahoe Total Maximum Daily Load (TMDL) likely underestimates the PM mass deposition fluxes. (California and Nevada TMDL, 2010) Dry deposition accounts for only 13 - 24% of deposited particle number but 67 – 84% of particle mass. Accounting for all potential uncertainties, TMDL likely underestimates mass deposition fluxes and the impact of atmospheric deposition to sediment loading. The contribution of atmospheric deposition to lake clarity degradation may, therefore, be larger than anticipated. (P094)



Lake Tahoe's Air Quality
Winter ski traffic near Stateline

ROAD DUST

As was stated earlier, road dust is a major source of PM_{2.5} particles. However, due to the prevailing onshore winds, most dust is pushed away from the Lake during peak traffic hours. El Dorado and Douglas Counties are the exception and efforts to solely control dust could be focused there. Project 041 found that only about 2% of PM₁₀ road dust reaches the lake – a stark contrast to earlier estimates, and most of those particles come from roads close to the Lake. (P041) This research reset the airborne coarse standards since it concluded that atmospheric dry deposition to the lake is only about 6% of the total estimated in the Total Maximum Daily Load (TMDL) 2010 report.

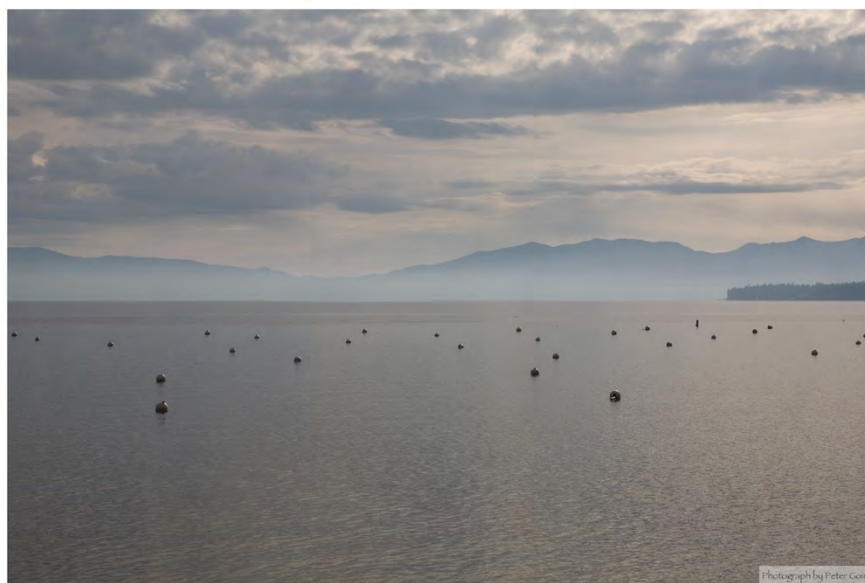
KEY FINDINGS:

- Re-suspended paved road dust is the major source of PM₁₀ in the basin. The most important sources to control are road dust, followed by wood smoke and mobile sources. (P013)
- Proximity to the lake, prevailing wind directions, and traffic patterns play a dominant role in determining which roads have the greatest potential to deposit fine sediment into the lake. (P041)
- Models showed that road dust in the PM_{coarse} size fraction, partly from de-icing procedures during winter months, is an important source to control. Road dust generated by traffic along the major highways such as Highways 50 and 28 can account for as much as 60% of PM₁₀, and has the potential of being deposited in Lake Tahoe. (P013)
- Coarse/large PM deposition is dominated by mineral dust, with minor contributions from sulfur, phosphorous, and organic particles. It was found that 74 – 87% of coarse and large particles > 4µm diameter resulting from atmospheric deposition are mineral dust. Sulfur-contained and



phosphorus-contained particles, though minor, were found suggesting an appreciable loading of pollutant and nutrient into the lake through atmospheric deposition. (P094)

- Wintertime street sweeping when roads are dry after storms (ASAP sweeping) was the strongest predictor of Emissions Equilibrium (EE, a traffic speed independent measure of road emission strength). Many secondary and tertiary roads are only swept seasonally and serve as a reservoir of material that is suspended into the air when abrasives are tracked onto higher speed roads. (P001)
- Although South Lake Tahoe (in El Dorado County, CA) already employs an aggressive street sweeping program, its high level of vehicle miles traveled (VMT) causes it to be a major source of atmospheric deposition of particles into the lake. (P041)
- Only roads close to the lake have a substantial impact on atmospheric deposition of coarse particles. Moreover, most areas around the lake benefit from onshore wind directions during peak traffic times (i.e. daylight hours) that effectively push emissions away from the lake. However, this is not the case in El Dorado County, California and Douglas County, Nevada, which are calculated to be responsible for 67% of the paved road dust deposited to the lake. More aggressive measures to reduce the reservoir of suspendable material on roads in these areas will be more cost-effective than applying a blanket policy to the entire road network. (P041)
- Emissions vary both by season and by location. Wintertime Total Suspended Particle (TSP) emissions are around 5 times greater than summertime TSP emissions due the application of traction control material to the roads during the winter. (P041)
- Only ~2% of road emissions of PM₁₀ (20 Mg/year) and ~1.5% of TSP (35 Mg/year) are estimated to reach the lake. The vast majority of PM_{large} emitted into the air is deposited within minutes, especially in the presence of dense vegetation. An analysis of vegetative density coverage was overlaid on the spatially resolved emission inventory so that each road segment could be assessed based on the type of vegetation on the shortest path to the lake. (P041)
- Results indicate that PM_{large} and PM_{coarse} are rapidly depleted near their source and thus the shoreline concentrations may only be representative of the first 1-to-3 kilometers offshore. The results support much lower estimates of dry deposition to the lake than calculated by the Lake Tahoe Atmospheric Deposition Study (LTADS). Estimates from paved road travel, indicate that the atmospheric dry deposition to the lake is approximately 6% of the total LTADS dry deposition. (P041)



Lake Tahoe's Air Quality
View of an inversion layer from Tahoe City, California

HAZE

Visibility is an important asset to the scenic Lake Tahoe Basin. Since 1990, long term visibility monitoring has been conducted at D.L. Bliss State Park and South Lake Tahoe. Haze monitoring stations in the Lake Tahoe Basin have shown that air clarity has improved steadily over the past 25 years, improving 26%. This probably reflects better control of motor vehicle emissions, residential wood burning controls, and less dust as a consequence of street sweeping. (P060) The current trend is for continuing improvements in the cleanest days, but a worsening of haze during the worst days as a result of the increasing frequency of large forest fires. (P061)

KEY FINDINGS:

- Light extinction coefficient (b_{ext}) is the most complete and practically quantified indicator of visibility metrics. It can be measured optically or from the chemical composition of particulate matter (PM). Chemical Extinction Coefficient (b_{ext}) has shown a decreasing trend between 1981 and 2004 with median values dropping 26% at D.L. Bliss State Park and 32% at South Lake Tahoe. Decreasing ammonium nitrate (NH_4NO_3), organic carbon (OC), elemental carbon (EC), and coarse-mode particulate matter (PM_{coarse}) concentrations from reductions in motor vehicle exhaust, residential wood combustion, and road dust emissions, have resulted in this improvement. (P060)
- The 90th percentile b_{ext} , which represents regional visibility on the haziest days, shows a slightly positive trend since 1990 and appears to increase in recent years (2001–2009). Extremely high b_{ext}



often resulted from large wildfires, of which frequency and intensity are expected to increase over time owing to climate change. (P060)

- Current Lake Tahoe visibility standards are too low and do not address the national haze rule. The TRPA standards more reflect visibility conditions in 1980-1990. The Clean Air Visibility Rule selected 2000-2004 as the baseline period and requires reasonable progress goals to be established for the most impaired days (worst 20%) and no degradation in visibility to occur for the least impaired days (best 20%). (P060).
- Visibility is uniform across the Tahoe basin; PM pollutants are confined within small urban neighborhoods. Wildfires and prescribed burns could cause short-term extreme and inhomogeneous aerosol concentration, visibility across the basin depending on burn location, fuel condition, and meteorology. (P060).
- Light scattering and absorption by aerosols are the largest contributions to visibility limitations at all but the cleanest locations where light scattering by clean air (Rayleigh scattering) can be equally or more significant. (P061)
- Three-fourths of the increased light extinction at South Lake Tahoe compared to D.L.Bliss State Park was due to much higher organic and elemental carbon aerosol at South Lake Tahoe, especially in winter. (P061)
- Comparison of 20% best and worst visibility days at D.L.Bliss State Park for the regional haze rule during the baseline period of 2000-2004 and 2005-2009 showed the cleanest days getting cleaner and the haziest days getting hazier, mainly due to increased organic and elemental carbon. (P061)

PRESCRIBED FIRE

Prescribed fire to reduce the threat from wildfire has been controversial in the Lake Tahoe basin for a very long time. It is used to dispose of excess woody material either as a thinning treatment by itself in overly dense forest stands or as a disposal method for stands mechanically thinned. The premise of this process is that routine use of prescribed fire produces fewer harmful emissions than wildfires and is more representative of natural air quality, which typically had small fires burning throughout the summer at a rate of about 25 acres per day, every day from May through October (Cliff & Cahill, 2000). Current research has focused on fuel moisture and fuel types, and on air quality differences during burn events. Results have shown that summer burning has the most favorable atmospheric conditions, winter the worst; burning dry piles produces less smoke than wet piles or broadcast burns, and, wood stoves are even cleaner (P062), although wood stoves used during winter months do produce a significant amount of haze and particulate matter.



Lake Tahoe's Air Quality

Fire crews managing a controlled burn near Incline Village, Nevada

KEY FINDINGS:

- Biomass burning is a significant emission source of PM_{2.5}. Chemical composition of the PM_{2.5} emissions typically include elemental carbon, organic carbon, polar organic compounds, water-soluble potassium (K⁺), and particle-bound mercury. Data showed higher ratios of organic to elemental carbon in green fuels (19.2 ± 4.2) compared to dry, wooden logs (7.3 ± 1.9) both in prescribed burns in the field and in controlled stove combustion, indicating that more moisture in green biomass resulted in more smoldering-phase combustion. (P062)
- Organic/elemental carbon ratios were lower in wood stove burns compared to prescribed burns in the field, which was attributed to higher combustion temperatures in wood stove burns. (P062)
- Laboratory tests and emission models underestimate prescribed burn emissions and combustion efficiencies. Understory burns show higher emission factors than slash pile burns, implying larger environmental effects. (P076)
- Except for occasional misforecasts, smoke from the ignition and first several hours of prescribed burning usually rises and moves away from the population centers as expected. However, smoldering combustion can continue long after the active ignition period. Model prediction indicate that the smoldering smoke often impacts communities due to changes in wind direction. The impact often shows up in the evening under a shallow surface layer. This



could happen for prescribed burns in any part of the basin. Individual prescribed burn impacts are inhomogeneous and of short duration compared with wildfires. (P076)

- New tools for use in forecasting and making burn day decisions prescribed burns were produced including, 1) 300m gridded climatology of surface wind; 2) 4km mixing height climatology with associated transport wind; 3) 400m resolution gridded operational forecasts of surface wind; 4) new weather station observations; 5) customized smoke prediction website tool. (P065)



2. CLIMATE CHANGE

BASIC CLIMATE CHANGE PREDICTIONS

The global climate is undergoing relatively short-term but significant changes in response to anthropogenic emissions of greenhouse gases (GHG). This is resulting in warmer temperatures, changes in precipitation, increased frequency and intensity of extreme storms, and many other effects. Several decades of warming and a variety of hydrologic and landscape responses have already occurred and are expected to accelerate in the absence of significant measures to mitigate GHG emissions, globally (U.S. Global Change Program, <http://www.globalchange.gov/climate-change>).

Over the last several decades Lake Tahoe Basin has encountered warmer temperatures, changes in winter precipitation (more rain/less snow), extended droughts, and extreme winter storms. These and other related meteorological factors are impacting forest health, wildfire risks, invasive species survivability, habitat integrity, air quality, lake levels, and nearshore conditions. Historically, the percentage of precipitation that falls as snow ranges between 50%-60% for elevations in the Tahoe basin where most development has occurred (predominantly around the lake shore at elevations ranging from 6,230 feet to 6,600 feet). At the end of the 21st century, one model predicts that the percentage of precipitation that falls as snow will decline to an annual range of 30%-40% or even less for developed areas in the Tahoe basin (Coats, et. al., 2010). Climate change also affects forests by altering the physiological responses of trees and generates subsequent changes in forest composition and succession.

Decreases in snowfall and increases in heavy winter rains may reduce lake clarity, disrupt transportation, energy, communication and other critical infrastructures, overwhelm stream and wetland restoration projects, and negatively impact the tourism economy (Albano et. al., 2014). Scientists and managers in the Tahoe Basin are also very concerned about the impacts that changes in climate may have on the physical properties and ecological conditions of the lake itself. Warming air and water temperatures are likely to



alter the processes in which water circulates and mixes in the lake; these changes may result in a loss of dissolved oxygen at the bottom of the lake, which may in turn lead increased nutrient levels in the lake. (UC-Davis, 2014 State of the Lake Report). Additional areas for research are presented in a research strategy for climate research in Tahoe developed for the TSC, entitled Climate Change Research Strategy for Atmospheric Processes Impacting Lake Tahoe (Kunkel, 2014).

KEY FINDINGS:

- Climate change impacts to the Lake Tahoe Basin will likely be dictated by more than just temperature and precipitation. Other variables that may or may not be directly attributable to climate change such as wind speed, dew point, humidity, air pollutant transport, and extreme storm frequency and intensity are likely to compound the impacts to aquatic, terrestrial and atmospheric environments in the Tahoe basin. (Dettinger, 2013)
- Climate change models indicated a shift in the distribution of snowfall towards rainfall. A modeled time series for snowpack under the one emission scenario showed a 55-60 percent reduction in snowpack during the last part of the century (2067-2099) relative to that seen in the period 1967-1999. (P030)
- Beginning and end dates for the snowpack period in the Lake Tahoe Basin are predicted to change significantly by the end of the century. During the period 2067-2099, under one emissions scenario, the models indicate that the start of the snowpack could be three weeks later than the 1967-1999 historic baseline; peak snowpack could occur two weeks earlier; and the end of the snowpack could be five weeks earlier, resulting in up to a 25% reduction in snowpack duration. (P030)
- Annual Secchi depth measures of lake clarity in the later portion of the 21st Century could be in the range of 15-20 m as compared measured values of 21-22 m since 2000. (P030)
- Climate change may increase the inter-annual duration of droughts, which may result in prolonged periods of the lake surface level being below the natural rim. (P030)
- By the middle of the 21st Century (after about 2050) Lake Tahoe could cease to mix to the bottom. This may in turn result in complete oxygen depletion in the deep waters, significantly affecting the deep lake ecosystem, and an increase in sediment release of nitrogen and phosphorus. (P030)
- Annual loading of soluble reactive phosphorus under sustained conditions of lake stratification (no deep mixing) and anoxic sediments could be twice the current load from all other sources. Loading of ammonium under these conditions could increase the amount of biological available nitrogen that enters the lake by 25 percent. This effect on the Lake Tahoe's nutrient budgets could have a dramatic and long-lasting impact on the food web and trophic status of the lake. (P030)
- Species-specific growth sensitivity to shifting climate and the resultant forest carbon stock



changes vary considerably as a function of the climate projections for a given emission scenario. The large influence of global climate models on carbon storage suggests that reducing uncertainty in modeling forest growth response to wildfire mitigation treatments will require further refinement of climate projections. (P029)

- While a great deal of uncertainty remains in forecasting the magnitude and even direction of climate change for the Lake Tahoe Basin, models suggest that if drying and warming occurs, an increase in the suitability of conditions to support cheatgrass will follow. As temperatures warm and cheatgrass suitability rises (if and where it does), the threat of enhanced fire activity will also increase. (P028)

MANAGEMENT IMPLICATIONS

Integrating both climate variability and climate extremes into ecological management plans and programs has been a challenge for Lake Tahoe Basin managers. Model uncertainties (temporally and spatially), multi-decade timeframes in global climate models, and interactions of natural climate variability and anthropogenic global warming presents challenges to environmental managers who need to make timely decisions about ecological and community well-being. The following SNPLMA science projects focused on understanding the potential impacts of climate change; however, additional work is needed to provide managers with more actionable information about climate impacts in the Tahoe Basin.

KEY FINDINGS: VEGETATION

- Effects from future climatic changes in the Tahoe Basin included reduced establishment ability of the subalpine and upper montane tree species; stimulated growth of particular conifers, aspen and re-sprouting shrub species; and potential increases in size and severity of wildfire activity. (P049)
- Changes in the wildfire regime had the strongest impact on forest response. An increase in wildfire activity (area burned) in a changing climate caused higher mortality rates across the Lake Tahoe Basin and lower carbon sequestration potential by year 2110. Increased wildfire activity was caused by a reduction in fine fuel moisture across a longer growing season. (P049)
- The potential for continued forest growth and sequestration of above and below ground carbon across the Lake Tahoe Basin remains, despite any potential shifts in climate into the coming decades. The forest is essentially a carbon sink, regardless of changes in climate, with higher growth rates than emissions from ecosystem respiration and wildfires. As the forest matures, climate effects – both direct (e.g., loss of establishment, enhanced growth) and indirect (e.g., increased area burned) – may become more evident especially if climate follows the more extreme predictions. The high rate of growth suggests that the legacy effects of intense clear cut logging during the Comstock Era and fire suppression will continue into the next century or longer, despite the potential effects of climate change. (P049)
- Seedlings and saplings present in forest communities in the Lake Tahoe Basin have successfully transitioned through critical stages (i.e., seed and germinant) and are influenced by multiple



factors and complex interactions, at both local and regional scales. Local biological and environmental conditions as well as regional climatic conditions influence white pine recruitment in the mountains of the Sierra Nevada, but the strength and importance varies by species across elevational forest types. (P009)

- There may be some capacity to leverage fuel treatments to improve adaptive capacity for forest carbon sequestration. Changes in species-specific carbon stocks varied by global climate model and emission scenario and trade-offs between species caused a smaller reduction in stand-scale forest carbon stocks than would have occurred had all species been similarly impacted. Relative to baseline, all treatments had increased live tree carbon with the largest mean gains made by the burn-only (14.5%) and thin and burn (16.9%). (P029)
- Results suggest that stand dynamics following treatment are sensitive to projected climate. A changing climate may alter how effectively different species can capture additional resources released by density reduction treatments, however, improving projections of the effect size of treatment under changing climate will require additional data from forest stands with a range of densities that have experienced climate variability over an extended period. (P029)
- Variability in downscaled global climate projections adds considerable uncertainty to projecting how management actions to alter forest structure and composition and climate will interact in the future. Additional investigation into the effects of climate on regeneration and mortality is needed. Results indicate that under some projected climate scenarios the results of the simulated management actions suggest little or no interaction between climate and management. Understanding interactions among climate, wildfire frequency, and forest growth deserves further research. (P029)
- Species specific mean live tree carbon stocks varied as a function of global climate model and emission scenario projection. White fir and ponderosa pine are the dominant species on the west and east sides of the Basin, respectively, and had the largest changes in live tree carbon stocks of the five species modeled. Mid-century, both white fir and ponderosa pine had declines in live tree carbon, relative to the baseline. (P029)
- Predicted climate change will create stresses on both terrestrial and aquatic ecosystems in the Basin, and pose serious challenges to resource managers, especially in the latter half of this century. These challenges include increased risk of wildfire, increased tree mortality from insects and disease, increased erosion and sediment yield, and adverse impacts to and losses of aquatic habitat. (030)
- There is significant segregating genetic diversity for western white pine within the 1,300 km² of the Lake Tahoe Basin. For western white pine this segregating genetic diversity appears to have been structured by natural selection in the past; hence, if change continues to occur in the environmental variables that were important selective forces in the past, it is reasonable to



hypothesize that these traits will continue to be important components of biotic responses to ongoing and future changes. (P044)

KEY FINDINGS: WILDFIRE REGIMES

- An increase in wildfire activity (area burned) in a changing climate will result from tree stress and higher mortality rates across the Lake Tahoe Basin. A consequence of this trend will also be lower carbon sequestration potential by year 2110. (P049)
- In a changing climate, increased wildfire activity was caused by a reduction in fine fuel moisture across a longer fire season. (P049)
- Wildfire activity was further enhanced under future-climate scenarios, especially towards the end of the 21st century, by projected increases in natural and anthropogenic ignition sources. (P049)
- Continuous fuel treatments reduced area burned and fire severity across the Tahoe Basin regardless of climate or fuel treatment scenario applied. Projected increases in ignitions under one climate scenario dramatically reduced the ability of the forest to sequester carbon, but continuous fuel treatments moderated the reduction. (P049)
- Continuous fuel treatments strongly suppressed target species (e.g., white fir and incense cedar) in managed areas and improved the regeneration environment for more shade-sensitive species (e.g., Jeffrey pine, sugar pine). (P049)
- Properly balancing the spatial arrangement of management activities in order to achieve multiple objectives on the landscape (e.g., Daugherty and Fried 2007, Rhodes and Baker 2008, Schmidt et al. 2008) requires more information about the inherent trade-offs among these objectives and improved awareness of the opportunities for optimizing management at the landscape scale (Scheller et al. Biol. Cons. in review). (P049)
- Although fuels treatments may reduce carbon storage in the short term, the benefits of reduced fire risk and improved forest species balance provide compelling evidence that fuels treatments will likely remain an important and perhaps critical component of forest management in the coming decades. (P049)

KEY FINDINGS: LAKE QUALITY

- Sediment and nutrient loading to Lake Tahoe may not change significantly as a direct result of climate change, but may be impacted by increased extreme winter storms resulting from natural climate variations compounded by global warming. (P030)
- Models using selected climate scenarios, show a downward trend in the timing and amount of annual runoff in the Upper Truckee River (UTR) by the end of the century. The shift toward earlier timing of the hydrograph centroid reflects both earlier spring snowmelt and the shift in



precipitation from snow to rain. A downward trend in UTR 5-day low flows may cause serious biological disruptions because the UTR (like many of the Basin streams) flows through coarse alluvium in its downstream reaches, and in very dry years, there is no surface flow. (P030)

- Data collected from Lake Tahoe has shown that since 1968, the lake mixes (circulates) completely to the bottom (~500 meters) on the average of once every four years. Using output from one climate emissions scenario the Lake Clarity Model suggests that by the middle of the 21st Century (after about 2050) Lake Tahoe will cease to mix to the bottom, with a typical mixing depth of only about 100m. As the surface water heats, the resulting density difference between the warmer surface water and the colder deeper water will be too strong for the wind energy to overcome. This change in density has already been observed in the historic data. (P030)
- When the lake fails to completely mix, the bottom waters are not replenished with oxygen and eventually dissolved oxygen at these depths will fall to zero. When this occurs both soluble reactive phosphorus and ammonium-nitrogen (both are readily available for algal growth) are released from the deep sediments resulting in an increase in nutrient loading from sources not observed, to date, in Lake Tahoe. By around 2075 the model indicates that dissolved oxygen levels below 200 m fall to a sustained level of zero year round. At the same depths, dissolved oxygen concentrations could drop to levels inhospitable to salmonids (below 6 mg/L) even earlier. The model also suggests that intermittent periods of anoxia in the deepest waters may occur within the next 20 years. (P030)
- The resulting annual Secchi depth in the later portion of the 21st Century will be in the range of 15-20 m as compared measured values of 21-22 m since 2000. If nutrients released from the bottom sediments periodically mix or otherwise become entrained into the upper waters the impact on algal growth below the Secchi depth could be significant, with an attendant impact of lake food web dynamics and trophic status. (P030)

KEY FINDINGS: GROUNDWATER AND WETLANDS

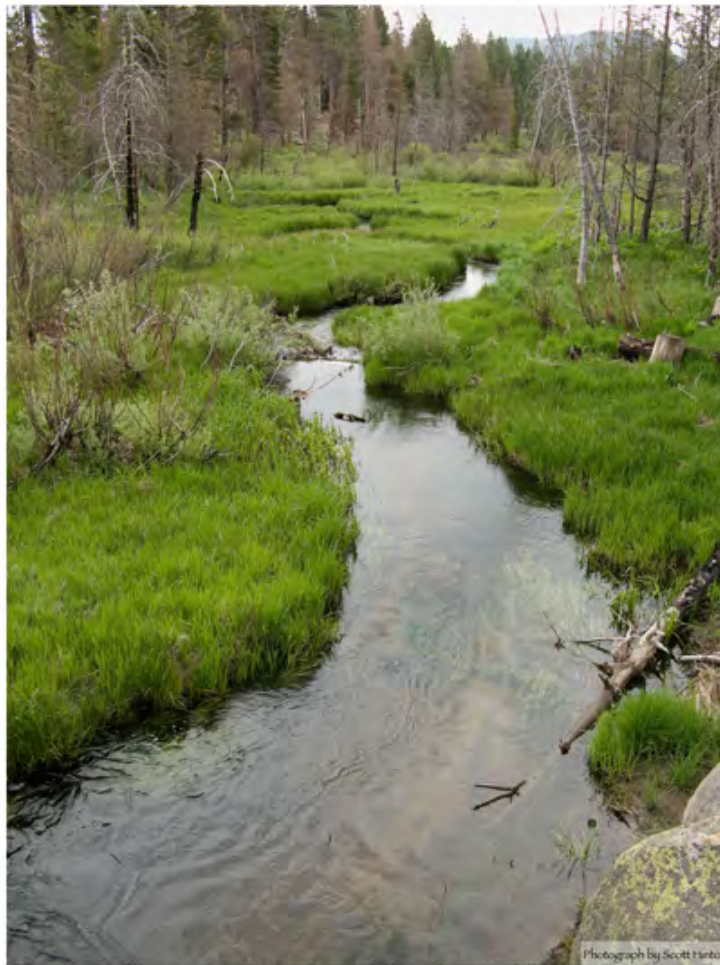
- The largest peatland in the Sierra Nevada is Grass Lake (96 ha), located on Luther Pass, south of Lake Tahoe, California. Peatlands are wetlands with thick organic soils that have formed in place. The formation of these organic soils requires perennial saturation to prevent decomposition of the organic material. High evapotranspiration rates and low summer precipitation in the Sierra Nevada Mountains suggest that most, if not all, montane peatlands in the Sierra Nevada are sustained by substantial groundwater input. The largest threat to peatlands is aerobic decomposition of organic material due to desaturation and exposure to oxygen. A decrease in late-season groundwater flow due to earlier snow melt may result in increased decomposition of the peat. One study suggests a rain dominated precipitation regime due to climate change may lead to desaturation of the Grass Lake peatland. (P045)



- The predicted increase in temperature is expected to further increase the rate of peat decomposition (Ise, Dunn, Wofsy, & Moorcroft, 2008). The center of the peatland maintains saturation levels above 80% of total saturation in all simulations, suggesting this area is least susceptible to aerobic decomposition and may contain the longest history of peat accumulation despite changes in the precipitation regime. (P045)

KEY FINDINGS: INVASIVE SPECIES AND PESTS

- There are large areas within the Lake Tahoe Basin that are climatically suitable for cheatgrass (*Bromus tectorum*), but do not yet contain the species. This notorious, invasive annual grass has been a major driver of ecosystem change in the intermountain west due to its tendency to dramatically increase the frequency of early season fires via the highly flammable nature of its early-drying herbage. Global climate based models suggest that if drying or warming occurs, the Lake Tahoe Basin may be more susceptible to cheatgrass invasions, and in turn, more wildfires. (P028)
- Climate forecasts suggest climatic suitability for cheatgrass will continue to be high for the Lake Tahoe Basin for at least the next 20-60 years. Most notably, low precipitation areas (south and east shores) are consistently suitable across time and models. This suggests that invasion will proceed most quickly and uninterrupted in these areas, providing source populations for new invasion elsewhere in basin in the foreseeable future. To mitigate the potential impacts of increased cheatgrass presence in the Tahoe Basin, it is imperative to carry out a baseline inventory of potential invasion sites and to monitor cheatgrass invasions. Burned areas should also be monitored for cheatgrass presence. Quick action should be taken if cheatgrass establishment is documented. (P028)
- Under a range of climate scenarios, potential bark beetle outbreaks and wildfire activity did not overlap significantly due in large part due to wildfires generally occurring near the wildland-urban interface, and bark beetle outbreaks occurring in more remote and high elevation areas. If the beetle infestations are sustained at lower elevations then a significant increase wildfire risk and impacts would be expected. (P086)
- The effects of bark beetles and fuel treatments had compensatory effects on species interactions, where, e.g., fire tolerant or less targeted species (by beetles or management) regenerated in areas affected by these disturbances. Under high climate emission scenarios, this compensatory capacity was reduced in the latter half of the century, when effects from bark beetles were severe and forest recovery lagged behind outbreak frequency and intensity. (P086)
- Forest treatments used in the basin, primarily mechanical thinning with some prescribed fire, are intended to reduce fire risk but may also have the potential to reduce drought stress and potential beetle-related mortality. This may be particularly important in a changing climate, where higher temperatures may exacerbate these conditions (Coats et al. 2010, Loudermilk et al. 2013). (P086)



Streams and Meadows Lake Tahoe

View down stream of Angora Creek Restoration

4. HABITAT IMPROVEMENT

The Lake Tahoe Basin contains a diverse array of habitats and associated biodiversity. The high elevation, oligotrophic lake, surrounded by steep montane gradients of over 1,200 meters (4,000 feet) with a variety of forest types, provides an interesting and assorted set of habitat types. A number of species and ecological communities of special concern are included among these found in the basin. Some of these species and communities are at risk because of their rarity and/or vulnerability to alteration by natural and human forces.

The overall understanding of nearly all aspects of Lake Tahoe's habitats and biodiversity—from species found in lakeside meadows, to those on alpine peaks above—is still rudimentary (Manley et al. 2010). Scientific research can help us better manage and conserve these special communities and species. Conservation of the native habitats and species of this area is one primary theme for continued scientific discovery. However, perhaps one of the more crucial information needs revolves around understanding how invasive species have established and proliferated in a number of the sensitive habitats within the basin. Numerous invasive species (both terrestrial and aquatic) now have established populations in the Lake



Tahoe Basin, and the threat of additional introductions persists. The effects of aquatic invasive species are most pronounced in the nearshore habitats of Lake Tahoe, while recently disturbed forest and urban areas are most susceptible to the invasion of terrestrial species.

Many years of work to address habitat improvements in the basin under the Lake Tahoe Environmental Improvement Program (EIP) have included efforts to restore watersheds, habitat, and water quality (improved more than 13,927 acres for wildlife habitat, restored 739 acres of wetlands, and revegetated or removed 55 miles of dirt road in forests). However, much more is needed. Particular species of concern include:

- Tahoe yellow cress (*Rorippa subumbellata*)
- Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*)
- Aspen (*Populus tremuloides*)
- American marten (*Martes americana*)
- Sugar pine (*Pinus lambertiana*)
- Western white pine (*Pinus monticola*)
- Whitebark pine (*Pinus albicaulis*)

More work is needed, and land and resource management agencies intend to address a number of such needs in time. Research is essential in helping to better understand the special management needs of species and ecological communities that are particularly rare or vulnerable in the Tahoe Basin.

SNPMLA research was focused on improving our understanding of the status, requirements, and sensitivities of ecological communities and species of special interest to inform their management and conservation. There have been 11 research projects funded by SNPLMA which focused on habitat improvement in some way over the past eight years. In summarizing research findings on improvement of habitat and conservation of species, inevitably some of the relevant work ends up being reported in other topic areas, particularly in the “Forest Fuels and Vegetation Management” section where we address conservation and restoration of sugar pines in particular. Please see those sections for more information.

The research done on habitat improvement addressed a limited range of critical questions that have a bearing on how we can improve conditions for certain species and habitats that we are trying to conserve. We have identified three categories of this research and the contributions of the scientific findings to future management actions:

- Habitat improvement efforts
- Species conservation efforts
- Management of invasive species



HABITAT IMPROVEMENT

Some of the most biodiverse and important habitats within the basin are the riparian habitats that are found along stream corridors. Such habitats tend to support much higher biomass per unit area and more diverse assemblages of biota, however, these narrow bands of habitat are inextricably joined with upland conifer forests and thus part of the matrix subject to periodic fire. There has been extensive research done to understand response of upland conifer forests to fire but there is very little information on how riparian forests in the basin or the entire Sierra respond to periodic fire.

Project 007

Van de Water and North (P007) conducted research in the Tahoe Basin to determine whether adjacent coniferous riparian and upland forests burned historically with different frequencies and seasonalities, and whether these relationships varied by forest type, site, and stream characteristics.

KEY FINDINGS:

- Coniferous riparian forests in the northern Sierra Nevada historically had forest structure, composition, fuel loads, and fire behavior similar to adjacent uplands.
- Both riparian and upland stands currently appear to be more fire prone than their historic conditions, with riparian areas significantly more so than adjacent upland areas.
- Coniferous riparian forests in the Sierra Nevada historically experienced frequent fire, often at intervals not significantly different from the adjacent upland forests.
- This relationship does vary as a function of forest, site, stream and climate conditions.
- Riparian areas surrounded by forests with a high proportion of fire-tolerant pine species, especially those east of the Sierra crest, likely experienced more frequent fire, and could be treated similarly to upland areas.
- Riparian areas in other forest types or at higher elevation typically experienced longer fire return intervals could be treated less intensively than the adjacent upland areas.
- Riparian forests could be considered a high priority for restoration and fuel reduction treatments, with objectives similar to adjacent upland forests.

Project 059

Fens are another sensitive and rare habitat type found in the Basin. Fens are a rare, peat-forming wetland type that receives nutrients usually from upslope sources through drainage from surrounding mineral soils and from groundwater movement. Sikes et al. (P059) conducted research intended to provide detailed survey information to identify new rare plant locations that add to the knowledge base of sensitive species in the Basin. This project also endeavored to classify these fen sites for their vegetation type diversity and presence of rare species, and rank them for their ecological integrity and quality. Land managers can use this information to employ a ranking system to recognize high priority fen sites for maintenance and restoration.



KEY FINDINGS:

- 15 detailed fen site maps were produced, showing a diversity of vegetation types from woody to herbaceous types in fens.
- 49 confirmed fen sites in the Lake Tahoe Basin were ranked based upon eight Conservation Significance criteria, including inherent diversity considerations and management related criteria.
- The most highly rated fens for Conservation Significance are Grass Lake East and Dave Immeker Fen, with several other fens of the South Basin Region being more highly rated than those in any other Fen Region.
- The three subwatersheds (HU-12) of the Truckee River Watershed had the three highest average Conservation Ranks, in addition to being the subwatersheds with the most fens currently recorded.
- The average Conservation Significance rating for fens of the Angora Creek Subwatershed was the highest at 25.0 (based on 10 fens).
- The combined Conservation Significance ranks can assist land managers in making restoration and other management decisions

Project 090

Deepwater ecosystems in Lake Tahoe are unique and poorly understood. These systems include special status aquatic plant (stoneworts, liverworts, and mosses) and invertebrate (Tahoe stonefly and blind amphipod) communities in deepwater “hotspot” areas of Lake Tahoe. Their unique habitat type is formed and characterized by depth, subsurface irradiance, substrate type, and availability of organic matter in sediments. Research by Chandra et al. (P090) was conducted to 1) increase our understanding of the biology and ecology of deepwater special status plant and invertebrate communities, 2) determine mechanisms (e.g. decreased water clarity and the introduction of non-native species) that have contributed to declines in these communities over the past 40+ years, and 3) to create a restoration and monitoring plan based on determined mechanisms. This project is to be completed.

SPECIES CONSERVATION

A number of species found in the basin receive particular attention because of a given species is thought to be declining, rare, or for other conservation reasons. Land and resource managers require reliable information on why these species are at risk, what their limiting factors are, and specific information on what is suitable habitat, to name a few key information needs. Some specific research projects were selected and completed to address certain information needs identified by resource managers.

Project 022

The Pacific marten is a rare forest carnivore that is found at the higher elevations of the mountains throughout the western United States. Slauson and Zielinski (P022) have completed research at Lake Tahoe to address one particular concern; do ski resorts have a net negative, neutral, or positive effect on Pacific marten populations in the Lake Tahoe region. Specifically, they gathered information necessary to evaluate



the influence of ski resorts on: a) loss and fragmentation of forest habitat, b) marten movement, c) marten seasonal occupancy and space use, and other population considerations.

KEY FINDINGS:

- The overall results of this study suggest that winter ski recreation at developed ski areas may be compatible with the maintenance of marten populations in the Lake Tahoe region of the Sierra Nevada.
- However, ski area development and winter ski recreation activities do have negative, sex-specific effects on martens. Results suggest that marten conservation within ski areas will be best achieved by considering the following suggestions:
 - Maintain reproductive habitat and its use by adult female martens through specific actions that can maintain important habitat features needed by female marten.
 - Maintain or enhance habitat connectivity within ski operations areas.
 - Maintain or enhance the proportion of ski run crossings < 20m between non-reproductive habitat patches that are >10 ha and the operations areas boundary. Where smaller patches function as potential 'stepping-stones' between patches >10 ha and/or the operations boundary, maintain or enhance the proportions of ski run crossings that are < 20m.
 - Evaluate ski area expansion using a variety of spatial criteria for habitat and connectivity that are sex specific (as described above).
- The scope of inference of this study are limited to ski area development that involves the creation of ski run, road, and development infrastructure with very limited modification to remnant forest habitat within operations areas. Modifications such as thinning of trees to increase space for skiing or removal of logs and rocks to improve surface consistency in remnant forest patches were not included in the ski study areas used in this study. These activities are known to be used elsewhere for ski area development and likely represent additional degradation of habitat suitability.

Project 050

Land managers strive to maintain suitable habitat for the full array of species that are found in the Lake Tahoe Basin. Manley et al. (P050) conducted research using existing empirical field data that were collected in a systematic manner in the Lake Tahoe Basin to develop species distribution maps and habitat occupancy models for forest associated vertebrate species in the Lake Tahoe Basin. These model results help with evaluation of potential management treatments, impacts of climate change, and other change agents that affect forest structure and composition today and in the future.



KEY FINDINGS:

- Abiotic variables (e.g. elevation) within the basin have perhaps a greater influence on species distribution than variability in forest structure.
- Habitat variables do influence species distribution; percent canopy cover significantly influenced the occurrence probability of 35 species, diameter at breast height (DBH) for 12 species, percent shrub cover for 22 species, and percent herbaceous cover for 19 species.
- A consistent effect of development and the importance of heterogeneous habitat for maintaining species diversity were found.
- The density of snags was associated with significant changes in the probability of occurrence for three (soft snags) and one (hard snags) bird species.
- 16 species of small mammals were detected during 525 days of trapping at 175 sites. However, four small mammal species, considered very rare, (montane vole *Microtus montanus*, brush mouse *Peromyscus boylii*, western gray squirrel *Sciurus griseus*, and western jumping mouse *Zapus princeps*), were observed at fewer than 10 sites (see Table 5 in the final report), and thus these species were eliminated from some analyses because derived estimates could be misleading.
- The results of these models can be used by managers in the Lake Tahoe Basin to better understand how variation in different abiotic and biotic variables can influence the suite of species that currently occur in the area.
- Management actions that are driven by one or a few focal species are not likely to maintain biodiversity if they result in decreased variability in habitat conditions. An integrated approach that emphasizes conserving a diversity of habitats across environmental gradients and minimizing the extent of urbanization impacts is likely to more effectively conserve and restore biodiversity and enhance ecosystem functioning than a single-species focus.
- The use of multi-species approaches to inform land management can also enhance biodiversity conservation by identifying habitat conditions that support unique suites of species. Management approaches that consider the extent and distribution of habitat conditions across landscapes have the greatest likelihood of conserving and restoring biodiversity and ecosystem functions.
- The results of this study's model indicate that practices and management approaches that lead to increased homogenization of the forest will have negative impacts on diversity. Management approaches, such as fuel reduction treatments, or the use of prescribed or managed wildland fire, may be designed to restore at least some of the variability within and among stands that existed during an active fire regime, thereby enhancing habitat conditions for conserving biodiversity.

Project 053

Woodpeckers are one of the keystone species in conifer habitats as a primary cavity excavator. This activity creates nesting and resting habitat not just for primary cavity nesters but for many other bird and mammal



species. Research by Manley and Tarbill (P053) examined how woodpeckers utilize burned areas as they provide this keystone function by creating habitat for other organisms.

KEY FINDINGS:

- Woodpeckers play an important role in post-fire habitats by rapidly colonizing burned areas and creating cavities that are used by many other species that rely upon them for nesting, denning, roosting, and resting.
- All woodpecker species were more likely to have nests in more highly scorched trees, underscoring the importance of fire in creating habitat for these species.
- The Black-backed Woodpecker was a significant contributor to the establishment of bird and small mammal species and communities in areas with high burn intensities, and it appeared to have a more narrow range of suitable habitat conditions for nest site selection compared to the Hairy Woodpecker.
- Post-fire harvest prescriptions in the Angora fire footprint prescribed the removal of all small snags and retention of approximately 5-10 large snags per hectare for wildlife use (Angora Fire Restoration Project, Environmental Assessment, 2010). The removal of most or all small snags within a burned area is likely to render the site unsuitable for Black-backed Woodpecker nesting.
- Management plans with multiple objectives of maintaining species diversity while promoting fire safety may benefit from integrating strategies to maintain a diversity of woodpecker species in burned forests. White-headed Woodpeckers in burned forests will require decayed large diameter snags in open areas. Black-backed and Hairy Woodpeckers will require areas with high densities of small to medium sized snags, especially in highly scorched areas. This management goal may be achieved by leaving large patches of high-density small snags and harvesting other areas while leaving larger diameter snags.
- The results from this research indicate that management plans that incorporate habitat for multiple woodpecker species would maintain the greatest biodiversity. This management goal may be achieved by leaving large patches of high-density small snags away from urbanized areas and some larger diameter snags in open areas where they pose fewer fire risks.

Project 092

There are some species in the Basin that are either formally listed as threatened or endangered or being formally considered for addition to the list. The Sierra Nevada mountain yellow-legged frog (*Rana sierrae*) was listed by the Fish and Wildlife Service as an endangered species in 2014. Research by Knapp and Vredenburg (P092) addressed whether the success of mountain yellow-legged frog reintroduction efforts can be increased by augmenting the microbial communities living on the skin of translocated frogs with probiotic bacteria that are known to suppress the growth of the highly infectious and lethal chytrid fungus, *Batrachochytrium dendrobatidis* (Bd), which is known to be significant threat to this species. Research results are not yet reported.



Another federally listed species in the Basin is the Tahoe yellow cress (*Rorippa subumbellata*). Tahoe yellow cress (TYC) will always be a rare plant because it occurs only on the shores of Lake Tahoe. The degree of endangerment to the species in this high profile habitat depends on a host of factors, many of which can be managed on some level. Since the adoption of the Tahoe yellow cress Conservation Strategy (CS) in 2002, the Adaptive Management Working Group (AMWG) has worked together to address threats to Tahoe yellow cress and coordinate efforts to manage and protect the species. A central emphasis has been the implementation of a field-based research program conducted between 2003 and 2010 testing the role of genetic, hydrologic, and logistical factors in population restoration using container-grown Tahoe yellow cress plants. This work addressed 1) conduct a synthesis and meta-analysis of this existing dataset (2003-2010); and 2) incorporate resulting protocols for outplanting and translocation into a series of new management tools in the CS for restoration and mitigation, using data from 1979-2011 to 3) update the conceptual model of TYC population dynamics; 4) evaluate and update indicators in the CS, and 5) develop a geo-database for data management and analysis. Final results have not yet been reported.

INVASIVE SPECIES

Invasive species, particularly in the near-shore environment, have become one of the most challenging problems in the effort to preserve the natural resources of Lake Tahoe. Substantial changes to the Lake Tahoe Region's ecology, economy, pristine water quality, aesthetic value, and recreational pursuits are occurring, in part (and growing) due to the harmful impacts of non-native aquatic plants, fish, invertebrates, and other invaders. These non-native aquatic organisms are considered 'invasive' (or aquatic invasive species [AIS] in water) when they threaten the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent upon such waters

Among the most threatening species, the invasive freshwater bivalve *Corbicula fluminea* (Asian clam) is currently established in parts of Lake Tahoe. Since its initial introduction in Washington State along the Columbia River in the late 1930s, its spread in the United States has been both rapid and extensive. It now is found in waterbodies in 38 states. Because of its economic and ecologic effects, it is considered to be the most problematic non-indigenous aquatic animal in North America. It was discovered in Lake Tahoe in 2002 and since then there has been significant work to address this invasion.

KEY FINDINGS:

- The current known distribution (area ~1 million m², 250 acres) is patchy along the southeast shore from Zephyr Cove, NV to El Dorado Beach, CA. This is changing due to rapid growth rate of Asian clam, and ability to colonize in the abundant sandy bottom of the lake.
- In 2008, researchers and managers in the Tahoe basin became increasingly concerned at the apparent expansion of clam beds in the southeastern part of Lake Tahoe and the possible link to eutrophic conditions developing resulting in a large scale visible algal bloom.
- Laboratory experiments conducted in September 2008, showed that Asian clams collected from Lake Tahoe excrete nitrogen and phosphorus at levels, several orders of magnitude greater than ambient lake levels.



- Surveys in 2008 indicated rapid expansion of the population, with extensive and often dense beds of Asian clam in nearshore areas from Zephyr Cove to El Dorado beach.
- Movement of clams to deeper regions may occur in 2 ways; floatation or wind driven waves.
- There is an estimated 36 million m² of suitable habitat (i.e., sandy substrate) in Lake Tahoe; at the date of this report approximately 20% of the habitat is occupied.
- Many substrates can support the successful invasion of Asian clam, including cobble, gravel, mud, fine slit and sand with clams having the greatest success in sandy substrate.
- The dispersal of Asian clam larvae by wind-induced currents occurs mainly on small spatial scales. The risk of new Asian clam infestation outside the existing beds in Marla Bay on account of transport of Marla Bay juveniles is close to zero.

Project 057

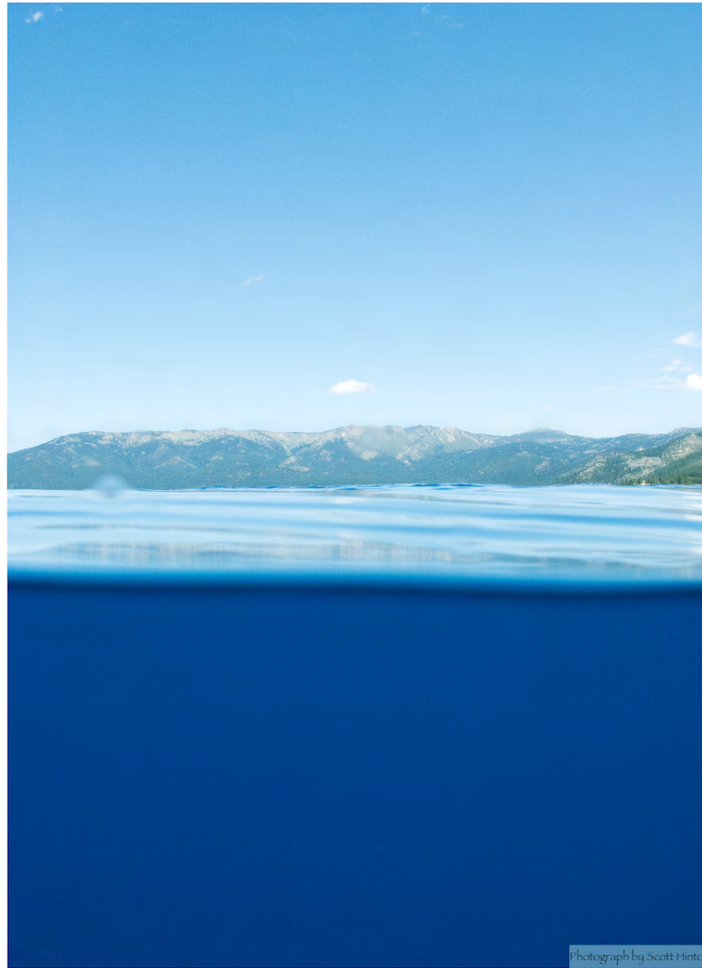
Additional work on the Asian clam addressed the limitations to Asian clam distribution and recolonization around the lake-- the factors that could impact the management and control of the Asian clam in Lake Tahoe. Wittmann et al. (P057) examined Asian clam growth, reproduction and transport in deep and shallow zones of Lake Tahoe.

KEY FINDINGS:

- Through field based collections coupled with laboratory experimentation, researchers found that Asian clams are capable of significant growth and reproduction in the nearshore zone of Lake Tahoe.
- Populations can exist at deep water depths (about 50 m), but with much less productivity than those observed in the nearshore zone.
- Passive transport of adult Asian clam individuals is a potential dispersal mechanism for Asian clam in Lake Tahoe, transporting adults and juveniles from shallow depths to deeper zones, and potentially vice versa.
- Asian clam populations are significantly reduced immediately after experimental bottom barrier removal, with 95-99% mortality observed. Native macroinvertebrate communities are also significantly reduced, but after a one-year period, both Asian clams and macroinvertebrate communities demonstrated statistically significant recolonization in the treatment plots relative to the control plots.
- The dynamics of species are complex and have a great deal of uncertainty associated with habitat and other climate variables not represented in this study and recommend the continuation of a long term experimental and monitoring program that applies to Asian clam management.



- Importantly, these studies should be broad enough to prepare for the establishment of other potentially harmful introduced aquatic species.
- Researchers strongly recommend the establishment of a long-term monitoring and surveillance program to improve the likelihood of detection of Asian clams and other harmful introduced species to Lake Tahoe's nearshore.



Photograph by Scott Hinton

Water Quality and Clarity

Two miles off the shore of Sand Harbor State Park, Nevada

5. LAKE QUALITY

Leading up to and following President Clinton's visit in 1997, efforts for resolving the decline in Lake Tahoe's clarity were focused on eutrophication, and primarily on the buildup of nitrogen and phosphorous that resulted in algal growth. The primary delivery mechanism of Nitrogen to the lake was believed to be through atmospheric deposition, while phosphorous was delivered as a component of sediment (Murphy and Knopp, 2000). Research identified phosphorous as limiting algae growth, so management focused on controlling sediment as the carrier of phosphorous. However, research conducted in 1999 by Alan Jassby et al. identified very fine sediment particles as the primary problem, rather than phosphorous associated with the sediment. The importance of fine sediments to lake clarity was verified by Swift (2004) and Swift et al. (2006). It is ironic that prior to 1997 we focused on the right pollutant, but essentially for the wrong reason. A restoration strategy to control phosphorous would have missed fine sediment. These key research findings created the breakthrough that enabled a broader solution to declining clarity that was not possible under the previous paradigm. As a result, effective (we believe) regulation in the form of the Lake Tahoe TMDL was created, and an effective restoration process begun.



Since then, despite improvements to deep water clarity (measured as secchi depth), water quality in the nearshore of Lake Tahoe has shown signs of continued degradation in the form of algal growth and invasive species. As a result, the focus of much recent research has shifted to the nearshore.

The following discussion focuses on work accomplished using SNPLMA funding. Details for these projects and their respective findings can be found in Appendix B and at <http://www.fs.fed.us/psw/partnerships/tahoescience/>. We identify each individual project by its assigned project number (e.g. P007) that will enable the reader to locate the full project in either Appendix B, or on the Pacific Southwest Research Station website identified above.

THE NEARSHORE ZONE

Lake Tahoe's nearshore zone is usually thought of as a region extending 100 to 200 meters from shore. It is the primary mixing zone between water that flows off the land surface and water from deeper portions of the lake. Sediment is generated from many sources associated with urbanization and delivered to the lake through constructed drainage systems, while sediments from the mostly wild upper watershed are delivered to the lake via natural streams. The nearshore zone is also the area where most recreation occurs, and where most of Lake Tahoe's visitors receive their impression of the lake and its watershed. Algae growth and dirty water have been apparent in this zone for at least the past decade, but the causes were poorly understood. In 2009, Schladow et al. (P002) undertook a massive investigation of the nearshore to uncover basic information regarding this portion of the lake. Through this project's seven separate but related investigations, researchers learned that suspended sediment concentrations varied considerably in the nearshore zone around the lake. This was important, because it made it clear that simple numerical water quality standards would not work; the nearshore was too dynamic at different locations around the lake, and in the same locations over time. This work also quantified the differences between urban runoff and sediment delivery from the upper watershed, in this case mostly from the Upper Truckee River. Heyvaert et al., 2011, (P014) revealed that fine sediment particle concentrations in stormwater runoff from urban areas exhibited concentrations several orders of magnitude greater than that of lakes and streams. Not only were fine sediments the problem, but also they originated mostly in urban environments.

A three dimensional modeling component of Schladow's 2009 (P002) investigation revealed a counter-clockwise water circulation pattern in the northern half of the lake, and a clockwise pattern in the south. Additional resolution afforded by a "Nested Grid" module revealed that additional patterns occur at smaller scales. This work was important because it identified complex interactions between sediment or nutrient source areas and reductions in lake clarity away from the initial delivery site.

KEY FINDINGS:

- Suspended sediment concentrations show pronounced fluctuations in the nearshore zone around the lake and at the same locations over time (P002).
- Resuspension of sediments from wave action only occurs in shallow waters, very close to the shore. Resuspension of sediment from wave action is not a primary source of fine sediments (P002).



- Urban runoff primarily affects water quality within 100 to 200 meters from shore (P002).
- For each unit of sediment discharged to the lake, urban runoff contained 260% more nitrogen and 100% more phosphorus than that in surface runoff from the Upper Truckee River (P002).
- Fine sediment particle concentrations were several orders of magnitude greater in urban stormwater runoff compared to lake or stream samples (P014).
- In contrast, sediment from the Upper Truckee River is infrequent, but when it occurs it has regional impacts. Upper Truckee River high flows are primarily in response to spring snowmelt (P002).
- The distribution of clarity and chlorophyll 'a' in the nearshore is controlled by the transport process within the lake (P002).
- Fine suspended sediments are transported in a counter-clockwise gyre in the northern part of the lake and clockwise in the southern part (P002).

EROSION AND RUNOFF PREDICTION

The new focus on fine sediments dictated improved methods for project design that could realistically model runoff, fine sediment yield, and predict phosphorous transport, in order to reduce their impacts. The Water Erosion Prediction Project (WEPP) model had sediment and runoff capabilities, but was not optimized for Lake Tahoe basin soils. Elliot, Traeumer, and Brooks (2012; P024), performed WEPP optimization on basin soils, which greatly improved the value of WEPP as a modeling tool in the Lake Tahoe basin. This work is reflected in WEPP version 2012.8. Ongoing work by Elliot et al. (P084), is expanding the utility of the model by adding groundwater, flood routing, fine sediment production, and phosphorous delivery.

Model calibration and optimization depends on the collection of water quality samples to compare with the model's predictions. Since the gathering of fine sediment data can be time consuming and expensive, surrogate measures were evaluated that would reduce costs and allow a larger sample size of fine sediment data. Heyvaert et al. (in progress, P081) has determined that turbidity can provide the desired benefits, however different calibrated instruments produce different results. To resolve this issue, Heyvaert developed a series of regression equations that allow a meaningful comparison of turbidity results among dissimilar equipment. The consequence is that fine sediment information can now be gathered in a very cost effective way, providing data to update the Lake Tahoe WEPP model and allow managers to better meet the goals of the Lake Tahoe TMDL.

KEY FINDINGS:

- The WEPP runoff/sediment model was optimized to work for Tahoe basin soils, to predict runoff, soil and nutrient losses associated with prescribed fire (P024).



- The model (in progress) allows managers to evaluate the quantity of eroded material, its particle size distribution, and phosphorous transport in surface and subsurface water, which in turn enables a dynamic project design to occur to maximize BMP efficiency. This has the potential to effectively reduce human impacts to Upper Truckee River runoff quality as well as urban runoff quality, and as a result, Lake Tahoe (P084).
- Turbidity was identified as a reliable proxy to predict Fine Sediment Particle concentrations at urban stormwater sites, with small improvements in statistical power if region and month are included in the conversion (P081).
- Project P081 also demonstrated that different turbidity instruments produce different results from the same runoff samples, even when properly calibrated.
- Recommendations are provided for normalizing turbidity data from diverse instruments as needed, and for reporting original data with the corresponding transformation functions and instrument IDs (P081).

PILE BURNING EFFECTS

Prior to SNPLMA, the consequence of pile burning on upland sediment generation and on sediment and nutrient delivery to the lake was uncertain. An unanswered question regarding upland sediment generation was the consequence of pile burning on both sediment and nutrient delivery. Traeumer and Brooks, 2012, (P024) focused on erosion in their calibration of soils within the Lake Tahoe Basin and utilized research conducted by Hubbert, Busse and Overby, 2013 (P035) to look at the effects of pile burning on nutrient delivery. Together, these projects clarified that while pile burn areas result in a range of consequences for forest soils, the effects were very localized within the burned area and relatively minor. Hubbert et al. concluded that since the burn piles themselves were so limited across the landscape that pile burning did not pose a risk to water quality.

KEY FINDINGS:

- Burning of hand-built piles of various sizes and fuel types did not result in extreme soil temperatures unless large wood (10,000-hour fuels) was the dominant fuel type. Even then, extreme heating above 400 oC was limited to the surface 10-cm (4-inch) soil depth (P035).
- Pile size was of minor importance. The soil heat pulse did not increase significantly for piles ranging from two to seven meters in diameter (6.5 to 23 feet in diameter). Thus, decisions regarding pile size and arrangement can be made based on safety issues and cost effectiveness, not soil heating (P035).
- Soil temperatures declined precipitously from the pile center to the pile edge. Roughly one-half of the ground surface area beneath piles reached maximum heating, whereas the soil on the outer half of the pile perimeter remained considerably cooler (P035).



- Soil physical properties were altered moderately (water repellency, porosity) to severely (water infiltration) by pile burning. As a consequence, some localized erosion may be expected in the first few years after burning before surface litter or plant cover return. It is unlikely that this will create erosion problem in the Lake Tahoe Basin, however, because of the scattered, discontinuous arrangement of pile burn scars across treatment units (P035).
- Burning of wood piles and slash piles did not produce a detrimental change in soil fertility indices such as total soil carbon, nitrogen, phosphorus, pH, inorganic nutrients, or visual observations of fine roots production (P035).
- Pile burning did not sterilize the soil. Ample evidence of surviving soil microorganisms was noted regardless of the severity of heating. The results suggest that short-term changes in soil microbial populations and their nutrient cycling processes will not be severe at any soil depth beneath burn piles (P035).
- A strong spike in soil nitrates and sulfates was found within burn scars in the late spring following the initial snowmelt after burning. Consequently, the potential exists for a short-term nutrient pulse in surface and subsurface water following pile burning (P035).
- Nitrate concentrations in overland flow were low in 2010 regardless of sample location. Although the concentrations were higher in 2011, they decreased two-fold moving downslope from the pile burn. This reduction in nitrate concentration with distance from the burn piles is attributed to the filtering effect of ground cover. Subsurface flow of nitrates also decreased about two-fold going downslope from burn piles, although the differences were not statistically significant due to high pile-to-pile variability (P035).

INVASIVE SPECIES (FISH AND ASIAN CLAMS)

The Lake Quality category in this research summary also includes work on aquatic invasive species. Fish species and Asian clams are separated for convenience.

FISH

In the 1870's, Lake Tahoe supported a large population of Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*). Commercial fisheries existed to feed the region's expanding population (Lindstrom, Rucks and Wigand in Murphy and Knopp, 2000)). As this population was exploited, new species such as Mackinaw (Lake Trout, *Salvelinus namaycush*) were introduced in an effort to replace the diminishing Lahontan trout populations. The Mackinaw transplant was only marginally successful, however, Mackinaw weren't the only aquatic species introduced to Lake Tahoe. Exotic zooplankton, other fish, mollusks, and crustaceans were also seeded into the lake. Some were deliberately introduced and some not. The concern, based on past experience, is that new introductions can dramatically change the current ecology of the lake in undesirable ways.

The Tahoe Keys have been an area of concern since its shallow waters were constructed from the Upper Truckee River marsh in the 1960s. The waters of the Tahoe Keys are considerably warmer than the open waters of Lake Tahoe, and are the home to several introduced warm water species like black bass and



bluegill. Research conducted by Schladow et al. 2009 (P002), demonstrated that these warm water fish were leaving the Keys basin and traveling around the lake. This caused a great deal of concern that they might become established as a result. However, work done by Ngai et al., 2010 (P027) provided some hope that this might not be the case. Their studies revealed that the ultraviolet transmissivity of the nearshore significantly affects the survival of warm water fish larvae and partially influences their ability to become established in Lake Tahoe. The team found that native fish species were up to six times more tolerant of UV radiation than the introduced fish. Unfortunately, their measurements of native fish populations in the nearshore showed that native populations were diminishing, with few exceptions. The reason remains elusive. The importance of this work is that it revealed a real threat to the native diversity of Lake Tahoe's fishes through the expansion of warm water fish populations, and also the importance of regaining the clarity in this zone as a potentially viable strategy for restoring it.

KEY FINDINGS:

- Warm water fish move out of the Tahoe Keys during summer and late fall, suggesting that the Tahoe Keys may be an important source population for the rest of the lake (P002).
- Contemporary assessment suggests that the health of Lake Tahoe's nearshore native fishery is deteriorating (P027).
- UV exposure and in situ incubation experiments show that UV transparency of nearshore sites significantly impacts the survival of warm water fish larvae and influences whether these potentially invasive fish species are able to establish in Lake Tahoe's nearshore (P027).
- Native fish larvae (Lahontan redbside shiner) were at least six times more tolerant of UV exposure than non-native warmwater fish larvae (bluegill and largemouth bass) (P027).
- The observed difference in UV tolerance between native and non-native fish was used to develop a UV attainment threshold (UVAT, i.e. a water clarity threshold based on water transparency to UV) that is lethal to non-native fish larvae with no observed effect on native fish larvae (P027).



Invasive Species in Lake Tahoe

Eurasian water-milfoil removal from the Tahoe Keys, California

ASIAN CLAM

The Asian clam (*Corbicula fluminea*) is a well-established aquatic invasive species in Lake Tahoe (TRPA 2014, Wittmann 2015). First recorded in Lake Tahoe in 2002, Asian clam densities of up to 5,000 individuals/m² have since been reported, and their range has expanded substantially throughout much of the lake's southeastern area (Wittmann et al. 2012; Wittmann et al. 2015). The Asian clam often dominates the benthos where it occurs in Lake Tahoe (Wittmann et al. 2015).

Location of some clam beds (or other macrophytic invasive populations) are known for specific sites, but a method was desired that could tie in situ measurements with broadly available remotely sensed data to quantify the extent of these populations. Watanabe et al. 2012, (P080) found that for depths up to about 10 meters, clams could be detected using remotely sensed imagery. However, in portions of the lake deeper than 10 meters or dominated by sand substrates, Watanabe et al. found that higher resolution imagery was needed.

Initial studies to control a known population of Asian clams focused on Emerald Bay, because of the population's limited extent and the bay's special status. Researchers believed that an effective strategy could be developed and tested in Emerald Bay and transferred to the rest of the lake if successful. Schladow et al. 2012, (P087) selected rubber gas impermeable barriers to suffocate the clams. He found the barriers were generally effective but susceptible to leakage from currents and hyporheic flows that could provide oxygen to the covered clams. Proper sealing of the barriers during the warmest portions of the year (June through October) eliminated a high percentage of the population. Further work by Odagiri et al. 2012, (P056) to investigate the water quality consequences of clam eradication using barriers found release of ammonium



and phosphates 10 to 1000 times above background levels, but negligible amounts of bacteria harmful to humans. These results suggest that gas impermeable barriers can be used to control Asian clams, however many variables, such as upwelling, wave action, and temperature contribute to the success of these barriers. While the barriers were effective they did not result in complete elimination of the clams. Future efforts will require periodic treatments to maintain low levels of Asian clams in Emerald Bay or where ever the barriers are used.

KEY FINDINGS:

- In general, with present technology, it appears that only larger patches of macrophytes are sufficiently distinguishable from remotely sensed datasets. It will require higher sensitivity and high spectral resolution data (e.g., hyperspectral airborne sensor, PRISM by NASA-JPL) for other substrate types to be distinguishable (P080).
- During treatment with impermeable gas barriers, nutrient release rates at summer temperatures were one order of magnitude higher than at winter temperatures (P056).
- Release rates of ammonium and phosphate estimated at summer temperatures were 10 to 1000 times higher than release rates from sediment reported in Lake Tahoe, suggesting that dead Asian clams were possible sources (P056).
- The June – October period when water temperatures are $> 10^{\circ}\text{C}$ is the most effective time to kill Asian clams in Emerald Bay using benthic barriers to induce hypoxic conditions (P056; P087).
- Substrate permeability and the resulting potential for hyporheic flows affected the ability of the benthic barriers to induce hypoxic conditions. Substrate permeability must be considered in developing expectations for the performance of benthic barriers, particularly in areas such as sills where variations in bottom slope are pronounced (P087).
- Clam mortality during the winter period was not significantly different from the control site, (P087).
- Clam mortality rates during the summer period were the highest and very similar under the two undisturbed barrier treatments (reduced and enhanced permeability), while lower levels of clam mortality occurred under the disturbed barriers (P087).
- The model pathogens, *Campylobacter jejuni* and *Salmonella enterica*, did not significantly increase in numbers under the barriers at either winter or summer temperatures as measured by DNA (P056).



NEARSHORE MONITORING

Over the four years from the initial characterization of Lake Tahoe's nearshore by Schladow et al. (P002) to the comprehensive evaluation by Heyvaert et al. 2013 (P048) that culminated in a nearshore monitoring plan, dramatic development occurred.

Heyvaert et al. 2013 (P048) was a multi-year effort that summarized available information on Lake Tahoe's nearshore condition, developed an integrated set of metrics and indicators to characterize nearshore condition, considered reference conditions and the relevance of existing thresholds and standards, and provided recommendations for a monitoring and evaluation framework that could be used to guide the tracking of changes in nearshore condition and to support regional program planning needs.

The amount of work required to accomplish this task was immense. The team created a conceptual model of the nearshore based largely on Schladow's 2009 (P002) work. By necessity, the model identified primary components of a complex system, the relationships between components, and what was known regarding the information or materials transferred. Focal areas monitored included lake clarity, trophic status, community structure, and human health measures of the lake. 17 potential metrics were evaluated to become the metrics included in the final monitoring plan; ten were eventually selected. Once the metrics had been selected, the team then identified the frequency of sampling necessary to accurately characterize the annual condition of that metric, the regions of variability for each metric around the lake, and finally the background measurements for each metric in each region. From this and other information, the team proposed threshold levels for each metric. Lastly this information was combined into a single monitoring plan for Lake Tahoe's nearshore. This work became the basis for the nearshore monitoring plan in the Lake Tahoe TMDL.

KEY FINDINGS:

- A nearshore conceptual model was developed to reflect the measurable health of Lake Tahoe's nearshore zone (P048).
- Seventeen attributes were evaluated for consideration for monitoring metrics. Ten were selected as usable metrics (P048).
- Metrics were organized in four categories to reflect the health of the nearshore zone: lake clarity, trophic status, community structure, and human health impacts (P048).
- Monitoring frequency and monitoring locations were selected in Lake Tahoe to reflect its natural variability in the nearshore zone (P048).
- Background conditions were determined for each metric in each monitored zone (P048).
- Interim Thresholds were developed for each metric (P048).
- A nearshore monitoring plan was established (P048).



Water Quality and Clarity
Remnant snow piles in South Lake Tahoe, California

6. STORMWATER MANAGEMENT

MANAGEMENT TOOLS

Universal challenges for any assemblage of management models is to maximize their utility by having them correctly applied to a given problem, to be able to utilize existing data sets and generate new compatible data, and to consistently and accurately analyze the results they produce. Projects 011, 088, and 023 dealt with these challenges. The purpose of project 011, the Tahoe Stormwater and Best Management Practices (BMP) Database, was to guide the collection of consistent and reliable information on stormwater runoff characteristics and performance information regarding BMPs around the Tahoe Basin. Project 088 developed specific recommendations to align urban stormwater monitoring datasets with priority Total Maximum Daily Load (TMDL), the Environmental Improvement Program (EIP) and other water quality implementation and management questions in the Tahoe Basin so that insightful technical evaluations of the data could be made, and their implications to the TMDL, EIP, and BMP programs be available to inform programmatic management decisions. Finally, project 023 sought to organize the stormwater models into a toolbox to facilitate their application. Researchers and environmental managers have just begun to use models for water quality planning at Lake Tahoe as evidenced by the current Lake Tahoe TMDL effort (http://www.waterboards.ca.gov/lahtontan/water_issues/programs/tmdl/lake_tahoe/). Project 023 was intended to extend this process by using the toolbox concept to help organize and integrate the current loose confederation of models. Each of these projects contributed an essential train of development that will enable a much more effective implementation of the Lake Tahoe TMDL.



KEY FINDINGS:

- Project 011 created a centralized system for accessing and analyzing existing stormwater data. Consistent formats were developed for reporting stormwater runoff and treatment BMP data. The database is available to support data collection, management and reporting for the Tahoe Regional Stormwater Monitoring Program (RSWMP).
- Project 088 focused on creating compatible stormwater data sets for use by agency staff. It created definitions, guidance and processes, which translate the datasets for two high priority objectives into meaningful and easily interpretable results. In addition, it recommended data analysis and reporting techniques that could be consistently and cost-effectively implemented by resource agency staff who are not necessarily statistical experts.
- Project 023 assembled the many stormwater models into a usable toolbox framework. It's intended to facilitate future model development, application and revision.

POLLUTANT LOAD REDUCTION MODEL (PLRM) REFINEMENT

The Pollutant Load Reduction Model (PLRM) is the primary modeling tool used in the Lake Tahoe TMDL to evaluate the effectiveness of proposed restoration projects with respect to the reduction of fine sediment particles. The entire clarity recovery program is highly dependent on the accuracy of this model, and a great deal of research has been focused on validating or improving its performance. Projects 038, 039 and 071 all focused on refinement of the PLRM.

The primary focus of project 038 was to obtain a representative and reliable stormwater dataset to compare to applicable predictions from the PLRM (NHC et al. 2009) and provide road specific data to inform the development of Road Rapid Assessment Methodology (Road RAM; 2NDNATURE et al. 2010). These currently are the only tools approved for use by the Lake Clarity Crediting Program (LRWQCB and NDEP 2009), a program intended to incentivize and measure progress toward the attainment of urban stormwater load reductions established in the Lake Tahoe TMDL (LRWQCB and NDEP 2010).

Project 039's objectives were to: 1) develop a new land use category for road cut and fill slopes for the PLRM that leverages existing quantitative data and builds on the treatment tiers and functional condition classes already developed in earlier stages of the TMDL; and, 2) develop well-defined classifications and field identification protocols for a range of disturbed and treated cut and fill slope conditions with associated loading potentials. The end product of this effort was the Road Cut and Fill Slope Sediment Loading Assessment Tool (RCAT), a simple and repeatable field assessment methodology and spreadsheet tool designed to assist the Lake Tahoe erosion control and stormwater community in characterizing the functional condition of road cut and fill slopes and estimating the associated sediment and fine sediment particle loading from these areas.

Project 071 also looked at the PLRM model with the goal to obtain and report reliable seasonal and annual urban catchment fine sediment particle (FSP) loads that can be compared across outfalls and allow detection of decreasing trends in urban pollutant loading as a result of management actions.



Together, these model refinements work toward the goal of being able to accurately predict the effects of restoration and sediment load reduction efforts. This in turn will allow managers to prioritize their efforts and resources to efficiently achieve real, quantifiable improvements in lake clarity.

KEY FINDINGS:

- Project 039 developed a stand-alone spreadsheet tool (RCAT) that predicts sediment loss from road cut and fill slopes on various soil types, condition classes, and slopes. The predictions are able to separate the fine sediment component from total sediment.
- Comparison of the volume-weighted average FSP concentrations from project 038 indicates that the PLRMv1 guidelines for defining and categorizing road risk may be insufficient to reasonably capture differences in operational practices across jurisdictions, and detailed recommendations for PLRMv1 user guidance improvements are recommended. Comparison of road specific sampling and mixed land use catchment water quality data support assumptions that the average FSP and total suspended sediment (TSS) concentrations from roads per unit area are significantly higher than the average mixed land use signal. In contrast, the average soluble reactive phosphorus (SRP) concentration is lower, suggesting that roads may not be a primary source of SRP to catchment pollutant loads (P038).
- A comparison of seasonal estimates generated from three water years of stormwater treatment (SWT) hydrology data collection to PLRM predictions show a very strong correlation (significant above 99% confidence) between measured and modeled treated outflow volumes across a range of hydrologic conditions experienced by dry and wet basins. When the modeled to measured hydrologic comparisons are limited to seasons when baseflow is negligible, the alignment between measured and modeled hydrologic performance greatly improves. Future PLRM improvement should consider allowing a user to define a baseflow component for a modeled SWT facility (P038).
- Results suggest that: 1) the PLRMv1 characteristic effluent concentration (CEC), FSP, and TSS values are currently lower than achievable effluent quality from wet basins and dry basins for typical Tahoe Basin maintenance practices; and 2) the treatment capability to achieve effluent FSP concentrations < 100 mg/L are limited when inflow concentrations are relatively elevated (> 300 mg/L). Poor road condition in the late winter/early spring can result in a substantial downslope water quality risk when rains efficiently transport these pollutants into the stormwater system, requiring treatment and/or retention to prevent FSP from reaching the Lake (P038).
- Project 071 developed a series of data to document the runoff volumes and FSP pollutant loading from three urban catchments, evaluate the influence of changing road conditions on these pollutant loads, and build representative PLRM models to compare to the measured water quality datasets (P071).



- Available turbidity to FSP rating curves developed using thousands of paired samples obtained in the Tahoe Basin (2NDNATURE et al. 2014) were used to consistently convert 10 minute turbidity data to FSP concentrations, P071.
- The results of the model calibration exercise and comparison to measured pollutant loads suggest that PLRM models can perform reasonably well on the seasonal and annual time scales, as intended based on the objectives of the model design. However, the model's predicted runoff volumes and pollutant loads can have notable discrepancies with the measured data at the event time scale (P071).

WATERSHED EROSION PREDICTION PROJECT (WEPP) MODEL

While urban roadways have been the primary focus for controlling fine sediments, questions existed regarding forest management and forest roads. The primary management tool for design and evaluation of forest management has been the Watershed Erosion Prediction Project (WEPP) model. However, this model had three limitations; it had not been optimized for Tahoe Basin soils, it didn't separate or predict the generation and delivery of fine sediments, and it didn't estimate the delivery of soluble reactive phosphorous. Projects 005, 010, and 052 focused on correcting these deficiencies, and as a result, have provided wildland managers with an effective tool.

KEY FINDINGS:

- Close agreement between simulated and observed snow water equivalent, streamflow, and both fine (<20 micron) and coarse (>20 micron) sediment load was achieved at each of the major watersheds located in the high precipitation regions of the Tahoe Basin with minimal calibration (P005).
- Lake Tahoe Basin derived effective hydraulic conductivity was nearly 2.5 times larger than the generic WEPP values for the granitics (9.3 vs. 3.8 mm hr⁻¹) and nearly 30 times larger for the volcanics (7.5 vs. 0.27 mm hr⁻¹). Based on soil texture rather than parent material, the volcanics were nearly 2 times larger than the WEPP recommended value for a sandy loam soil (7.5 vs. 3.8 mm hr⁻¹). In any case, the Lake Tahoe basin derived effective hydraulic conductivities were larger than the generic WEPP recommended values by at least two times (P010).
- For the Glenbrook Creek watershed, an optimal BMP application strategy was found that minimized sediment from the existing network, subject to a variety of road budget constraints. This optimum application of BMPs resulted in a 64% reduction in sediment over the 30-year planning horizon (P010).
- SRP in surface runoff is likely less than 0.01 mg/L, whereas SRP concentrations in lateral flow and base flow are likely to be around 0.02 mg/l (P052).



- SRP concentrations are the lowest during March and April when surface runoff is contributing to runoff and diluting lateral and base flow, but higher from June onwards when lateral flow and base flow are the main sources of water in the stream system (P052).
- Total phosphorus delivered is likely to be the highest during the peak flow times associated with snow melt in April and May (P052).

FINE SEDIMENT CONTROL

An important step towards improving lake clarity has been to quantify the effectiveness of current facilities in removing fine sediment particles from urban runoff. Quantification puts erosion and stormwater control efforts in perspective, both in terms of whether they work, and to quantify the investment required to achieve the desired reductions in fine sediments.

The most direct approach is to not put sediment into urban runoff to begin with. In project 038, 2NDNATURE and Northwest Hydraulic Consultants looked at sweeping city streets and concluded that roads that are swept regularly, especially after the winter application of road abrasives, often had lower FSP concentrations in their runoff than less heavily travelled roads that were swept less frequently. Their message was that the longer the abrasive material stays on a roadway, the more of it is pulverized by traffic to become fine sediment. Their recommendation was to keep city streets as clean as possible throughout the winter and spring seasons.

Since sanding city streets will continue, other work looked at treating the runoff to remove those sediments. In project 037, efforts to improve the effectiveness of stormwater control facilities included looking at filtration screens, which were found to reduce fine sediments up to 75%. However, they are also prone to clogging and catching other debris entrained in urban runoff, which made them maintenance intensive, and as a result, not cost effective for use in routine drop inlet drainage structures. Perhaps their place will be found on localized high priority detention basins where a large reduction in fine sediments would be worth the cost/credits.

Flood plains are usually created through the settling of sediments from flood waters, building up a surface of deposited material. In project 025, Stephen Andrews, S. Geoffrey Schladow, and Daniel Nover found that utilizing flood plains are an effective strategy for reducing fine sediments, and that their effectiveness is basically related to the volume of water in contact with vegetation that can flocculate the fine particles out of suspension. Increasing the size of the floodplain inundated has another benefit; it increases the proportion of flood waters infiltrated to groundwater, which also filters fine sediment particles. Andrews et al. found that intentionally flooding more of a flood plain is likely to be a better strategy than trying to change the characteristics of the routinely flooded area. This single conclusion represented an important change of perspective for streamside restoration work and fine sediment control for the Basin's streams.

In project 040, researchers looked at detention basins to determine their effectiveness. This study quantified the actual removal of total suspended solids, fine sediments, and the change in turbidity as a result of stormwater detention in Cattleman's detention basin on Trout Creek. The study of flood plains and detention basins quantified fine sediment removal from actual structures in the Tahoe basin and ultimately



opened the door to evaluating the likelihood of success for the Lake Tahoe TMDL. The paradigm for recovery shifted from general sediment control concepts to quantifiable outcomes.

In project 097, Geoff Schladow, Juanfran Reinoso and Carlos Leon took the next logical step and asked what change might be possible if we took the detention basin concept to its limits. Using LiDAR to obtain high definition elevation data, they were able to locate potential sites for detention basins in Incline Village and South Lake Tahoe, and determine the area that would flow into each basin. They discovered that we could increase the volume of urban stormwater treated in detention basins by approximately five times.

KEY FINDINGS:

- In the Lake Tahoe Basin, a TMDL credit equals 1.0×10^{16} fine sediment particles (FSP) with a diameter smaller than 16 micron or its equivalent, 200 pounds of fine sediment particles (Lake Clarity Crediting Handbook 2011). The range in annual load reduction based on actual monitoring data and modeled flow data determined that the annual <16 micron load reduction can range from 12-24 pounds / filtration unit / year. This equates to .06 - .12 credits annually per filtration unit when operated optimally with intensive maintenance (P037).
- The preliminary results indicated that the filter (perlite filtration media) and Drop Inlet plug fairly easily with debris and material transported from the road. This is discouraging in that it creates both flooding and liability issues (P037).
- The results of this study indicate that perlite filtration system can be effective, (removing up to 75% of FSP) but would be maintenance intensive and therefore, cost prohibitive (P037).
- Observations support previous assumptions that increased sweeping frequency during winter months removes coarse material delivered to road surface prior to pulverization. The lowest observed FSP concentrations were actually on high and moderate risk roads where high abrasive applications were coupled with frequent sweeping with high efficiency sweepers (P038).
- Project 040 looked at FSP and detention basins. Results are listed as Median inflow, basin outflow and floodplain event mean concentrations for the following constituents: TSS (mg/L): 54.4, 9.27, 21.6; FSP (#/mL): 2.57×10^6 , 7.34×10^5 , 6.56×10^5 ; inorganics (mg/L): 39.22, 3.94, 12.46; and turbidity (NTU): 82.05, 15.22, 29.95, respectively, P040.
- Cattleman's detention basin provided significant reductions of total loads of all constituents listed above (P040).
- Andrews et al. 2011 produced a calibrated model that indicated, of the physical mechanisms leading to fine sediment removal considered, flocculation was the largest, with gravitational settling and sediment stranding by infiltration also being significant (P025).
- Small weirs placed in the channel during flooding will have large effects on fine sediment removal, with increases in sediment retention of 20%, if weir placement results in the flooding of previously dry areas (P025).



- For Incline Village the analysis showed that a system of 1300 distributed detention basins could detain (and potentially infiltrate) approximately 49,000 m³ of stormwater in the urban area. Such a system would be capturing water from 56% of the urban area (P097).
- For South Lake Tahoe the analysis showed that a system of 1600 distributed detention basins could detain (and potentially infiltrate) approximately 1,200,000 m³ of stormwater in the urban area. Such a system would be capturing water from 42% of the urban area (P097).

FINE SEDIMENT SOURCES

Another avenue to investigate regarding reducing the number of fine sediment particles in Lake Tahoe to understand what material is actually producing them, and in so doing, learn to select road abrasives that are don't degrade into FSP as quickly.

KEY FINDINGS:

- Project 026 investigated whether we can identify where road-related particles are coming from. Despite a robust statistical separation by discriminant analysis, source samples of road sediments from different areas are quite similar and discrimination between them is based upon very small differences in their composition. This fact, in conjunction with a broader range of element concentrations naturally represented in the highway runoff samples, means that there is too much overlap in their constituents to reliably identify their source at this time (P026).
- Sediment accumulation in a constructed treatment wetland in Tahoe City averaged 3.7 centimeters per year. Over the 16-year period of active use this accretion raised the sediment surface approximately 60 centimeters, sufficient to interfere with hydrologic function so that ultimately excavation was required to restore capacity and reestablish flow paths (P054).
- Approximately 2300 cubic yards of accumulated material was removed during excavation from the Tahoe City wetland basin after 16 years of use (P054).
- Total inorganic matter accumulation in the cores averaged 7.0 kg cm⁻² y⁻¹, of which approximately 54% consisted of fine sediment particles less than 16 µm (FSP), indicating an FSP accretion rate of 3.8 kg cm⁻² y⁻¹. About 45% of total particle mass retained by the wetland system was in the <10 µm size fraction and 30% was in the <5 µm size fraction (P054).
- Wetland retention basins efficiently combine the physical properties of a retention basin with the biological characteristics of wetlands. The Tahoe City system was designed to remove nutrients and fine sediments from urban runoff through retention basin physical processes and wetland basin biological properties. It was so successful in meeting these goals that it ultimately accumulated too much material and needed to be restored after 16 years of useful performance (P054).



Streams and Meadows Lake Tahoe

Stream monitoring equipment along Angora Creek

4. RIPARIAN / STREAM RESTORATION

Riparian areas serve many important functions in montane forest ecosystems. The area of the entire Lake Tahoe Basin is 506 mi², including the surface area of the lake (192 mi²) and the surrounding watershed (314 mi²). Sixty-three streams drain into Lake Tahoe, carrying rain and snow melt, sediments, and nutrients. Riparian corridors throughout the basin provide vital connections between the surrounding watershed and the lake. Inputs of nutrients such as nitrogen and phosphorus and fine sediment particles, coming from the surrounding watersheds, are suspended in the flowing water that eventually enter the lake. It is largely through this connection that the water quality of Lake Tahoe is regulated. Healthy, functional stream zones can help limit sediment and nutrient runoff concentrations by as much as 70 to 90%.

Riparian areas also have significant intrinsic ecological value to the landscape of Lake Tahoe. The 63 riparian zones within the basin compose a very small proportion of the Lake Tahoe landscape but they are among the most diverse and productive ecological communities in the basin. Plant and animal diversity is greatest in these zones of terrestrial/aquatic integration. Ecologically, each riparian area encompasses the aquatic ecosystem as well as adjacent terrestrial areas directly affecting the aquatic system. Although riparian zones only comprise about 5% of the land area in the basin, they provide key habitat for 84% of the 250 wildlife species found in the basin.

Given the physical and biological importance of riparian areas, this habitat type has been the subject of numerous policy and regulatory efforts to protect or restore ecological function. Three of the nine Tahoe Regional Planning Agency (TRPA) adopted environmental threshold carrying capacities (thresholds) directly address concerns for the riparian areas and their ecological function: water quality (i.e. reducing nutrient and sediment in surface runoff), vegetation (increasing plant diversity in forests, preserving



uncommon plant communities), and wildlife (providing habitat for special interest species, preventing degradation of habitats of special significance). The California Tahoe Conservancy (CTC) developed a Stream Environment Zone (SEZ) program, and denoted perennial, intermittent and ephemeral streams and drainages as well as marshes and meadows, to preserve and/or restore these habitats. The Lahontan Regional Water Quality Control Board (LRWQCB) administers programs such as the Clean Water Act, which encourages watershed-level analysis and protection to sustain functions of wetlands, riparian areas, and headwater streams, including pollutant removal, flood water retention, and habitat connectivity. The Lake Tahoe Basin Management Unit (LTBMU) identifies ecological restoration as a core objective in their Land and Resource Management Plan, watershed assessments, and individual project plans, and strive to restore meadows and riparian areas to improve watershed function, species habitat and diversity.

Stream restoration projects were a priority research area for the SNPLMA program. There were seven projects implemented to restore geomorphic and ecological functions, including retention of fine sediments and providing habitat for plants and animals. These restoration efforts are underway in the watersheds of the Upper Truckee River, Blackwood Creek, Ward Creek, Trout Creek, and other streams around the basin. Research projects are synthesizing the results from past stream restoration projects as well as conducting in-depth field, modeling and laboratory studies to improve understanding of how stream channels erode and sediments deposit in floodplains. The findings will help design projects that more effectively reduce pollution and enhance habitat.

Several riparian-related projects are also reported in the “Forest Fuels and Vegetation Management” section of this chapter. The reader is directed to that section to obtain more information on projects that inform us on how riparian areas respond to fire, past and present.

STREAM AND RIPARIAN RESTORATION PROJECTS

Degraded streams can be a troublesome source of sediments and nutrients to downstream locations, including Lake Tahoe. Much effort and many resources have been devoted to restoring streams in the Lake Tahoe Basin, however, there are still questions regarding the most effective techniques for restoring fully functional stream courses.

Project 003

Bankhead, Simon, and Thomas (P003) conducted experiments and refined models to simulate bank stability and assess erosion rates to assess how various mitigation strategies might perform. This work was intended to enhance and further validate the predictive, numerical models CONCEPTS and BSTEM to fully realize their potential as state-of the-art tools for stream management in the Lake Tahoe Basin and elsewhere. Their specific study objectives included a) quantifying the effects of riparian vegetation and bio-engineered treatments on the resistance of bank materials to hydraulic erosion and bank undercutting for inclusion into both models, b) developing algorithms for CONCEPTS to simulate lateral migration of meandering channels, and c) validating the use of the CONCEPTS and BSTEM models at the project-scale for existing and restored reaches of selected Tahoe basin streams.



KEY FINDINGS:

- Results of model simulations show that failing to account for the erosion resistance of riparian roots resulted in over-estimation of bank erosion.
- BSTEM was improved by adding the Tahoe Basin riparian species to the database in the RipRoot submodel.
- The height of riprap needed to reduce sediment loadings sufficiently depended on the load reduction required and the geometry and materials at each specific site.
- The effectiveness of an ELJ (engineered log jam) greatly reduced hydraulic erosion of the bank toe and face.
- As the trees matured, the additional root- reinforcement reduced geotechnical erosion by increasing the resisting forces acting on the bank. Root networks can take a few years to grow and develop to sufficient depths to cross potential shear surfaces within the banks.
- Grading the banks back may be a useful mitigation strategy for reducing eroded bank volumes and thus sediment loadings, in conjunction with other techniques that maintain channel roughness elements.
- The CONCEPTS and BSTEM models are ideal numerical tools for addressing the types of critical issues concerning stream-restoration design and performance aimed towards reducing fine-sediment loadings to Lake Tahoe.
- The most effective mitigation strategies were those that were able to reduce or prevent hydraulic erosion from the bank toe and bank face.
- The growth of riparian trees also indicated that root-reinforcement can be a significant factor for maintaining geotechnical stability, but only once they have matured enough for the roots to cross potential failures planes within the banks.
- Vegetation was also seen to be very important in terms of channel roughness. Removal of vegetation would, therefore, decrease channel roughness and likely increase erosion rates throughout these channel systems.

Project 004

In project 004, 2nd Nature and Dr. Catherine Riihimaki from Princeton University examined methods to predict fine sediment load reductions that result from floodplain inundation along streams in the basin. This study operated under the assumption that SEZ restoration actions that increase the frequency and duration of overbank flow events may result in substantial removal of the pollutants of concern, particularly fine sediment particles (FSP <16 μm). However, an accepted method for estimating and supporting data does not exist. The research provided a cost-effective data collection and analysis technique that quantified



the fine sediment particle load reductions as a result of floodplain inundation, and this analysis showed that stream restoration is a potentially significant FSP load reduction opportunity.

KEY FINDINGS:

- Resource managers need tools to quantify the water quality benefits of SEZ restoration efforts in a manner comparable to and consistent with the stormwater quality load reduction tools that have been developed.
- This research provides evidence that FSP retention by floodplains does occur and may provide a significant FSP load reduction during overbank flow events. However, the load reduction estimates provided are not yet directly comparable to an estimate of load reductions achievable by stream restoration for Tahoe streams. The data from one floodplain over three water years is limited in both its spatial and temporal resolution; however it is a site-specific and representative dataset, which is very challenging to obtain given the infrequency of overbank flow events.
- Upcoming research will explore methods to integrate both site-specific and readily available regional data with critical geomorphic and FSP fate and transport principles and to provide resource managers with a reasonable approach to consistently predict the FSP load reduction expected from stream restoration actions in the Tahoe Basin.

PROJECT 021

In project 021, a team from 2nd Nature, River Run Consulting, and Environmental Incentives worked together to improve the quality of stream restoration effectiveness evaluations in the basin. This work took a careful look at available documentation and effectiveness reports on riparian ecosystem restoration projects conducted prior to winter 2009 in the Lake Tahoe Basin. The Riparian Ecosystem Restoration and Effectiveness Framework (Framework) was developed to focus the process and improve the communications when stream restoration practitioners are implementing specific restoration projects. Their work led to the conclusion that the documentation of a clear process and format would greatly benefit the future development of riparian restoration effectiveness evaluations.

KEY FINDINGS:

- One primary goal of the Framework is to simplify the communication and documentation process for stream practitioners. The Framework process and the final products provide significant progress towards this goal.
- The Framework establishes a complete process that will help managers better identify measurable project objectives for an array of ecosystem attributes, measure progress toward these objectives, and track and report the physical, chemical and biological effectiveness of riparian ecosystem restoration projects.



PROJECTS 042 AND 074

Specific efforts were made to quantify and characterize the effectiveness of restoration efforts at Trout Creek, the second largest watershed in the Lake Tahoe Basin (P042, P074). This stream course had undergone significant disturbances over the past 150 years, including grazing, logging, and stream channelization – disturbances which degraded aquatic and terrestrial habitats and increased nutrient and sediment loads entering Lake Tahoe. Research goals were to obtain and leverage SEZ specific data to develop a methodology that estimates the average annual pollutant load reduction associated with SEZ restoration efforts. A successful restoration of self-sustaining fluvial processes is expected to reduce pollutant inputs from chronic bank and bed erosion and increase pollutant retention on the floodplain as a result of increasing the frequency and duration of overbank flows.

KEY FINDINGS:

- Significant temporal and financial requirements make the quantification of the actual long-term water quality benefit of a restored SEZ extremely challenging. The episodic nature of elevated flow conditions that cause erosion and/or inundate the floodplain means these events are unpredictable, infrequent and costly to monitor. In order to adequately capture and constrain the long-term variability of the hydrology conditions that drive the water quality signal, consistent monitoring would need to be conducted for decades.
- The measured reach scale load reductions and the floodplain specific sampling conducted on both Trout Creek and the Upper Truckee River provide undeniable evidence that long-term FSP load reductions can be achieved as a result of successful SEZ restoration efforts.

PROJECT 073

Research by Fauria (P073) focused on measuring the rate of particle capture by emergent vegetation for a range of particle sizes and flow conditions. Using native vegetation for stream restoration can improve water quality and restore habitat conditions for native wildlife. This study examines the process of particle removal from a continuous distribution of particle sizes in a laboratory flume using submerged, synthetic vegetation. The particle size distribution embraced the size range 1.25 – 109µm, and was provided from road dust removed from roadways in the Lake Tahoe Basin. By reporting capture rates and discussing the effects of particle size, the existence of biofilm, flow velocity, stem density, and initial particle concentration on particulate trapping, the results demonstrate which variables are most important to particulate capture and help inform modelers and floodplain restoration efforts.

KEY FINDINGS:

- Flow velocity, initial particle concentration, stem density, and presence of biofilm were found to have statistically significant effects on the rate of particle capture. The rate of particle trapping increased with stem density and the presence of biofilm and declined with increasing flow velocity.



- Experimental results show that L50 (the distance on the floodplain over which half of the particles drop out of suspension) increases with flow velocity and decreases with particle size. This means that the effectiveness of trapping by plants increases as flow velocity decreases and particle size increases.
- The tendency for particles to be more effectively removed by settling as flow velocity decreases and particle size increases is well known. However, it is worth noting that L50(p) (particle capture by plants alone) for 9.9 μ m particles is less than L50 (s,f) (settling/flocculation).
- This demonstrates that trapping by plants may be more effective than settling and flocculation combined for 9.9 μ m particles. The combined effects of settling, flocculation and plant capture result in the smallest L50 distances.
- All the tested factors (biofilm, flow velocity, initial particle concentration, the presence of plants, and plant density) are statistically significant to particle capture.

PROJECT 089

The Lake Tahoe Total Maximum Daily Load (TMDL) has focused water quality improvement actions to significantly reduce FSP loading to the lake over the next several decades. Research and monitoring that supported the development of Stream Load Reduction Tool (SLRT) suggests effective SEZ restoration can reduce sediment generation from bank erosion and significantly increase FSP removal in flood flows as a result of floodplain deposition. While standard methods to estimate the urban derived fraction of this FSP loading do not exist, it is likely some load reduction from catchment urban lands are being treated. There is a lot of political and social interest associated with the evaluation of restoration effectiveness within the Upper Truckee River Watershed, making the results of this research (P089) done by 2nd Nature relevant and important to many stakeholders within the Lake Tahoe Basin.

KEY FINDINGS:

- Estimates of the average annual FSP load reduction in metric tons per year for seven stream restoration projects in the Upper Truckee River Watershed were completed using the SLRT.
- A simple accounting method was developed to estimate the urban fraction of the average annual FSP load reduction provided by each restoration effort.
- If all seven restoration projects are implemented, the estimated potential FSP load reduction would be 105 MT/yr, or nearly a 20% reduction in the annual FSP load of the Upper Truckee River Watershed. More than 69% of this cumulative FSP load reduction estimate on the Upper Truckee River is achieved by floodplain retention, which likely includes a significant contribution of urban-derived FSP.
- While the cost effectiveness of SEZ restoration actions to achieve pollutant load reductions varied across projects, this analysis does suggest that SEZ restoration is another valid and cost-effective



tool in the pollutant load reduction opportunity toolbox for Tahoe Basin managers to reduce pollutant loads to Lake Tahoe.

PROJECT 093

One of the most problematic yet important considerations of managing riparian zones is to find agreement on how a riparian zone is defined and mapped. This project, done by Spatial Informatics Group (P093) responded to Lake Tahoe Basin stakeholders' identified needs to review and potentially update the current SEZ policy to ensure implementing ordinances and program elements are consistent with best available science and data, and support desired SEZ conditions, functions, processes and values. Specific objectives included: a) Review and documentation of SEZ desired conditions, functions, process and values; b) Review SEZ definitions; c) Review of SEZ field delineation criteria and indicators; d) Review of wetland and riparian area classification schemes with an eye towards identifying which system might be most applicable to SEZ; e) Map aquatic resources as a foundation to SEZ mapping; f) Confirm the SEZ classification scheme recommended by the Field Delineation Workgroup; and, g) Produce a Basin-wide SEZ map based on proposed SEZ classification scheme and proposed indicators provided by the Field Delineation Group.

KEY FINDINGS:

- Workgroups have forwarded a set of recommendations that very likely can be integrated into the Tahoe SEZ program with some additional stakeholder, public and decision-maker review and discussion. A review found that existing SEZ definitions were adequate, with no need for revisions. Desired SEZ conditions, functions, processes and values have been documented and can help to focus management and regulatory actions.
- Several updates were proposed for SEZ indicators. The Field Delineation Workgroup found that updates to soil, vegetation, aquatic habitat, and floodplain indicators would bring the SEZ program up to date with current industry standards. Similarly, current methods for evaluating proposed indicators and thus determining SEZ boundaries are suggested to improve the consistency of SEZ delineation across SEZ practitioners.
- The Field Delineation Workgroup has proposed a pragmatic scheme for SEZ delineation and review that takes into account the different types and scales of project actions.
- A simple SEZ classification scheme is proposed based on California's Aquatic Resource Classification System and augmented to reflect Tahoe Basin ecology and existing SEZ policy. The proposed classification scheme includes and describes the different types of SEZ that exist in the Basin and should be valuable in supporting monitoring, restoration and regulatory efforts.
- The aquatic features mapping resulted in the most accurate and comprehensive datasets ever developed for the Lake Tahoe Basin. Additional attribution work is needed to bring the aquatic resource map into compliance with CARI and NHD standards.
- The aquatic resource map was core to developing the first ever basin-wide map of SEZ. SEZ types and boundaries should be considered as *potential SEZ*; some of the features were developed from



soils and LiDAR-derived topographical and hydrological models, they do not necessarily reflect on the ground conditions.

- The map of potential SEZ produced in this project indicates that there is considerably more SEZ (29,391 acres) than has been previously reported (approximately 17,700 acres according to TRPA 1977). This is likely a function of higher resolution base data used for this project.

More work is necessary to continue to refine our understanding of the watershed/lake relationships and the role of streams in both mitigating potential harmful inputs to the lake as well as the intrinsic habitat values of riparian habitat to the Tahoe Basin ecosystem. However, the findings of research completed in the last few years will clearly help design restoration projects that more effectively reduce pollution and enhance habitat values.



Exploration and Outreach
Education about meadows at the Tahoe City Field Station

CHAPTER 4: FUTURE SCIENCE NEEDS

TAHOE FUTURE SCIENCE NEEDS WORKSHOP – SUMMARY MAY 31, 2016

FUTURE RESEARCH NEEDS

On May 31, 2016, over forty representatives from the science community and Lake Tahoe Basin management agencies met to discuss the role science has played in supporting management actions and to suggest future research needed to sustain science-based decision-making. The group was asked to share their insight on the role the SNPLMA Science Program has had informing management actions, identify gaps in our current knowledge, and suggest ways to enhance information sharing among scientists, managers and the public. Future research needs were identified from both an inquiry-driven science perspective and a management-driven science needs perspective. The points summarized below represent high priority issues identified by a diverse set of Lake Tahoe Basin stakeholders. That said, we acknowledge that these thoughts are not an exhaustive, comprehensive, or exclusive list of future science needs but it gives us a perspective as we look towards into the future of science in the Lake Tahoe Basin.

Projects funded by SNPLMA Science Program (through ~\$3.4M in research grants awarded annually during the years 2007-2013) fell under seven major science theme areas: 1) Air Quality; 2) Climate Change; 3) Forest Fuels and Vegetation Management; 4) Habitat Improvement; 5) Lake Quality; 6) Stormwater Management; and, 7) Stream Restoration. Future Science Needs Workshop participants were asked to reflect on whether these theme areas cover all of the science needs for future research in the Lake Tahoe Basin and to suggest new topic areas that should be considered for future research. They were also asked to



identify gaps in existing knowledge and ways to improve the conveyance of scientific findings to managers. Major topics covered by this discussion included climate change, basin-wide studies and data needs, air quality, road infrastructure impacts on water quality, and socioeconomic studies. The following are key points raised by the workshop participants.

I. CLIMATE CHANGE

SCIENCE PERSPECTIVE:

- Climate change evolved as a pressing area for scientific research in the Lake Tahoe Basin after the SNPLMA Science Program was established and during a period when the management agencies were still grappling with understanding the near-term impacts that climate change may have on the ecological and built communities in the basin. Projects focused on understanding the impacts of warming temperatures and changes in the timing and form of precipitation on lake clarity, vegetation composition, and habitat integrity were supported during the later years of the SNPLMA Science Program.
- A key study (Coats, et al, 2010) examined the impacts of climate change on lake clarity using one Global Climate Model (GCM) and several emissions scenarios. Although the study was limited in scope, it did reveal the potential for major impacts to lake clarity and mixing with warming temperatures. In particular, it predicted a decline or cessation of full (top-to-bottom) lake mixing by mid-century with warming air and lake temperatures. Without mixing the lake would become anoxic near the bottom, which could cause nutrient leaching from lake sediments, which will in turn have significant impacts on the lake nutrient budget. Important follow-on research would be to explore the likelihood of these changes under new GCMs and emission scenarios. Another research area would be to investigate the role that extreme weather events (e.g., atmospheric river storms, high wind events, prolonged heatwaves) may have on aquatic, terrestrial and atmospheric processes in the lake and basin. These events could have disproportional effects on basin ecology and may occur more often because of climate change, but GCMs do not model such events very well.
- Understanding the impacts of climate change on hydrology in the Tahoe Basin is still a pressing research need. At present, more is known about the climate impacts on water quality than on water quantity. When the water level in Lake Tahoe drops below the rim, there are obvious effects on downstream water users, but the impacts on ecological and human communities inside the basin has not been studied extensively, e.g., we need to understand the impacts of extended droughts with numerous years with lake levels below the natural rim. In addition, as more winter precipitation comes as rain instead of snow, the impact of changing hydrologic conditions on streamflows, groundwater supplies, and restoration projects needs to be examined.



- The Tahoe Basin could serve as a model site for integrated research on climate impacts and adaptation in mountain aquatic ecosystems and wildland-urban interfaces. Extensive research and environmental monitoring already conducted (or ongoing) in the basin, along with the established partnerships between scientists and environmental managers make Tahoe an ideal venue to further the science of climate impacts and adaptation. This may be an opportunity to draw researchers from outside of the basin, positioning Tahoe at the forefront of climate research.
- Additional areas for research are presented in a research strategy for climate research in Tahoe developed for the TSC, entitled Climate Change Research Strategy for Atmospheric Processes Impacting Lake Tahoe (Kunkel, 2014).

MANAGEMENT PERSPECTIVE:

- Managers in the Tahoe Basin are aware that long-term climate impacts are likely, but aren't sure what to do with climate change information, or how to apply and incorporate it into near-term management practices.
- Climate resiliency seems a worthy goal, but it is hard for managers to determine how to define, achieve or measure this.
- Many federal and state agencies have been directed to develop climate adaptation plans and have already invested significant resources to develop these plans at the national or regional level. Similar efforts at the local or field remains a daunting, politically charged, and often unfunded task.
- National-level climate studies are difficult to interpret at a local level. Coordination between scientists and managers is necessary in order to downscale results of national-level climate studies, develop strategies for climate science in the Lake Tahoe Basin, and interpret the results of climate studies in ways that are relevant to managers.
- An integrated strategy for dealing with climate change throughout the Lake Tahoe Basin that addresses both ecological and socioeconomic impacts would be useful.
- Unanswered questions remain about how climate change may impact the ability of basin agencies to meet their goals under the Total Maximum Daily Load (TMDL) program. In particular, more information is needed to understand how/when changes in deep mixing may occur and the resultant potential impacts from the release of nutrients stored in bottom sediment on lake clarity and TMDL targets. At present it is not clear if current TMDL regulations will be effective and achievable under future climate conditions.
- Better translation of the science is needed to help managers anticipate and mitigate the impacts of climate change.



II. BASIN-WIDE STUDIES & DATA NEEDS

SCIENCE PERSPECTIVE:

- The science community has a strong interest in developing more comprehensive (temporally/spatially) and centralized basin-wide datasets and basin-wide models that can be accessed and updated regularly. Securing funds to collect and manage a basin-wide data repository has been a major challenge. Shared data resources would greatly enhance information sharing among scientists and with managers.
- A lake-wide program for monitoring the introduction, spread and impacts of aquatic invasive species (AIS) is needed. Project-level AIS monitoring studies are not sufficient to validate the impact of AIS lake-wide. Surveillance, monitoring and modeling are needed to map the nearshore areas at the highest risk for AIS invasions. More research is needed to characterize the range, lifecycle and impact of current significant problem invasives (e.g., Asian Clams, Eurasian Milfoil) and to predict how climate change will impact these species and/or support the introduction of new AIS. Increased and longer monitoring activities will provide for more accurate assessments of the effectiveness of treatment projects and help determine if future treatments are needed, how often, and how extensive (e.g., in deeper water).
- New measurements and focused research are needed understand the physics of the nearshore (including streamflows, stormwater runoff) and littoral processes around the entire lake. These studies will directly inform resource management plans to guide and prioritize future nearshore restoration efforts.
- Soil science research was limited during SNPLMA to soil impacts from prescribed fire. Future research to characterize the type and health of soils and vegetation basin-wide would inform the implementation of new land-use designations, guide fuel management and treatment projects, and further refine erosion modeling capabilities.

MANAGEMENT PERSPECTIVE:

- Additional monitoring data is needed to assess the long-term effectiveness of restoration projects; however, acquiring funds and developing statistically rigorous sampling schemes to monitor projects beyond the implementation phase is still very difficult.
- Creation of an interactive data portal that includes technical reports, publications, datasets, and other sources of scientific information would be exceedingly beneficial to managers.
- When using datasets that were collected by researchers, managers need guidance on how to interpret and use the data.



- More robust basin-wide datasets and baseline data are needed to enable managers to prioritize ecosystem restoration and protection projects and to justify funding requests for landscape scale restoration efforts.
- Integrated scientific approaches are needed to evaluate multi-benefit aspects of major large-scale restoration projects. Future project assessments should incorporate metrics for evaluating landscape scale projects across a range of factors including habitat and ecosystem protection, lake clarity, fire risk reduction, recreational benefit, and climate resiliency.

III. AIR QUALITY

SCIENCE PERSPECTIVE:

- Projects funded by the SNPLMA Science Program have studied ozone and particulate matter distributions in the basin and the interactions between air and water quality; however, major questions still remain about the how much of the pollution (ozone, PM_{2.5} and PM₁₀, NO_x, and others) is being transported into the basin vs. how much is produced locally. A major impediment to improving the models of airborne pollutants is the lack of continuous air quality monitoring in the basin, along the Sierra Crest, and on the western slope. Advanced computational capabilities and transport models are available now that could significantly improve our understanding of pollutant transport in the Tahoe Basin. Maintaining and expanding air quality monitoring is required to validate the models and to assess the potential impacts of climate change on pollutant distributions.
- Reevaluating and improving air transport models is essential to understanding the relative contribution of airborne deposition of nitrogen compounds on the lake surface and how this impacts nutrient loading. New models are currently available that could refine the estimates of airborne nitrogen loading on the lake. These data could help inform future TMDL targets and compliance goals.
- Developing the next generation of air quality models to include aerosols, black carbon, and other factors could contribute to better understanding visibility standards, vegetation health, snow albedo and snowpack dynamics, and the impacts of climate change on terrestrial and aquatic ecosystems.

MANAGEMENT PERSPECTIVE:

- Air clarity (not just “quality”) may be as important to the public as lake clarity. We need new tools and approaches to determine what about air clarity is the most important to people who live, recreate, and travel in the basin, e.g., what constitutes good, bad, acceptable days for different purposes.



- Resolving (or reaffirming) the current models of nitrogen loading on the lake is essential to ensuring the current TMDL targets are obtainable.
- Tradeoffs between prescribed burns and air quality management exist throughout the west, including the Lake Tahoe Basin. From a management perspective, prescribed fire smoke is significantly less disruptive than wildfires. Better approaches are needed to assess and communicate to the public the relative risks and impacts of wildfires vs poor air quality/clarity events.
- Regardless of whether pollution is coming from out-of-basin or in-basin, there remain major advantages to implementing programs get more cars off the roads including enhancing basin-wide transportation and increasing bikeways. Refining the air quality models to improve estimates of the relative contribution that reducing vehicle miles traveled (VMT) has air quality, noise and other threshold standards would be beneficial to the basin agencies involved in evaluating and prioritizing current and future threshold standards.

IV. ROAD INFRASTRUCTURE IMPACTS ON WATER QUALITY

SCIENCE PERSPECTIVE:

- Projects funded by the SNPLMA Science Program, Nevada License Plate Program, and other state/local agencies have been focused on quantifying how fine sediments washed from roadways and urban areas degrade lake clarity. Long-term monitoring of nearshore conditions and integrated water transport models are needed to assess the effectiveness of stormwater management, road maintenance, and other management actions on lake clarity.
- Research into alternative roadway composition such as new mixes of asphalt, changes in grading and maintenance, and improvements in driveway sealers could help state and local agencies prioritize investments and rules/regulations designed to reduce the impact of the built environment on lake clarity. To date no research has been done to probe the impacts of volatile chemicals and asphalt composition on water quality.
- Integrated physical and socioeconomic models could be used to evaluate how and when changes in the built environment (e.g., the creation of town centers throughout the basin) may be reflected in changes in water quality thresholds for both the nearshore and pelagic lake.

MANAGEMENT PERSPECTIVE:

- Many of the roads in the Tahoe Basin are continuously in need of maintenance and repair due to winter freeze/thaw, intense snow removal, and heavy winter/summer traffic. Current estimates are that 15-25% of the total fine sediment in stormwater results from particulates from the degrading roadways themselves. New research is needed to evaluate the potential



benefits that may result from changes in asphalt composition and changes in road maintenance techniques.

- State agencies and local jurisdictions responsible for road maintenance need more specific data about how improving roads may improve (or not) water quality including measurements of the pavement condition index (PCI) and evaluations of methods to improve pavement integrity.
- Limited research has been conducted to date to understand how climate change – in particular increased extreme winter storms with more precipitation as rain vs. snow – will impact stormwater composition, roadway integrity, and lake clarity. Quantifying the potential impacts that changes in temperature and precipitation will have on roadways and paved surfaces would help agencies and jurisdictions prioritize resource investments in road infrastructure maintenance and improvements.

V. SOCIOECONOMIC STUDIES

SCIENCE PERSPECTIVE:

- Socioeconomic research was not supported by the SNPLMA Science Program despite being presented as a major science need in the 2010 Tahoe Science Plan (USDA USFS/PSW GTR PSW-GTR-226, May 2010). To date, there has only been a limited number of research projects (supported by agencies outside of the Tahoe Basin) that studied the socioeconomic drivers of environmental change, public perceptions of ecological conditions, and the cost/benefits of ecological remediation and protection. Engaging the socioeconomic research community in the Tahoe Basin would provide the agencies with more rigorous data to support the development and implementation of policies, regulations, and programs to protect the unique natural resources and community development of the Lake Tahoe Basin.
- Recently collected demographic and community indicator data could be incorporated into socioeconomic models to assess the well-being and resilience of Tahoe Basin communities and to inform measures to enhance the economic prosperity of the residents, improve visitor experiences, and preserve ecological resources.

MANAGEMENT PERSPECTIVE:

- There is a lot of pressure from the public and public entities to bring more people into the basin to live, and recreate in urban areas, recreational areas, and the backcountry, but management agencies have few data and validated tools to assess how increases in access and usage will impact wildlife, forest health, water and air quality, recreation experiences, and other factors.
- Socioeconomic studies could help inform the development and implementation of policies and programs to maximize both ecological preservation and the quality recreational



experiences through actions including (but not limited to) placing a cap on the number of people that have access to particular areas at particular times.

FUNDING FOR FUTURE RESEARCH

With the end of the SNPLMA Science Program funding, scientists and managers are exploring new ways to fund future research. Various ideas on how to fund new projects were discussed.

SCIENCE PERSPECTIVE:

- Some individual and/or teams of scientists are returning to a more traditional funding approach that involves pursuing support for research from the science-based federal agencies including the National Science Foundation (NSF), National Oceanic & Atmospheric Administration (NOAA), U.S. Forest Service (USFS), Environmental Protection Agency (EPA), U.S. Geological Survey. It should be noted that the research budgets for most of these agencies have declined over the last decade and they do NOT, in general, support dedicated place-based research for the Lake Tahoe Basin.
- The SNPLMA Science Program provided a unique opportunity for the science community to work collaboratively with Tahoe Basin agencies to identify science themes, prioritize research areas, and address management needs. However, the timeline for science delivery was not always able to meet the immediate near-term needs of the management agencies. A more diverse portfolio of science funding spanning inquiry-driven research funded by federal science agencies to applied research funded by state/local entities may provide a more robust basis to support science-based decision-making in the Tahoe Basin.
- One option to better integrate science and management would be to build specific applied research objectives into management projects, e.g., scientists and managers cooperatively develop research plans, collect data, and assess the findings for informing adaptive management. This approach could provide a more direct path to integrating science and management. While this may add to the cost and timeline of some management projects initially, it may in the long run reduce project implementation costs and improve project effectiveness.
- Advancing the education of the general public is an area that could be expanded in future science programs in the basin. Incorporating public education into federal grant proposals to agencies such as NSF is an effective means of demonstrating the broader impacts of inquiry-driven research.

MANAGEMENT PERSPECTIVE:

- With the end of SNPLMA Science Program, alternative funding sources need to be identified to support landscape-scale, basin-wide studies such as a Tahoe Basin Climate Assessment. A growing number of public agencies and private research foundations are now focusing their



resources on science in support of landscape-scale ecosystem management. This opens up opportunities for Tahoe basin management agencies and scientists to develop integrated approaches for ecological restoration, remediation and protection based on multi-benefit criteria (e.g., wildfire risk reduction, stream restoration, habitat protection, and recreation benefit).

- Another possibility for obtaining funding for applied scientific studies would be to incorporate them directly into multi-agency, basin-wide adaptive management plans. One example of this would be the development a basin-wide stormwater plan that would integrate research to support TMDL implementation with focused assessments of the risks and impacts of climate change on lake clarity and nearshore conditions.
- A major, ongoing challenge for management agencies and scientists is the lack of funding for long-term, persistent environmental monitoring, especially for measuring environmental change over times that extend beyond the scope of project effectiveness evaluation. These monitoring data are critical for both future scientific research and effective adaptive management planning and implementation. Including robust monitoring programs as an integral component of future management projects would help reduce future project costs and streamline the evaluation of project effectiveness.
- An informed and engaged general public can help garner more support for both science and management projects.

SCIENCE DELIVERY NEEDS

TRANSLATING SCIENCE TO PUBLIC

- The SNPLMA Science Program did not explicitly focus on translating science to the general public including science educators and K-12 students. Complementary programs including the University of California Davis, Tahoe Environmental Research Center (TERC) (<http://terc.ucdavis.edu>) have been very effective in making science accessible, interesting and fun for general audiences. TERC programs include volunteer docent-led tours of the TERC Science Center, 3-D visual movies about the formation, history, and ecological health of Lake Tahoe, hands-on science activities and training for K12 students and educators, a Youth Science Institute for high school students, a monthly lecture series targeted at bringing timely and interesting science to Tahoe residents and visitors, and content-specific technical workshops. These programs and similar efforts need to be expanded and become an integral component Tahoe science in the future. Building awareness and appreciation for science and the scientific methods among the general public, youth, and diverse communities can be an effective way of broadening the commitment to science-based management in the Tahoe Basin.



- Another effective program that has engaged the public in science discovery are the education and citizen science programs supported by the League to Save Lake Tahoe (<http://www.keeptahoeblue.org>) including, Blue Schools program for K-6 about stormwater and aquatic invasive plants, the Eyes on the Lake and Pipekeeper programs that engage recreation enthusiasts and the public in monitoring nearshore conditions. By collaborating with management agencies these programs are breaking down the barriers between scientists, managers, and the public and making environmental protection a shared responsibility.

DELIVERING SCIENCE TO MANAGERS

- Future research efforts will benefit from more direct collaborations between scientists and managers throughout the lifecycle of the projects including developing proposals, sharing results during the project, and assessing the policy and management implications of the findings. This approach can be time intensive for both scientists and managers, but often results in science that is impactful and informative to stakeholders. Dedicated funding to support people who are expressly devoted to science delivery and bridging the gap between scientists and managers is usually an investment that pays noteworthy dividends.
- A persistent challenge in applied research is bridging the gap between the time it takes to conduct a credible scientific experiment and the planning/execution timescale of management actions. Engaging the scientific community early in program planning stage can help bridge this gap. Successful examples of this approach include the joint development of a basin-wide Aquatic Invasive Species Science Action Plan by both scientists and managers, development and implementation of the TMDL Program, and building the Water Erosion Prediction Project (WEPP) model.
- Science briefs, workshops, panel discussions, on-line interactive tools, and field tours remain cornerstone tools for forging more regular and effective partnerships between the science community and their management agency partners.

THOUGHTS FROM THE AUTHORS

As the Lake Tahoe basin transitions from the SNPLMA-supported research era into new ways of supporting science-based decision-making in the future, several additional questions regarding the delivery of science should be considered.

- *How will future research needs be prioritized?* Prioritization of research needs by scientists and managers enabled the progress to be made within the SNPLMA Science Program. How will this be done in the future in the absence of a fixed pool of resources to support applied science in the Basin? Some managers have suggested that the newly created Bi-State Science Council might create a list of science priorities that could be used to encourage interest in priority areas. Prioritization of research needs is key to implementing adaptive management



and increase the sense of urgency for the research. For example, given the above discussion it is likely that the current iteration of the TMDL it is likely to change as monitoring results validate or identify the need for modifications to the TMDL goals/targets. Applied research will be needed to guide that change and continue to improve our basic understanding of lake clarity.

- Is more or different coordination among research entities and agencies desired to avoid duplication and maximize the utility of funded projects? If so, what mechanisms need to be maintained or establish to accomplish this?
- Is a new shared data portal needed to stimulate information sharing about standard monitoring methods and equipment, standardized sampling protocols, and uniform quality control processes. Some managers and scientists have suggested that this basin-wide resource would help streamline approaches, coordinate projects, and make results more accessible and relevant to multiple stakeholders.
- Would the research and management communities benefit from supporting a shared resource that encourages technology transfer of the research capabilities? This may involve engaging other organizations in the Tahoe Basin including the Tahoe Prosperity Center to educate and encourage scientists to transition their research tools into innovative marketable technologies.
- How will long-term environmental monitoring be supported beyond project implementation to ensure that current and future management decisions and scientific research are based on reliable data? Every management project has monitoring requirements associated with it, which at present are heavily focused on agency-specific project evaluation needs.
- Coordinating and funding integrated monitoring programs is required to assess landscape-scale, multi-benefit aspects of large-scale projects and to ensure uniform protocols and tools are used to collect and analyze data.

IN CONCLUSION

The Lake Tahoe basin has served as a proving ground to demonstrate how focused research can be integrated into management actions to address complex ecological problems. With the sunset of the SNPLMA Science Program, it is critical that the scientists and managers do not lose this momentum and continue to build on the strong partnerships that have developed over the last decade. The breadth and pace of ecological change in the Tahoe Basin suggests that an engaged scientific community in partnership with active, energetic, and informed managers will continue to be the linchpin for preserving Lake Tahoe as a national treasure for all to experience for generations to come.



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¹ Basic research was needed, however, executives acknowledged that in retrospect, there was distrust between agencies that caused some research to be focused on proving that work done outside the basin was also applicable in the basin. They also pointed out that this perspective has changed as time has passed and as agencies have become more collaborative in pursuing their shared objectives.

² Research Needs for the Lake Tahoe Basin (LTARCB 1974), Lake Tahoe Environmental Assessment (WFRC IRTF 1979), Lake Tahoe Case Study (Elliott-Fisk et al. 1996), Environmental Improvement Program (EIP) (TRPA 2001), Lake Tahoe Watershed Assessment (Murphy and Knopp 2000), Key Management Questions (SAG 2001). The latest iteration is “An Integrated Science Plan for the Lake Tahoe Basin: Conceptual Framework and Research Strategies” 2010.

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APPENDIX A: TSC FACT SHEETS

Science and Management Partner to Assess and Improve Lake Tahoe's Air Quality



Thick plume of smoke rising from 2007 Angora Fire

Residents and visitors to Lake Tahoe expect clean mountain air and a spectacularly blue lake. Maintaining the air quality around Lake Tahoe is important to the health and well-being of the people who live, work and visit Tahoe, as well as to plants and wildlife in the basin. Current research and monitoring efforts are helping land managers and regional regulatory agencies understand how human activities and natural phenomenon affect Tahoe's air quality.

Key Management Questions

Research and monitoring is needed to help managers and regulators understand the sources of air pollution in the basin, the impact of airborne pollutants on lake clarity, and what can be done locally to improve Tahoe's air. Key management questions include:

- Is Lake Tahoe's air healthy to breathe?
- What pollutants most affect the clarity of Lake Tahoe?
- What causes regional haze in the basin?
- How does air pollution affect the health of Lake Tahoe's forests?
- What are the sources of the observed air pollution?



Smog from smoke and suspended fine particles over the lake in summer.

Science Investments to Address Key Management Questions

Events such as regional haze, changes in lake clarity, wildfires, and unhealthy vegetation have prompted management agencies to partner with researchers to investigate the sources and impacts of air pollution in the Tahoe Basin. Examples of research activities include:

- Characterization of the nature and source of pollutants affecting lake clarity
- Monitoring and research to identify the chemical composition and source of gaseous, particle, and aerosol pollutants
- Transport models of local, regional, and global airborne pollutants
- Development of a basin-wide air quality monitoring plan and installation of a network of stations to track seasonal and long-term variations in air quality
- Analysis of 20 years of monitoring data from two visibility monitoring sites (Bliss State Park and South Lake Tahoe) to determine the role that natural and man-made aerosols play in creating regional haze in the Tahoe Basin.
- Leaf injury surveys and ozone monitoring to investigate the occurrence of ozone-induced leaf injury to Jeffrey pines and ponderosa pines in the Tahoe Basin.



Ozone injury to ponderosa pine needles

Key Science Findings

- As much as 15 percent of annual fine sediment load deposited into the lake may come from atmospheric sources. Approximately 55 percent of the nitrogen and 15 percent of the phosphorus annually deposited into Lake Tahoe also comes from atmospheric sources.
- Pollution originating in the Central Valley from photochemical smog, ozone production, and nitric acid emissions only modestly contributes to degradation of Lake Tahoe's air quality, due to the buffering effect of the mountains west of Tahoe.
- Vehicles and power boats are the dominant in-basin sources of the ozone-forming precursors.
- Biomass burning from wildfires, forest fuel reduction burns, and residential wood fires is the dominant source of regional haze. Road dust and traffic are significant contributors to haze in South Lake Tahoe, while industrial combustion and salting are minor sources of visibility impairment.
- Ozone causes premature leaf loss, reduced photosynthesis, and reduced leaf, root and biomass in about 25 percent of Jeffrey pines and ponderosa pines in the basin.

Management Actions Taken

Air quality management agencies are dedicated to improving Lake Tahoe's air quality and reducing the impact of air pollution on environmental and human health in the basin. Actions taken include

- Coordination and standardization of air quality monitoring efforts and increased sharing of monitoring results with the public
- Assessment of options to improve air quality in the Tahoe Basin, including targeted regulations, incentive programs, burn-time restrictions, innovative land use planning, and capital improvements to enhance access and use of green (low-emission) transportation on and around the lake.

Next Steps

Scientists and managers are working collaboratively to use meteorological and air quality data to predict future levels and sources of ozone and other pollutants and to assess the efficacy of alternative air pollution control strategies. Air monitoring data, satellite imagery, and meteorological data are being integrated to develop a science-based strategy for reducing the impacts of biomass burning in the Tahoe Basin.



Ponderosa pines with different sensitivity to ambient ozone

Where to go for more information

Current Lake Tahoe Air Quality Research:

www.fs.fed.us/psw/partnerships/tahoescience/air_quality.shtml

California Air Resources Board: www.arb.ca.gov

Science and Management Partner to Prevent & Control Aquatic Invasive Species in the Lake Tahoe Basin

Establishment of aquatic invasive species (AIS) is of great concern due to their adverse impacts to Lake Tahoe. Invasive aquatic plants and animals cause decreased water quality, algal blooms, fouling of beaches, health and safety concerns for swimmers, threats to native species, interference with watercraft function and marina operations, and economic impacts due to reduced recreation quality, decreased property value, and the high cost of control actions.

Key Management Questions

Over the last decade, the size of the areas affected and the scale of the ecological impact of AIS infestations has increased dramatically. Key questions for scientists and managers include:

- How extensive are AIS infestations and what impacts do they have on aquatic resources?
- Which control methods are most effective and affordable?
- Which species pose the greatest risk for invasion in the future?
- What management actions are needed to prevent, detect and respond to future AIS?



Photo courtesy: Tahoe Daily Tribune. Boat inspection station on road entering the Tahoe Basin.

Science Investments to Address Key Management Questions

The spread of invasive species into Lake Tahoe has prompted agencies to invest in science to understand AIS distribution and ecology, factors regulating colonization and growth, and options for removal. Research activities include:

- Lake-wide survey for Asian clams to study distribution and population structure
- Use of bottom barriers as a control strategy for Asian clams
- Lab experiments to determine risk of quagga mussel invasion
- Studies of the ecological response to removing non-native warmwater fishes (initiated in 2011)
- Modeling risks of introducing new AIS to Lake Tahoe as a result of boat movement between waterbodies in the region
- Testing and evaluating suction removal, hand-pulling, bottom barriers, and chemicals to treat rooted aquatic plants
- Studies on how resident AIS may facilitate new invaders
- Estimates of the economic impact of AIS invasions
- Development of cost effective prevention and control strategies for all invasive species



Photo courtesy of Phil Caterino. Algal bloom in Emerald Bay.

Key Science Findings

- Rubber bottom barriers result in 100 percent Asian clam mortality. This technique was successfully transferred to Lake George, New York where a recent invasion has occurred.

- Asian clams have a reduced reproductive capacity with spawning dependent on changes in water temperature.
- Calcium levels in Lake Tahoe are similar to those required for quagga and zebra mussel growth. Evidence of the presence of these species in the lake has not been observed, but the possibility of mussel survival and reproduction cannot be ruled out.
- Changing ecological conditions due to climate combined with the destruction of natural habitats may make the lake more vulnerable to future AIS invasions.
- The AIS aquatic plant, Eurasian watermilfoil, has been found in the Tahoe Keys and in more than 30 other locations lake-wide and its population is expanding annually; a more aggressive plant, curlyleaf pondweed, is expanding in the southern part of the lake.
- Smallmouth bass, a fish predator that prefers cooler water, has been confirmed in the lake and is expected to inhabit a larger portion of the lake than other fish invaders.
- Estimates of the economic impact of AIS in Lake Tahoe are as high as \$22 million/year.

Management Actions Taken

Research has helped guide the implementation of effective management strategies and effective treatment options including

- The Lake Tahoe Region AIS Management Plan
- The Watercraft Inspection Program
- Lake-wide AIS monitoring surveys
- Quagga and zebra mussel plankton monitoring to assist in early detection and rapid response
- Control programs for Asian clams, aquatic weeds and warmwater fish
- Public outreach and education



<http://tahoeboatinspections.com>

Next Steps

Recent gains in the AIS prevention and control program in Lake Tahoe rely on close cooperation between scientists and managers. Future work includes

- Expanding the number of control programs and lake-wide surveys to increase areas treated and evaluate program effectiveness
- Increasing our knowledge of AIS currently or potentially infesting the Lake Tahoe Basin to develop new cost-effective treatment methods and control strategies
- Expanding Early Detection and Rapid Response for new AIS
- Determining the impact of climate change on the spread of AIS
- Developing new proactive management strategies that shift from detecting and treating existing invasions to anticipating, preparing for, and preventing future invasions

Where to go for more information



More information on Tahoe AIS can be found at:

<http://www.cabnr.unr.edu/chandra/> and at
<http://terc.ucdavis.edu/research/aquaticinvasives.htm>

Science Impacts on Forest Health in the Lake Tahoe Basin

Forests are integral to the aesthetics, fish, recreation, urban values, water, wilderness, wildlife, and other ecosystem services in the Lake Tahoe Basin. Restoring and maintaining forest health is paramount to ecosystem resiliency to fire, insects and disease, and other disturbances and is critically important to local communities.

Key Management Questions

Forest management requires understanding the processes that contribute to forest health and understanding the impacts that treatment or protection measures have on valuable forest resources. Management actions typically aim to restore forest ecosystems to healthier and more fire-resilient conditions, while reducing the risk of catastrophic fire to the surrounding communities. Key management questions include:

- How can forest health be restored while minimizing the effects of treatment measures on water quality, air quality, soils, habitats (plants and wildlife), aesthetics, and recreational experience?
- What is the effect of prescribed burning (pile or broadcast) on soils and how will this affect their ability to infiltrate water and nutrients?
- How effective are current treatments for improving forest resiliency to fire, insect attack, and mitigating the impacts of a changing climate?
- What regulatory and economic factors impact the effectiveness of treatment measures for reducing hazardous fuels, and restoring and sustaining healthy forests?

Science Investments to Address Key Management Questions

Science continues to improve our understanding of what constitutes a healthy forest, historically and today. These investments are informing management by:

- Reconstructing historic forest structure and fire return intervals
- Demonstrating the use of operating mechanized equipment in stream zones
- Developing restoration options for forest components impacted by exotics
- Measuring impacts of restoration treatments on watershed and lake values



Slaughterhouse Canyon near Glenbrook, NV
Photo by C.E. Watkins: 1873

Key Science Findings

Research has examined the effects of using mechanized equipment and controlled burns for fuels reduction on air quality, fire history in riparian areas, aspen restoration, sugar pine and other five-needle pine restoration, soil nutrient cycling, runoff water quality, and erosion risks. Preliminary results, ensuing symposia and presentations resulting from this research have provided forest managers and policymakers the opportunity to discuss and generate feedback to the researchers, identify new questions, and refine policy. Based on the preliminary findings a common theme is emerging that many of the treatments typically employed within the Lake Tahoe Basin pose little to no risk of adverse impacts

on lake clarity especially when coupled with appropriate Best Management Practices (BMPs). Some key findings include:

- The use of low ground pressure equipment in stream zones has been demonstrated to be an acceptable practice.
- Current fire frequencies are at their lowest over the past 12,000 years.
- Lack of fire has had a major influence on forest composition and structure, drought-induced mortality, disease and insect infestation, nutrient cycling, runoff water quality, and erosion.



Before Hand Thin Treatment



After Hand Thin Treatment

Management Actions Taken

Information generated from the science community has and will continue to add to project-level planning. Management actions taken include:

- Using mechanized equipment in stream zones to conduct tree thinning, reduce hazardous fuels, remove encroaching conifers, and restore aspen stands
- Providing education and outreach to the communities through events, media and collaboration on emerging science related to management actions

Next Steps

Syntheses of the scientific literature with a focus on key management questions need to be compiled in order to better understand the social and economic interactions between forest ecosystems and the impacts of restoration treatments.

Where to go for more information

Forest Health and Fuels Management Research:

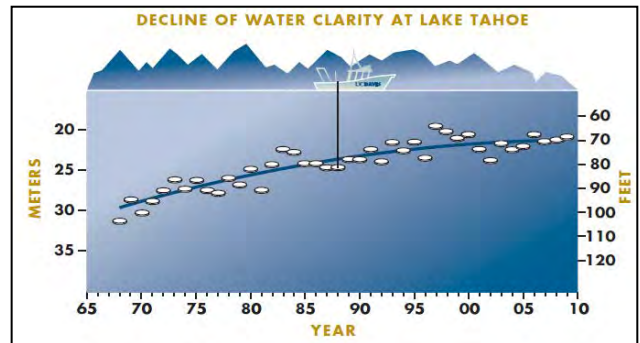
http://www.fs.fed.us/psw/partnerships/tahoescience/fuel_management.shtml

Proceedings of the February 2010 conference held at McClellan, CA, “Pre- and Post-Wildfire Forest Management for Ecological Restoration and Fire Resiliency”:

<http://ucanr.org/sites/Prepostwildfire/>

Science to Improve Lake Tahoe's Water Quality and Clarity

Lake Tahoe's water quality is world renowned. The rare deepwater lake has unique color and exceptional clarity, and contains a diverse aquatic ecosystem. However, long-term monitoring and research have revealed that Lake Tahoe has experienced a decline in water quality since the late 1960s. Degradation of Tahoe's water quality threatens its ecological functions and status, and its value as a recreational destination, its use as a drinking water source, and its value to the local and regional economies.



Source: UC Davis TERC (<http://terc.ucdavis.edu/>)

Lake Tahoe is differentiated into two zones: deep-water and nearshore. Monitoring data indicate a decline in the water quality of both zones. Since 1968, deepwater clarity has been reduced by approximately 30 percent, from 100 to 66 feet due to increased concentrations of fine sediment and nutrient levels. Similarly, the nearshore has been degraded due to algal blooms and the impact of aquatic invasive plants and animals.

Key Management Questions

- What are the types and sources of pollutants affecting the lake's water quality?
- How much pollution is entering the lake and what reductions are necessary to achieve water quality goals?
- What is the best way to go about restoring lake clarity?
- Is the strategy to restore lake clarity working and is it resulting in commensurate benefits to the nearshore environment?
- Are agency approaches for protecting the nearshore appropriate and based on the best available science?

Science Investments to Address Key Management Questions

During the past decade, research and monitoring activities have focused on understanding and quantifying pollutant inputs and lake response, and on evaluating the most cost-effective approaches to achieve pollutant load reductions. Major accomplishments include:

- Conducting a source analysis as a part of the Lake Tahoe Total Maximum Daily Load (TMDL) to provide baseline basin-wide pollutant load estimates from different sources
- Developing the Lake Clarity Model, capable of predicting the lake response to various pollutant loading scenarios in different combinations
- Implementing research projects to identify appropriate nearshore indicators and evaluate appropriate water quality standards to help guide restoration strategies
- Developing a monitoring program for evaluating Best Management Practice



Load reductions needed to meet TMDL targets for fine sediment particles (FSP), total nitrogen (TN) and total phosphorus (TP) (Source: Lahontan Water Board and Nevada Division of Environmental Protection).

(BMP) effectiveness and status and trends of urban stormwater quality.

Key Science Findings

- Inorganic fine sediment particles less than 16 micrometers (about 1/3 the diameter of a human hair) are the main pollutant impacting deepwater clarity. However, nutrients also play an important role, particularly with respect to the nearshore condition.
- Model results estimate that a 65 percent reduction in fine sediment particle, 10 percent reduction in nitrogen, and 35 percent reduction in phosphorus loading to the lake are needed to restore deepwater clarity for Lake Tahoe.
- While load reductions are achievable in all major source categories, restoration depends heavily on managing urban stormwater runoff which is both the greatest source and greatest opportunity to control fine sediment particle and nutrient inputs to the lake.

Management Actions Taken

New scientific information has changed the focus on how to restore Lake Tahoe's clarity and water quality. In response to this, the following management actions have been taken:

- Established the Clarity Challenge, which is an interim goal to achieve 80 feet of clarity within 20 years and considers the opportunities for achievable load reductions
- Developed a suite of urban stormwater tools including a hydrologic load reduction model to aid in the development and selection of alternative project designs, as well as rapid assessment methodologies to determine the relative condition of stormwater assets and to prioritize and evaluate maintenance activities
- Developed protocols and methods facilitating the consistent estimation and tracking of progress toward achieving restoration goals
- Initiated a TMDL Management System to ensure continual improvement through monitoring, research, and adaptive management



Pristine Lake Tahoe water on left vs. polluted urban stormwater on right (Source: A. Heyvaert).

Next Steps

Research and monitoring will continue to be an integral part of the restoration strategy through adaptive management. Future agency science priorities include:

- Evaluating the effectiveness of existing and new load reduction technologies and management practices
- Improving and enhancing tools and protocols that track and estimate progress toward achieving restoration goals
- Monitoring status and trends associated with deepwater and nearshore conditions to determine the effectiveness of restoration actions

Where to go for more information

Lahontan Water Board: www.swrcb.ca.gov/rwqcb6/

Nevada Division of Environmental Protection: ndep.nv.gov/bwqp/tahoe.htm

Tahoe Regional Planning Agency: <http://www.trpa.org/>

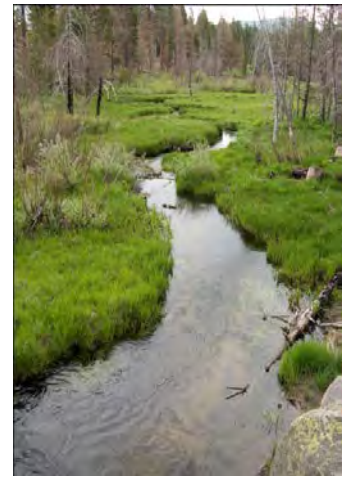
Science and Management Partner to Restore Streams & Meadows in Lake Tahoe

Stream and meadow habitats are critically important to native animal and plant species and provide natural water filtration and flood protection for local communities. Unfortunately, these habitats have been degraded due to development, fire suppression, and other land use practices. Approximately half of the meadow habitat in the Tahoe Basin has been permanently lost, fragmented, or altered.

Key Management Questions

Restoration and enhancement of stream and meadow habitats has been a priority for environmental managers for more than two decades. Despite these efforts long-term, self-sustaining restoration remains a challenge. Key management questions include:

- What is the condition of our stream and meadow habitats throughout the basin, and how is their condition changing over time?
- Have past restoration efforts been effective in rebuilding stream and meadow habitats and enhancing water quality?
- What impact have restoration efforts had on reducing the delivery of fine sediment to lake and restoring lake clarity?



Stream-meadow complex, Angora Creek, South Lake Tahoe, CA. Photo Scott Hinton.

Science Investments to Address Key Management Questions

Scientists and agency representatives are working collaboratively to complete several science projects of relevance to management issues:

- Evaluate the applicability of the California's Rapid Assessment Methodology (CRAM) to assess and track the condition of alpine stream habitats found in the Tahoe Basin.
- Develop and test new rapid assessment methods for wet meadow habitats throughout the Sierra Nevada.
- Develop a framework for planning and evaluating the effectiveness of stream restoration projects in the Lake Tahoe Basin.
- Assess how stream and meadow restoration can help improve the clarity of Lake Tahoe and develop methods to predict the amount of fine sediment that can be prevented from reaching the lake as a result of stream and meadow restoration projects.

Key Science Findings

- A new planning and evaluation framework has been developed, tested and validated to quantify the impacts of stream restoration on the environment and local population centers.
- Evaluation of past projects found shortcomings in Tahoe Basin restoration projects consistent with those found in similar areas across the country. These include inconsistent or incomplete project goals, lack of funding for monitoring and reporting,

and monitoring timelines dictated by funding or regulatory constraints rather than ecosystem response times.

- A restoration study on the Upper Truckee River indicated that up to 70 percent of fine sediment contained in streamwater flowing onto a floodplain can be retained on that floodplain, and hence, prevented from reaching the lake.

Management Actions Taken

- Federal, state and local governments have renewed their commitment to enhance and restore stream and meadow habitats in the Tahoe Basin.
- New research has informed the design of stream and meadow restoration projects, including the adoption of a new planning and evaluation framework.
- New methods for long-term monitoring of the health and functionality of stream and meadow habitats are being implemented.
- New models are being used to estimate the benefit to lake clarity from stream and floodplain restoration and inform stream pollution load reduction targets.



Aerial photo of the Upper Truckee marsh at Lake Tahoe. Photo courtesy of the CA Tahoe Conservancy.

Next Steps

Improving the effectiveness of stream and meadow restoration requires close collaboration of scientists and managers to

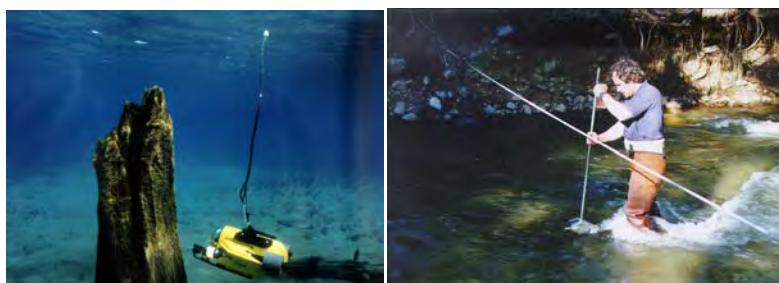
- Create new decision-support modeling tools that help managers understand and anticipate the impacts of restoration
- Implement rapid assessment methods to quickly evaluate the condition of stream and meadow habitats basin-wide
- Develop efficient monitoring and reporting tools to evaluate and communicate the effects of restoration efforts
- Implement adaptive management methods for future restoration projects that incorporate lessons learned and cost-risk benefit analysis

Where to go for more information

For more information on SNPLMA-funded research projects for the Lake Tahoe Basin go to: www.fs.fed.us/psw/partnerships/tahoescience

For more information about the California Rapid Assessment Methodology (CRAM) go to: cramwetlands.org or Lahontan Regional Water Quality Control Board (530) 542-5400.

TAHOE SCIENCE PROGRAM



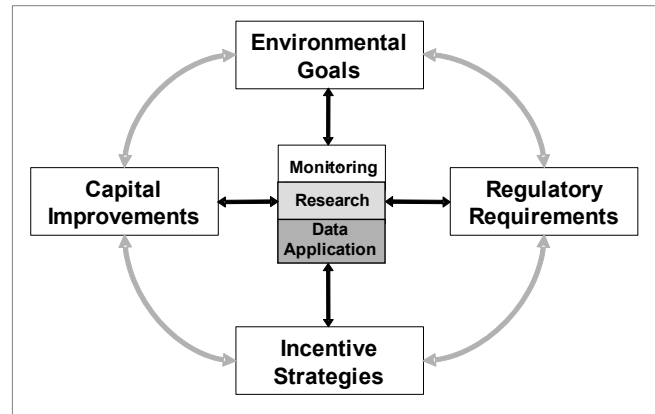
Tahoe Science Program Fact Sheet

“Knowledge is the basis for sound stewardship”

What is the Tahoe Science Program?

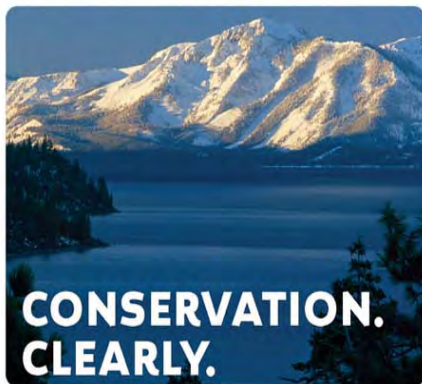
The Tahoe Science Program is a partnership between federal and state agencies, local jurisdictions, and the science community to achieve science-based decision-making and restoration of the Lake Tahoe Basin through environmental monitoring, applied research, and data application.

- *Monitoring* establishes baseline conditions and trends over time and tracks the effectiveness of restoration actions.
- *Research* seeks to understand the complex ecosystem of the Basin and generate information to support effective policies, regulations, and management.
- *Data application* analyzes, interprets, organizes, and reports technical information to environmental managers, regulators and the science community.



Why do we need a Tahoe Science Program?

The Lake Tahoe Basin is a unique and spectacular environment that has been significantly altered since the late 1800s by human activity. Restoring and conserving this area poses a substantial challenge to environmental managers and those responsible for encouraging sustainable development and recreational access.



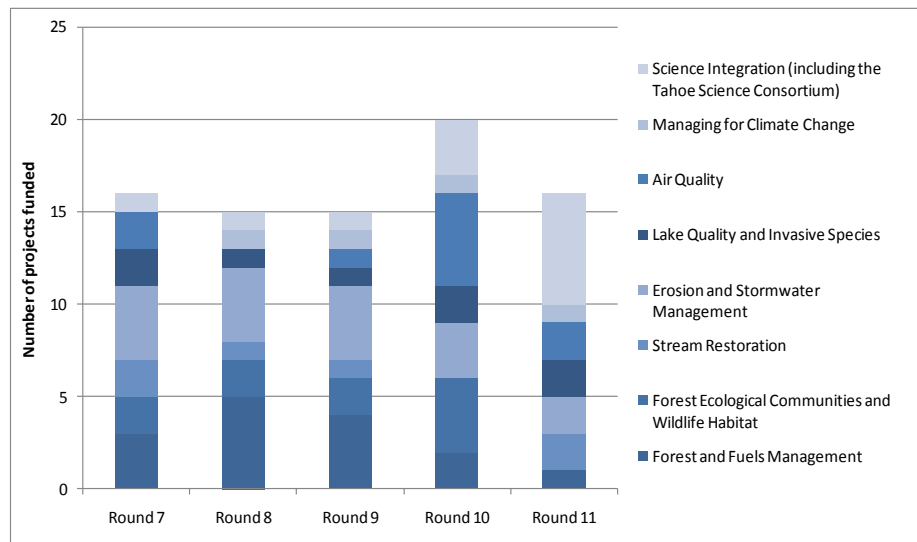
The known effects of past human actions (e.g., clearcut logging and inappropriate development) over the last 150 years and the unique character of the Lake Tahoe Basin have led to broad-based support for substantive conservation and restoration efforts over the last two decades. These efforts have involved close partnerships among government agencies, the private sector, and the science community. Determining the most effective and affordable methods for conserving and restoring Lake Tahoe and its watershed has required scientists, managers, planners, developers,

regulators, and the public to work together to achieve the goal of restoring this national treasure for generations to come. The many challenges that remain require a sustained investment in science to understand the impacts of a changing climate, redevelopment of aging infrastructure, and the effectiveness of today's restoration projects.

What has the Tahoe Science Program done?

The Tahoe Science Program identified key areas of research needed to support environmental restoration and conservation projects and established an applied research program that has engaged a diverse community of researchers from academia, government agencies and the private sector. Accomplishments include:

- Implementing an applied science program, as part of the Southern Nevada Public Land Management Act (SNPLMA), which has provided \$18.75 million since 2007 to support 77 applied research projects and the Tahoe Science Consortium through annual competitive award processes (www.fs.fed.us/psw/partnerships/tahoescience)
- Publishing *An Integrated Science Plan for the Lake Tahoe Basin: Conceptual Framework and Research Strategies* in 2010 (available at www.tahoescience.org)
- Forming the *Tahoe Science Consortium* and establishing the *Science and Management Integration Team*
- Revising the region-wide Status & Trends Evaluation Program to make it the primary source of monitoring information for characterizing long-term environmental and socioeconomic conditions in the basin (available at: www.tahoemonitoring.org)



Research projects funded annually (Rounds) since 2007

What are the benefits of the Tahoe Science Program?

Science is helping to focus and prioritize resource management issues including: Restoration of the lake's renowned historic clarity through the control of excessive fine sediment and nutrient loading, prevention and control of invasive aquatic species, reduction of wildfire risk and improving forest health, informing sustainable development strategies to cope with climate change, and protecting Lake Tahoe's nearshore environment. Partnerships between scientists and managers have resulted in:

- New models to quantify the sources of key water quality pollutants (i.e., fine sediment, nitrogen, and phosphorus) and their impacts on deepwater lake clarity



- New science-based tools to estimate the effectiveness of capital restoration projects and operations to reduce pollutant loads and achieve the goal of restoring lake clarity within 20 years
- Development of techniques to control the spread of aquatic invasive species in Lake Tahoe without the use of chemical pesticides
- Development of advanced planning practices to guide the reduction of excess forest fuels to reduce the likelihood of catastrophic wildfire and improve forest health while minimizing steep slope erosion and adverse impacts to sensitive stream environment zones
- Development of environmental indicators that can guide management solutions to improve the health of Lake Tahoe's nearshore environment

What is the Tahoe Science Consortium?

The Tahoe Science Consortium (TSC) is a unique partnership between two federal agencies and three academic institutions—U.S. Forest Service (Pacific Southwest Research Station), U.S. Geological Survey, the Desert Research Institute, University of California-Davis, and the University of Nevada-Reno—dedicated to providing science to restore Lake Tahoe and its fragile watershed, manage its wildland-urban interface, and anticipate the impacts of climate change. The TSC oversees the selection of the science themes and manages the peer and agency review process for the applied research program, prepares reports, and sponsors workshops, symposia, and interagency committees to enhance the integration of science in environmental restoration. It also sponsors a biennial Tahoe Science Conference that encourages scientists, engineers, artists, economists, environmental managers, regulators, policy-makers, business owners, federal, state, local and tribal representatives, and the general public from the Sierra Nevada and around the world to exchange ideas and develop collaborations to protect high alpine ecosystems under changing environmental and social climates (for more information: www.tahoescience.org)



What is the Science and Management Integration Team?

The Science and Management Integration Team (SMIT) is a standing group of agency representatives and scientists that meets regularly to exchange leading-edge scientific findings and evolving management issues. Its goal is to identify, prioritize, recommend, and communicate research and monitoring activities to accelerate the restoration of Lake Tahoe.

What is the future of the Tahoe Science Program?

The Tahoe Science Program has achieved great success in the past six years and has established the infrastructure, plans, and knowledge base to inform and guide environmental restoration now and in the future. New approaches and funding strategies are being developed to sustain this program beyond the conclusion of the 2000 Lake Tahoe Restoration Act in November 2011 and SNPLMA support for the Tahoe Science Program in 2012.

For more information about the Tahoe Science Program, please contact the Tahoe Science Consortium: (775) 881-7561; www.tahoescience.org

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1. AIR QUALITY

Projects: 1, 13, 41, 60, 61, 62, 63, 64, 65, 75, 76, 94, 95

P001, ROUND: 7, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Examination of dust and air-borne sediment control demonstration projects. Dr. Hampden Kuhns, Dr. Dongzi Zhu, Dr. John Gillies, Dr. Alan Gertler, Dr. Steven Cliff, Dr. Yongjing Zhao, Mr. Scott Brown, Ms. Domi Fellers, Mr. Michael Pook.

Objectives: This project report describes measurements and results collected in the Tahoe Basin that investigate the transport, deposition, chemistry, and emission control strategies of road dust that is a primary component of both the upland loading and atmospheric deposition sources.

Findings:

- Within 5 m downwind of the road, PM_{large} (Total suspendable material - PM₁₀) accounts for half of the airborne mass emissions. PM_{coarse} (PM₁₀ - PM_{2.5}) account for the other half with PM_{2.5} representing less than 0.5%.
- The bulk of airborne emissions will deposit within a few kilometers of the road.
- Phosphorous (a nutrient for algal growth in the lake) airborne concentrations in re-suspended road dust were greatest in fine particles. Phosphorus did not appear to be associated with most of the road dust mass since 85% of roadside phosphorus was in PM_{2.5} size fraction compared to only 20% of the crustal species.
- Roadside fine PM phosphorus concentrations are greatest during peak travel times. A potential source of roadside phosphorus is the burning of motor oil that contain the oil additive Zinc dialkyldithiophosphates (ZDDP). Conservative approximations suggest that the contribution of vehicle exhaust to lake phosphorus loading is very small with an upper limit of 0.02%, far below the major source storm water runoff at 65%.
- Wintertime street sweeping when roads are dry after storms (ASAP sweeping) was the strongest predictor of Emissions Equilibrium (EE, a traffic speed independent measure of road emission strength). Many secondary and tertiary roads are only swept seasonally and serve as a reservoir of material that is suspended into the air when abrasives are tracked onto higher speed roads.

Management Implications:

- On an annual cost effectiveness basis, street sweeping costs \$0.6 per kg PM₁₀ emissions reduced. This estimate does not include capital costs of the sweeper valued at ~\$250K each. These operational costs are less than 0.5% when compared with roads resurfacing of fair conditions roads (\$300 per kg PM₁₀ emission reduction) or resurfacing of poor condition roads (\$700 per kg PM₁₀ emission reduction).
- Road segments that employed anti-icing pretreatment on roadways had lower EE values by a factor of two. While being correlated with cleaner roads, anti-icing provides other benefits including reduced salt application, reduced abrasive application, and better utilization of resources since brine can be applied during routine shifts up to three days in advance of a storm. Although not rigorously quantitative, cost benefits are estimated to be on the same order as sweeping (~\$0.6 per kg PM₁₀ emissions reduced). Reduced

PM benefits of anti-icing need to be assessed in the context of roadside vegetative health since the anti-icing material may be more toxic to plants than the traditional sand mixed with salt.

- Roads with paved shoulders or barriers that prevented entrainment of material from the sides of roads had 50% lower EE than did roads with narrow (less than 3 feet) or unpaved shoulders. Shoulder improvement costs 10%-20% of road resurfacing and may prove to reduce airborne emissions. In comparison, ASAP Sweeping and anti-icing are substantially less expensive and more likely to provide significant emission reduction benefits.
- Emission control strategies should require that not only primary roads, but all roads, be swept after snow storms to recover applied abrasive material.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P013, ROUND: 7, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Lake Tahoe Source Attribution Study (LTSAS): Receptor Modeling Study to Determine the Sources of Observed Ambient Particulate Matter in the Lake Tahoe Basin. Dr. Johann Engelbrecht, Dr. Alan Gertler, Dr. Tony VanCuren

Objectives: To identify and model the sources of observed PM in the Lake Tahoe Basin. This is critical if basin management agencies are to develop effective strategies to reduce the ambient concentrations of PM, and subsequently deposition to the lake.

- Analyze and graphically represent the Lake Tahoe Atmospheric Deposition Study (LTADS) two-weekly and MiniVol ambient data sets, to identify outliers, and to distinguish site and seasonal data sub-sets.
- Apply multivariate statistical procedures, including Principal Components Analysis (PCA) and Positive Matrix Factorization (PMF) to identify factors and chemical species of relevance within the measured data set.
- From the Desert Research Institute's Lake Tahoe Source Characterization Study and other source profile data, compile a set of chemical source profiles applicable to the receptor modeling of the LTADS ambient results.
- Apply the Chemical Mass Balance (CMB) receptor model to the LTADS ambient together with the above compiled source data, to assess the source contributions to the observed PM samples.

Findings:

- *Hypothesis: Re-suspended paved road dust is the major source of PM₁₀ in the basin.* The results supported this hypothesis. This is best seen at the two high traffic sampling sites in the densely populated area of South Lake Tahoe, the one being the South Lake Tahoe site (45% of PM₁₀), 30 meters to the north of Highway 50 and approximately 100 m from the lake shore, and Sandy Way (36% of PM₁₀), 40 meters south of Highway 50 and approximately 200 meters from the IMPROVE site. The third site where road dust

is predominant is at Lake Forest (61% of PM₁₀), about 3 km northeast of Tahoe City, and about 20 meters south of Highway 28. The Thunderbird Lodge site on the east shore is not in a residential area and at least 650 meters west from the Highway 28, with only background levels of road (geological) dust. PMF was able to distinguish two types of fugitive dust, one low in Ca with a Fe/Ca ratio of approximately 2, and a second with high Ca and Mg values and a Fe/Ca value of approximately 0.23.

- *Hypothesis: Wood burning is an important source of PM_{2.5} during the winter months.* The results supported this hypothesis. Both the PMF and CMB demonstrated that residential wood combustion with possible contributions from wildfires and controlled burns are the major PM_{2.5} sources of pollution during the fall and winter months. For example, CMB results indicated the two south shore sites of Sandy Way (67% of PM_{2.5}) and South Lake Tahoe (51% of PM_{2.5}) were dominated by emissions from this source. Smaller amounts of wood burning were also modeled at the out-of-basin site at Big Hill. Lake Forest and Thunderbird Lodge modeled lower concentrations of wood burning.
- *Hypothesis: Motor vehicle tailpipe emissions is the major source of PM_{2.5} in the basin.* The results did not support this hypothesis. For example, the CMB showed gasoline and to a lesser extent diesel vehicle emissions as major contributors to PM_{2.5} at Sandy Way and South Lake Tahoe, both sites being close to the high traffic Highway 50 and in the residential and commercial areas of South Lake Tahoe. As a percentage of PM_{2.5} mass the value varies little, amongst Lake Forest (33%), Sandy Way (26%), South Lake Tahoe (29%) and Thunderbird Lodge (23%).
- *Hypothesis: Secondary pollutants from outside the basin are minor sources of PM_{2.5} and PM₁₀.* The results supported this hypothesis. Ammonium sulfate together with elemental carbon (EC₂), V, Se, and Br are contained in one PMF factor. Secondary nitrate may be from motor vehicle emissions inside the Tahoe Basin. From the CMB it was concluded that secondary pollutants are minor sources of PM_{2.5}, varying little amongst Lake Forest (ammonium sulfate 9%, ammonium nitrate 3%), Sand Way (ammonium sulfate 5%, ammonium nitrate 3%), South Lake Tahoe (ammonium sulfate 5%, ammonium nitrate 4%), and Thunderbird Lodge (ammonium sulfate 9%, ammonium nitrate 2%).
- *Hypothesis: Emissions from controlled burns inside the basin and wildfires outside the basin are minor sources of the observed PM.* The results were inconclusive in supporting this hypothesis. Due to the smoke from residential wood burning during the fall and winter, the contributions from wildfires and controlled burns in or outside the basin could not be assessed.
- *Hypothesis: Emissions from restaurants can be an important source of PM at some locations.* This could not be determined. In the absence of measured meat and other cooking markers in the ambient samples, or chemical source profiles, this source could not be identified or modeled.
- *Hypothesis: Overall, the most important sources to control are emissions from light-duty gasoline vehicles.* The results did not support this hypothesis. As stated under 1, 2, and 3 above, the most important sources to control are road dust, followed by wood smoke and mobile sources.

- *Hypothesis: The major source of phosphorous is soils, while the contributions from wood burning are small.* The results supported this hypothesis. Initial data analysis, including the calculation of correlation coefficients and PCA could not confirm any relationship of phosphorus with wood combustion. In the case of PCA (PC1), Phosphorus was highly correlated with Al, Si, K, Ca, Ti, Zr, and Ba - all soil forming species in PM10. Chemical source profiles of wood burning contain below detection limit amounts of P, and the contribution from wood burning can therefore be disregarded.
- *Hypothesis: Phosphorous concentrations in the coarse fraction are elevated and are therefore indicative of mechanically re-suspended soil.* The results supported this hypothesis. PCA and subsequent data analysis revealed that phosphorus occurs as individual mineral grains (probably the mineral apatite) in the coarse geological fraction, as re-suspended road dust. The concentration data set reveals only 39 samples out of the total of 387 with concentrations above zero. Of these, 17 are TSP (average 0.005 µg/m³), 15 are PM10 (average 0.006 µg/m³) and only seven PM2.5 (0.001 µg/m³) filters. The phosphate mineral apatite occurs naturally in granodioritic rocks and soils of the Tahoe basin.
- *Hypothesis: Phosphorous from mobile source tailpipe emissions is small.* The results supported this hypothesis. Phosphorus from motor vehicle emissions as measured in PM2.5 is very low. As in the above case, the phosphorus occurs in only seven out of the 129 PM2.5 samples, pointing to the sporadic distribution of individual apatite grains in coarse re-suspended road dust. If phosphorus had been in motor vehicle emissions in measureable concentrations, it would have occurred evenly distributed in all the South Lake Tahoe, Sandy Way, and Lake Forest samples.
- *Hypothesis: Nitrogen is a minor component of the coarse PM fraction. Hence the PM contribution to the atmospheric deposition of N is small.* The results supported this hypothesis. On average about 0.30 µg/m³ nitrate occurs in the TSP fraction, with about 0.26 µg/m³ in PM10 and 0.15 µg/m³ in PM2.5. Deposition in the lake from aerosol nitrate will therefore be small.
- *Hypothesis: PMcoarse, composed of road dust and other geological material, is the major contributor to atmospheric deposition in the lake.* The results supported this hypothesis. PMF and CMB modeling show that road dust in the PMCoarse size fraction, partly from de-icing procedures during winter months, is an important source to control. Road dust generated by traffic along the major highways such as Highways 50 and 28 can account for as much as 60% of PM10, and has the potential of being deposited in Lake Tahoe.

Management Implications:

None were listed.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Impacts of vehicle activity on airborne particle deposition to Lake Tahoe. Dr. Dongzi Zhu, Dr. Hampden Kuhns, Dr. John Gillies, Dr. Alan Gertler, Ms. Jacqueline Mason.

Objectives:

This study integrates the results of previous and ongoing research to quantitatively examine how road dust emissions and atmospheric deposition are affected by several factors, including season, local wind conditions, vehicle class, vehicle speed, vehicle kilometers driven, road type, road maintenance practices, vegetative density, and proximity of the source road to the lake.

Observations of these factors and patterns from several different studies have been combined and analyzed to create a basin-wide emission factor database based on road type and jurisdiction (road jurisdiction is a reasonable indicator based on consistency of traction control application and road maintenance practices). This database was then linked to a traffic demand model to create emission estimates for each of the 7000+ road segments around the basin.

Findings:

- Proximity to the lake, prevailing wind directions, and traffic patterns play a dominant role in determining which roads have the greatest potential to deposit fine sediment into the lake.
- It appears that only roads close to the lake have a substantial impact on atmospheric deposition of fine particles. Moreover, most areas around the lake benefit from onshore wind directions during peak traffic times (i.e. daylight hours) that effectively push emissions away from the lake. However, this is not the case in El Dorado County, CA and Douglas County, NV, which are calculated to be responsible for 67% of the paved road dust deposited to the lake. More aggressive measures to reduce the reservoir of suspendable material on roads in these areas will be more cost-effective than applying a blanket policy to the entire road network.
- Emissions vary both by season and by location. Wintertime Total Suspended Particle (TSP) emissions are ~5 times greater than summertime TSP emissions due to the application of traction control material to the roads during the winter. Vehicle kilometers traveled (VKT) are not evenly distributed in the basin's urban area; in particular, the South Lake Tahoe area has the highest VKT values in the basin.
- Although South Lake Tahoe (in El Dorado County, CA) already employs an aggressive street sweeping program, its high VKT causes it to still be a major source of atmospheric deposition of particles into the lake.
- Approximately 98% of the vehicles in the basin are in the light-duty class. So, although the wakes from mid- and heavy-duty trucks can entrain dust particles from the sides of roadways, the number of such vehicles is insufficient to make a major impact.
- Only ~2% of road emissions of PM₁₀ (20 Mg/year) and ~1.5% of TSP (35 Mg/year) is estimated to reach the lake. The vast majority of PM_{large} emitted into the air is deposited within minutes, especially in the presence of dense vegetation. An analysis of vegetative density coverage was overlaid on the spatially resolved emission inventory so that each road segment could be assessed based on the type of vegetation on the shortest path to the lake.

- Lake Tahoe Atmospheric Deposition Study (LTADS) referenced in the 2010 Total Maximum Daily Load report estimated that dry atmospheric depositions to the lake are 230 Mg/year of PM10 and 590 Mg/year TSP. Including wet deposition, the total atmospheric deposition to the lake are 375 Mg/year of PM10 and 755 Mg/year TSP. Our results indicate that PMlarge and PMcoarse are rapidly depleted near their source and thus the shoreline concentrations may only be representative of the first 1-to-3 kilometers offshore. The results support much lower estimates of dry deposition to the lake than calculated by LTADS. We estimate that from paved road travel, the atmospheric dry deposition to the lake is approximately 6% of the total LTADS dry deposition. Other sources of fine sediment that are not included in our estimates include unpaved road travel that is relatively small (due to development around the lake and especially in the wintertime when a snow pack is present) and located at greater distances from the shore than paved roads. In addition, re-entrained windblown dust is not factored into our estimates.

Management Implications:

- Based on the current study, it appears that only roads close to the lake have a substantial impact on atmospheric fine particle deposition. Moreover, most areas around the lake benefit by onshore winds during peak traffic times effectively pushing emissions away from the lake. However, this is not the case in El Dorado County and Douglas County, which are calculated to be responsible for 67% of the paved road dust deposited to the lake. More aggressive measures to reduce the reservoir of suspendable material on roads in these areas are likely to be more cost effective than applying a blanket policy to the entire road network.
- This study has illuminated new details that will help focus emission controls (e.g. street sweeping, anti-icing, reduced VKT) on the part of the basin where they will be most effective (i.e. near shore roadways in Douglas and El Dorado Counties). Substantial uncertainties exist on how controls will improve lake clarity since revised estimates of the contribution of road dust to the lake are orders of magnitude smaller than the total sediment dry deposition loading used in the TMDL.
- Long-term monitoring of road dust emission potential (or road surface conditions) is essential to ensure that current plans meet their targets. The Road RAM (Road Rapid Assessment Methodology) system provides an excellent opportunity to evaluate whether controls are effectively reducing the suspendable reservoir of material on paved road surfaces in the basin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P060, ROUND: 10, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Visibility monitoring and standards for Lake Tahoe Basin: assessment of current and alternative approaches. L.W. Antony Chen, John G. Watson, Xiaoliang Wang.

Objectives:

The goal of the project is to evaluate the current visibility measurements and indicators available for tracking haze in the Lake Tahoe Basin and provide recommendations for future monitoring, data analysis, and threshold development.

Findings:

- Regional and sub-regional visibility, as measured at BLIS1 and SOLA1, have been improving dramatically since 1980's, but there is a concern about their recent trends.
- Chemical *bext* has shown a decreasing trend between 1981 and 2004 with median values dropping 26% at BLIS1 and 32% at SOLA1. The finding is consistent with earlier reports. The change is attributed to lower NH₄NO₃, OC, EC, and PMcoarse concentrations, probably reflecting the control of motor vehicle, road dust, and residential wood combustion emissions. The 90th percentile *bext* (or the average of top 20% *bext*) at BLIS1 appears to increase in recent years (2001–2009). Extremely high *bext* often resulted from large wildfires, of which frequency and intensity are expected to increase over time owing to climate change.
- Current Lake Tahoe visibility standards are too low and do not address the national haze rule. The TRPA standards more reflect visibility conditions in 1980-1990. The Clean Air Visibility Rule selected 2000-2004 as the baseline period and requires reasonable progress goals to be established for the most impaired days (worst 20%) and no degradation in visibility to occur for the least impaired days (best 20%). These goals are determined as a uniform rate of visibility improvement from baseline visibility conditions to natural visibility conditions by 2065. To be consistent, the new visibility thresholds (both median and 90th percentile) should be based on *bext* in 2000-2004. To exclude hazy days caused by wildfires, a non-summer threshold may be developed as most wildfires occur in summer. Also, the 90th percentile threshold may be replaced with an 80th percentile threshold for determining compliance.
- Visibility is uniform across the Tahoe Basin; PM pollutants are confined within small urban neighborhoods. Observations from LTADS show similar *bext* and PM concentrations at non-urban sites around Lake Tahoe. This is confirmed by satellite-derived AOD, which varies within $\pm 15\%$ for most part of the Tahoe basin. BLIS1 has been well representative of the regional visibility conditions. This is consistent with earlier reports. OC and EC are relatively elevated at urban sites, such as SOLA1 and SLT-Sandy Way, due to traffic and RWC emissions. From the distinct seasonal variations of OC or EC between non-urban and urban sites, transport from urban to non-urban areas appears to be limited. Since the highest PM concentrations often occurred at sites within SLT, it is reasonable to base sub-regional visibility on a “neighborhood-scale” site that represents SLT conditions. Wildfires and prescribed burns could cause short-term extreme and inhomogeneous aerosol concentration, visibility, and AOD across the basin depending on burn location, fuel condition, and meteorology.
- Restoring chemical *bext* measurement in South Lake Tahoe is the top priority for a future visibility monitoring program. SOLA1 was discontinued in 2004 and the site has been used for other purposes. Restoring chemical *bext* measurement at South Lake Tahoe will 1) allow regional and sub-regional visibility monitoring to be based on the

same method; 2) maintain continuity in long-term trend data; 3) provide information towards evaluating various source contributions to visibility degradation; and 4) support NAAQS-related PM_{2.5} and PM₁₀ monitoring at the same time. Effort was made to identify a site (SLT-MS) that best serves the objectives. Joining the IMPROVE network appears to be the most cost-effective approach to initiate visibility monitoring at SLT-MS. To satisfy the requirement of the California state visibility standard, a nephelometer is also recommended for this site to determine optical *b*scat. Additional monitoring sites may be established at the north shore of the lake, e.g., Tahoe City, Kings Beach, and Incline Village, as future development in these areas (e.g., the proposed biomass plant at Kings Beach) may have negative impacts on local air quality.

- Establishing new monitoring sites based on real-time monitors will be efficacious and cost-effective for the long run. Real-time instruments usually require larger initial investment but can lower operating costs for the long run. They provide data with higher time resolution (minutes to hourly) and potential to distinguish contaminations from very nearby emitters (i.e., sub-neighborhood scale sources). As technology advances, many real-time techniques with proper calibration can yield data equivalent to time-integrated measurements. Particularly DustTrak DRX and 7-wavelength aethalometer are recommended for visibility monitoring at sites in addition to BLIS1 and SLT-MS. DustTrak DRX can simultaneously measure PM concentrations of different size fractions including PM₁₀ and PM_{2.5}, from which *b*ext would be derived. The 7-wavelength aethalometer, based on light absorption at different wavelengths, will not only quantify BC concentration but also differentiate vehicle and biomass burning contributions.

Management Implications:

None explicitly mentioned.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P061, ROUND: 10, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Lake Tahoe visibility impairment source apportionment analysis. Mark Green, Antony Chen, David DuBois, John Molenaar.

Objectives:

This study was performed to help inform TRPA and other agencies regarding the trends in visibility impairment in the Lake Tahoe Basin and the causes of haze in the basin. In addition to the TRPA, the results of this study will be useful to the states of California and Nevada, which are responsible for submitting regional haze plans to the U.S. Environmental Protection Agency, and to the U.S. Forest Service, which also has responsibilities for protecting its Class 1 areas, including the Desolation Wilderness.

Findings:

- Light scattering and absorption by aerosols are the largest contributions to visibility limitations at all but the cleanest locations where light scattering by clean air (Rayleigh scattering) can be equally or more significant.

- Three-fourths of the increased light extinction at South Lake Tahoe compared to Bliss State Park was due to much higher organic and elemental carbon aerosol at South Lake Tahoe, especially in winter.
- Seasonal patterns in light extinction were reversed for the two sites, with Bliss State Park having highest average values in summer due to wildfire impacts and South Lake Tahoe having highest average values in winter due to buildup of residential wood burning and traffic emissions under winter inversion conditions.
- For the 1990-2009 period at Bliss State Park, statistically significant decreases ($p=0.05$) in sulfate, nitrate, EC, coarse mass and total aerosol extinction occurred on the 20% best days. Corresponding middle 60% days showed statistically significant decreases in nitrate, EC, coarse mass, and total light extinction. For the 20% worst days at Bliss State Park for 1990-2009, nitrate and coarse mass light extinction had statistically significant decreases, while light extinction from organic aerosol had a statistically significant increase.
- At South Lake Tahoe on the 20% best days, statistically significant decreases in sulfate, nitrate, EC, coarse mass and total aerosol extinction occurred. For the middle 60% of days at South Lake Tahoe sulfate, nitrate, EC, and reconstructed total extinction all had statistically significant downward trends. Nitrate, organics, EC, and total reconstructed extinction showed statistically significant decreasing trends on the 20% worst light extinction days at South Lake Tahoe.
- Comparison of 20% best and worst visibility days at Bliss State Park for the regional haze rule (RHR) baseline period of 2000-2004 to 2005-2009 showed the cleanest days getting cleaner and the haziest days getting hazier, mainly due to increased organic and elemental carbon.
- Seven common PMF (positive matrix factorization) factors were resolved for the Bliss State Park 2000-2004 (BLIS I) and 2005-2009 (BLIS II) modeling groups: natural dust, road dust, biomass burning, traffic and industrial emissions, as well as secondary sulfate and nitrate.
- BLIS II data yielded two biomass burning factors that 11 were attributed to low and high combustion efficiency (LCE and HCE) burning.
- Only 6 factors were found for South Lake Tahoe (SOLA) including dust, biomass burning, traffic emissions, secondary sulfate, secondary nitrate, and a salting factor only found at SOLA.

Management Implications:

None given explicitly.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P062, ROUND: 10, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Particulate emissions from different types of biomass burning. Yanyan Zhang, Daniel Obrist, Barbara Zielinska, and Alan Gertler.

Objectives:

The objective of this study was to quantify the PM_{2.5} emissions from various types of prescribed burning activities using analysis of carbon (elemental carbon: EC; organic carbon: OC; and total carbon: TC); polar organic compounds (12 different compounds and four functional classes); water soluble potassium (K⁺); and particle-bound mercury (PHg).

Findings:

- Our data showed higher ratios of organic to elemental carbon in green fuels (19.2 ± 4.2) compared to dry wooden logs (7.3 ± 1.9) both in prescribed burns in the field and in controlled stove combustion, indicating that more moisture in green biomass resulted in more smoldering-phase combustion.
- Further, OC/EC ratios were lower in wood stove burns compared to prescribed burns in the field, which we attribute to higher combustion temperatures in wood stove burns.
- The suite of 12 select polar organic compounds showed that the most prevalent compounds emitted across all burns were levoglucosan, mannosan, and resin acids (dehydroabietic, pimaric, and abietic acids), while emissions of inositols and arabitols were only significant in combustion of leaves from a broadleaf shrub indicating their potential use as tracers for green foliage.
- Water-soluble K⁺, a common tracer for biomass combustion, showed a clear difference between field understory burns (low K⁺) and wooden pile burns (nearly 5 times higher), suggesting that K⁺ can potentially be used for differentiating between different prescribed burning types.
- PHg emissions were lowest in green vegetation and underburns emissions, which was unexpected due to inherently higher Hg levels in green foliage and surface duff.

Management Implications:

None given explicitly.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Zhang, Y., Obrist, D., Zielinska, B., & Gertler, A. 2013. Particulate emissions from different types of biomass burning. *Atmospheric Environment*, 72, 27-35.

P063, ROUND: 10, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Distribution of ozone, ozone precursors and gaseous components of atmospheric nitrogen deposition in the Lake Tahoe Basin. Andrzej Bytnerowicz, Mark Fenn, Alan Gertler, Haiganoush Preisler, and Barbara Zielinska.

Objectives:

This study characterized spatial and temporal distribution of ozone (O₃), O₃ precursors, O₃ formation, and gaseous pollutants that are important contributors to atmospheric nitrogen (N) deposition in the Lake Tahoe Basin. Passive samplers were used to monitor O₃, nitric oxide (NO), nitrogen dioxide (NO₂), ammonia (NH₃), nitric acid (HNO₃) and volatile organic compounds (VOCs) on a network of 34 sites inside and outside of the basin. Using statistical and geostatistical models, distribution maps of the measured compounds were created for the entire basin.

Findings:

Based on four hypotheses tested in this study, the authors have drawn the following conclusions and made some recommendations:

Hypothesis 1: While long-range transport from the Central Valley of California has little effect on the air pollution status in the Lake Tahoe Basin, locally emitted VOCs and NO_x significantly contribute to increasing O₃ concentrations and deterioration of air quality.

- High concentrations of O₃ were observed on the western slope of the Sierra Nevada mountain range and were likely caused by emissions from the Central Valley of California. For this region, the Toluene/Benzene (Tol/Bz) ratios were generally low, which indicates aged air masses and likely regional transport.
- High O₃ concentrations were found in the middle of Lake Tahoe, accompanied by high Tol/Bz and NO/NO₂ ratios, as well as high anthropogenic VOC concentrations (especially the higher molecular weight hydrocarbons n-decane and n-undecane). These results may indicate the influence of local spark ignition and diesel engine emissions (for example from large boats).
- High solar radiation (direct and reflected from the lake surface) over the Lake may promote photochemical reactions and increased production of secondary pollutants such as O₃ and HNO₃ vapor.
- High O₃ concentrations were also measured on the eastern side of the basin at high elevation sites, which exhibited low Tol/Bz ratios. This may indicate long range transport of pollutants aloft from the Central Valley. However, higher NO/NO₂ ratios may also indicate additional effects of local emissions from the South Lake Tahoe area.
- Meteorological analysis of O₃ distribution data for the ten megasites (Section 4.5, Synoptic Maps) indicate that O₃ transport from the southwest (i.e., from San Francisco, Sacramento and the Central Valley) into the basin may occur at higher elevation (i.e., 500mb). Questions still remain on how significant of an impact the upper level pattern differences have on O₃ levels around the basin and how the upper level O₃ is mixing down into the Tahoe Basin, which should be resolved through the use of chemical and meteorological modeling.
- Different diurnal patterns of O₃ concentrations were observed among the ten-mega sites during June – September 2010. Most of these differences were adequately ‘explained’ by wind direction and day-of-week. Almost all sites seemed to have higher O₃ values at night during weekend days with wind coming from the south to southwest.
- While all sites had similar O₃ concentrations in a range of 55-60 ppb during the daytime, at night, the low elevation sites showed much lower concentrations due to

their proximity to major traffic routes and possible titration of O₃ by the NO emissions from local traffic and possibly also from fires in local campgrounds. As site elevations increased, the nighttime O₃ concentrations also increased. The Angora Lookout and Genoa Summit 9000 sites show a small increase in average O₃ values during night-time hours.

- The only sites where the daily maximum 8-hour concentrations exceeded 70 ppb were the remote sites with the shortest distance to 'busy' roads being greater than 4 km. Those exceedances were observed when the ozone passive 2-week averages values were greater than 50 ppb.
- Eight-hour O₃ concentrations >75 ppb (greater than the federal primary O₃ standard) only occurred on a few occasions at high elevation locations.
- Because the 2010 summer season was quite typical from a perspective of the weather, the results of this study can be extrapolated to other years.
- Also, given that most of the variation between and within sites seems to be due to local conditions in the Basin, it is not possible to extrapolate these results to sites outside the basin. Data from other years and in particular real-time hourly data from sites outside the basin are needed if maps of exceedances are to be produced for a region larger than the Lake Tahoe Basin.

Hypothesis 2. Both naturally-emitted and anthropogenic VOCs contribute to O₃ formation in the basin, however, α -pinene emitted from coniferous trees have the highest O₃-forming potential in the basin.

- As indicated by Anthropogenic/Biogenic species ratios (see Section 4.3), biogenic species (isoprene and α -pinene) are generally more abundant than measured anthropogenic compounds at all sites and during all sampling periods. There were few exceptions, most notably at the TB2 site at the middle of the lake (Anth/Bio>1).
- However, contrary to our expectation, isoprene concentrations are usually comparable to or higher than α -pinene concentrations. Isoprene is emitted from deciduous species, including various shrubs and ground covers. Both, isoprene and α -pinene are very reactive, however isoprene has higher ozone forming potential.

Hypothesis 3: Ammonia is the most important contributor to dry-deposited N in the forest ecosystems of the Lake Tahoe Basin.

- The highest NH₃ concentrations were measured west of the Lake Tahoe Basin indicating the influence of mobile and stationary pollution sources in the Central Valley of California. However, local NH₃ emissions seem to contribute to enhanced concentrations of the pollutant on the south-western side of the Basin.
- The highest concentrations of reactive gaseous inorganic N were determined near the western shore of the Lake indicating the effects of local emissions of NH₃ from vehicle emissions.

Hypothesis 4: Deposition of N in some parts of the Tahoe Basin is in exceedance of critical loads for sensitive receptors.

- Nitrogen deposition in throughfall was low (1-2 kg/ha/yr) at megasites to the north or west of the lake, but was moderately elevated (> 5 kg/ha/yr) at three sites south or east of the lake.
- Nitrogen concentrations in lichen tissue were above the 'clean-site threshold' at five of the ten megasites and throughfall N deposition at three sites was above the critical load at which epiphytic lichen communities become dominated by eutrophic species.
- Throughfall deposition of NH₄-N was 60% greater than deposition of NO₃-N indicating the importance of reduced forms of N in the Tahoe Basin.

Management Implications:

None mentioned explicitly.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P064, ROUND: 10, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

The Tahoe Climate Information Management System (TahoeClim). Kelly Redmond.

Status: In progress. Final report was due in August 2012.

Objectives:

A joint collaboration between the Western Regional Climate Center at DRI in Reno and the UC Davis Tahoe Environmental Research Center (TERC) will develop an accessible archive of historical and current meteorological and climatological data for the Tahoe Basin. The Tahoe Climate Information Management System (TahoeClim) will include all past and present observations from the principal weather and climate networks operating in the basin and NASA space-borne thermal infrared imagery. A variety of specialized sites on and near the lake, and in and near the basin, will likewise be incorporated, including a small number to be added or augmented during this project. The data flow and management system will be established to allow the continued assimilation and archiving of real-time data in the future. The data sets will include direct measurements from in situ locations, interpolated and infilled data on fine grids, three-dimensional hourly fields of data from the last five years, and synthesized information in the form of products, many of which can be generated directly by the users and therefore be more responsive to their needs.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P065, ROUND: 10, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Improving meteorological data and forecasts for prescribed fire burn day decisions in the Lake Tahoe Basin. Timothy J. Brown, Narasimhan K. Larkin, and Miriam Rorig.

Objectives:

The overall goal of the project was to provide decision-makers (LTBMU Fire Management Officer and staff, CARB and Predictive Services) with improved meteorological forecasts and data for use in prescribed fire operational planning. Specific objectives were:

- Create a hi-resolution (100-m) gridded climatology of surface and upper level winds in the Basin
- Produce a 4-km gridded climatology of mixing height
- Develop operational forecasts of 100-m surface winds
- Implement a transect of weather stations for wind forecast and inversion verification
- Implement a customized smoke prediction website tool

Findings:

Project deliverables included:

- Monthly diurnal climatology 300-m maps of WindNinja surface (10-m) wind
- Monthly diurnal climatology maps of mixing height and transport wind 400-m WindNinja wind forecasts
- Data collected from the field observations
- Customized smoke prediction tool

Management Implications:

The tools provided are intended for management operations.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Mixing height and wind climatologies are available at:

- http://cefa.dri.edu/Cefa_Products/LakeTahoe/.
- The WindNinja forecasts can be found in the air quality section at: http://www.cefa.dri.edu/COFF/cansac_output.php?model=wrf.
- BlueSky Playground v2 is available at <http://playground.airfire.org>.

P075, ROUND 10, LEAD INSTITUTION, DESERT RESEARCH INSTITUTE

Secondary pollutant formation in the Lake Tahoe Basin. Barbara Zielinska, Alan Gertler, Andrzej Bytnerowicz, Wendy Goliff, and Chad Praul.

Status: Report is draft.

Objectives:

The proposed study will characterize the precursors and pathways of secondary pollutant formation, including ozone (O₃), secondary organic aerosol (SOA) and ammonium nitrate (NH₄NO₃) in the Lake Tahoe Basin. Specifically:

- Identify the precursors and pathways leading to the formation of secondary pollutants, including ozone, NH₄NO₃ and SOA
- To employ the air quality model CAMx to predict the formation of O₃, SOA and NH₄NO₃. Model output will be compared to observations made during the field campaign portion of this project to assess the model's capabilities and potential biases.
- Provide information for important policy decisions designed to reduce air and water impacts of atmospheric pollutants.

Findings:

The majority of O₃ precursors (VOC and NO_x) are emitted in the urbanized areas of the Central Valley and possibly the San Francisco Bay Area.

- Model simulations indicate the majority of SOA precursors are emitted upwind of the Lake Tahoe Basin. Ozone is transported from aloft upwind as well, influencing ozone levels in-basin significantly.
- In-basin contribution to observed O₃ and SOA level is limited.
- In-basin NO_x concentrations are very low. In basin O₃ control strategies may not be warranted.

Management Implications:

Reduction in ozone levels will reduce the amount of SOA by a modest amount. Ozone reaction rates with SOA precursors are slow compared with other oxidants, such as hydroxyl radical. In addition, since the majority of SOA precursors originate from out-of-basin sources, reduction of O₃ level in the Tahoe Basin area would not influence significantly the amount of SOA in the Basin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P076, ROUND 11, LEAD INSTITUTION, DESERT RESEARCH INSTITUTE.

Evaluation of Prescribed Burning Emissions and Impacts on Air Quality in the Lake Tahoe Basin. L.W. Antony Chen, Tom Malamakal, Xiaoliang Wang, Mark G. Green, Judith C. Chow, and John G. Watson.

Objectives:

This research combined ambient air quality monitoring, in-plume source measurements, and dispersion modeling to characterize prescribed burning emissions and evaluate the magnitude and spatiotemporal distribution of smoke impacts.

Findings:

- Laboratory tests and emission models underestimate prescribed burn emissions and combustion efficiencies.
- EFPM_{2.5} determined from the in-plume measurements of prescribed burning generally increases with decreasing CE, but with a wide range of EFPM_{2.5}/(1 - CE) ratios.

- The operational emissions model (i.e., FEPS), with its default settings, reports lower CEs than measured values due to a predefined flaming phase CE coefficient of 0.9. Much higher CEs (~0.99) were detected in the field. FEPS also underestimates EFPM2.5 for a given CE by up to a factor of six. The low-end EFPM2.5 predicted by FEPS are consistent with laboratory combustion tests for dry LTB fuels while the high-end EFPM2.5 as measured by the in-plume measurements agree with laboratory tests of moist fuels.
- For proper simulation of the largest possible impacts, CE coefficients in FEPS were increased to 0.99 for flaming and 0.9 for smoldering, and the EFPM2.5 coefficients were increased by a factor of six. This substantially increases the modeled PM2.5 emission rates, particularly for the smoldering phase.
- Understory burns show higher emission factors than slash pile burns, implying larger environmental effects.
- Lower overall combustion efficiencies were found for understory burns (i.e., DSP and TNC: CE < 0.9) of natural vegetation than for slash-pile burns (i.e., SKY and CLC: CE > 0.9). This is likely due to a higher moisture content and lower fire intensity.
- Higher emission factors for PM2.5 and NH3 associated with the low combustion efficiencies imply larger environmental impacts from understory burns with respect to air quality and nutrient (i.e., nitrogen) deposition. This should be of additional concern since more emissions from understory burns are associated with smoldering combustion which is accompanied by a relatively low heat release rate and plume height (i.e., staying longer near the surface).
- PM2.5 from pile burns, however, contain a higher fraction of light-absorbing BC or EC, which impacts visibility (or lake clarity when depositing into the water) more than light-scattering particles such as NH4NO3, (NH4) 2SO4, OM, and fugitive dust.
- Despite enforcement of smoke management plans, prescribed burning impacts air quality in the Lake Tahoe Basin.
- Multiple agencies have been carrying out prescribed burning in the LTB, with strict guidelines for smoke management. Preferred weather conditions include an unstable boundary layer (i.e., no inversion) with moderate winds to carry smoke outside the basin.
- Except for occasional misforecasts, smoke from the ignition and first several hours of burning usually rises and moves away from the population centers as expected. However, smoldering combustion can continue long after the active ignition period. The model prediction indicates that the smoldering smoke often impacts communities due to changes in wind direction. The impact often shows up in the evening under a shallow surface layer. This could happen for prescribed burns in any part of the basin.
- The extent of smoke impacts depends on the smoldering emission rate (i.e., emission factor × fuel consumption), which appears to be minor if using the default FEPS parameters.

- With modified settings, the smoke impact is appreciable as compared to ambient PM_{2.5} levels in the LTB. However, it does not cause exceedances of the 24-hr PM_{2.5} air quality standards of 35 µg/m³ or the 8-hr California visibility standard for the Lake Tahoe Air Basin (bext = 70 Mm⁻¹, or equivalently 16.7 µg/m³ of PM_{2.5}) at the current monitoring sites.
- Individual prescribed burn impacts are inhomogeneous and of short duration compared with wildfires.
- Prescribed burning impacts on air quality can be identified as episodic by examining baseline diurnal patterns in conjunction with wildfire and prescribed burn records.
- PM_{2.5} episodes associated with prescribed burning can be as short as 1–2 hours and rarely last more than several hours. This is confirmed by FEPS-HYSPLIT modeling.
- Transport of the smoke plume depends on meso-scale winds, which change direction frequently.
- The spatial distribution of smoke is also inhomogeneous. The Incline Village site is often influenced by nearby prescribed burns conducted by the NTFPD and NDF, while the Tahoe City site is more likely to experience smoke from burns on the west shore.
- Prescribed burns by the LTBMU in the Angora and Fallen Leaf areas could impact the South Lake Tahoe and Cave Rock sites more than other sites. Impacts from distant wildfires are usually more spatially homogeneous within the basin and last longer (e.g., >48 hours), and therefore can be clearly identified.
- Further model development and validation are required to quantify prescribed burning contributions to pollutants versus contributions from other sources.
- The FEPS-HYSPLIT model, driven by the high-resolution (2 km x 2 km) WRF meteorological data, is useful for simulating smoke transport around the LTB.
- The model-predicted PM_{2.5} episodes due to prescribed burning are consistent in time with measured PM_{2.5} concentrations in many cases. The model provides fire agencies with an additional tool to make/evaluate burn decisions. However, the model predictions are not reliable for "quantifying" prescribed burning contributions to PM_{2.5} and other pollutants.
- The real-world in-plume measurements helped to refine the emission factors in FEPS. However, the model is still limited by fuel consumption estimates and inaccurate/incomplete burn information such as ignition time, burn duration, rate of burn progress, and fuel conditions. Improved model resolution is also needed.
- For the fall burns, prescribed burning impacts on air quality often peak in the late evening, coinciding with a maximum impact from residential wood combustion.
- The current ambient PM_{2.5} chemical speciations do not offer markers to distinguish particles from these two sources to further validate the model. Model validation would preferably be made with spring or summer burns, which are not available in this study due to unexpected weather conditions in 2012 and a short project duration (i.e., no

prescribed burns in spring/summer 2012 with no ambient measurements in spring/summer 2011 and 2013).

Management Implications:

- Burn decisions should consult longer-term weather forecasts coupled with dispersion modeling.
- To address the potential impact of prolonged smoldering combustion emissions, it is not sufficient to base the prescribed burn decision solely on weather conditions of the burn day. A longer-term forecast (e.g., 72 hours) should be consulted, especially for burns close to population centers. This can be further rectified by dispersion modeling using updated combustion efficiencies and emission factors as described in this report.
- A cross-agency, post-burn reporting system should be available.
- The current burn records are mainly for acquiring a burn permit and do not reflect adjustments (e.g., ignition time and burn plot) made in the field. A post-burn reporting system needs to be developed, which would provide accurate burn information, facilitate hindcasting of smoke dispersion, and update emission inventories.
- The burn information needs to be entered into the system by a burn officer after each burn and made accessible on-line.
- Further research should focus on spring and summer burns for validating the emission and dispersion models.
- Source- and receptor-oriented modeling will be the ultimate tools for quantifying prescribed burning impacts on air quality and environment health. These models need to be continuously developed and validated. Spring and summer burns would be the preferred cases for validating models, since contributions from residential wood combustion are small and contributions from wildfires can be clearly distinguished.
- This study provides examples of smoke plume dispersion and characterization. Future research should include hourly measurements of more specific biomass burning markers, such as brown carbon, water-soluble potassium, and levoglucosan, at the ambient monitoring sites to reduce the ambiguity in model evaluation.

Publications:

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P094, ROUND 12, LEAD INSTITUTION, DESERT RESEARCH INSTITUTE

Refining estimates of atmospheric deposition for sediment particles and particulate nutrients in the Lake Tahoe Basin. Antony Chen, John Watson, Xiaoliang Wang, and Wen-Ming Chien.

Objectives:

Contributions to Lake Tahoe from atmospheric deposition of particulate matter (PM) have been suggested to be substantial, yet inadequately quantified. This study established three long-term monitoring sites (July 2013 – August 2014) to measure 24-hr, size-resolved dry and wet PM

deposition in near-shore, offshore-background, and upper watershed conditions in the Lake Tahoe Basin. The objectives were to:

- Investigate spatiotemporal variations of PM deposition flux
- Obtain dry deposition velocity using mass deposition flux and PM concentration measurements
- Provide estimated annual number and mass deposition flux (NDF and MDF, respectively) via dry and wet processes

Findings:

- The seasonal and annual NDF_{dry} flux (annual Number Dry Flux) at the three monitoring sites showed log-normal size distributions where particles of 0.5–1 µm and 4–10 µm diameter were the most abundant among five size bins (0.5 – 1 µm, 1 – 2.5 µm, 2.5 – 4 µm, 4 – 10 µm, 10 – 20 µm, 20 – 32 µm, and 32 – 64 µm).
- For the size range of 0.5 – 20 µm, all seasonal NDF_{wet} exceed NDF_{dry} though its size distribution is more skewed towards fine particles < 2.5 µm which contribute little to the particle mass.
- Dry deposition velocity appears to increase rapidly with particle size, while wet deposition velocity is more uniform across all size ranges.
- Higher NDF_{dry} and greater monthly variability are found at the near-shore than the offshore and upper-watershed sites, suggesting substantial impacts from nearby beach, traffic, and construction activities.
- Higher NDF_{wet} in spring across all three sites is consistent with increased precipitation.
- The annual NDF_{dry+wet} of “sediment only” particles (0.5 – 20 µm) is estimated to be between 6.18×10^{10} and 1.12×10^{11} # m⁻² year⁻¹, pretty consistent with a previous estimate of 1.01×10^{11} # m⁻² year⁻¹ (0.5–16 µm) by the Lake Tahoe Total Maximum Daily Load (TMDL) using ambient concentration and modeled deposition velocity.
- However, the annual MDF_{dry+wet} of 14.1 to 19.2 MT km⁻² year⁻¹ from this study is several times even the upper TMDL estimate of 2.35 MT km⁻² year⁻¹, despite that the partitions between dry and wet deposition do not differ very much. The discrepancy is mainly attributed to different size distributions in NDF, particularly NDF_{dry}, between the two studies.
- Overall, dry deposition accounts for only 13 – 24% of deposited particle number but 67 – 84% of particle mass. Accounting for all potential uncertainties, TMDL likely underestimates MDFs and the impact of atmospheric deposition on lake clarity.

Management Implications:

This study proves passive particle collection using an automated sampler, coupled with microscopic counting of individual particles, to be efficient for quantifying daily, size-resolved particle deposition fluxes. NDF_{dry} by this approach was verified with results of a larger-footprint eddy correlation method through a two-week collocated campaign. Moreover, the passive samples allowed analysis using a computer controlled SEM (CCSEM) technique to yield

elemental composition of single particles, based on which particles could be classified. It was found that 74 – 87% of coarse and large particles > 4 µm diameter are mineral dust. Sulfur-contained and phosphorus-contained particles, though minor, were found at all three sites, suggesting an appreciable loading of pollutant and nutrient into the lake through atmospheric deposition.

Publications:

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P095, ROUND: 12, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE.

Ozone modeling system and emission control strategies for the Lake Tahoe Basin. Darko Koracin, Julide Kahyaoglu Koracin, Alan Gertler, Travis McCord, Amela Jericevic, John Mejia, Eric Wilcox.

Objectives:

The main objectives were completed as follows:

- We have developed a complex modeling system (Lake Tahoe Air Quality Modeling System /LTAQMS/ consisting of a meteorological model (WRF), emission models (SMOKE and MOVES), and a photochemical model CMAQ (Fig. 1).
- We used the EPA National Emission Inventory (EPA NEI) for 2005, which has been fully evaluated.
- We have validated the ozone modeling system on an ozone episode recorded in August 2009 at the Lake Tahoe station.
- We have performed sensitivity simulations for various emission scenarios and determined what aspects of the planned cost effective control strategies might be cost effective for the Lake Tahoe basin to control ozone levels.

Findings:

- This project developed a comprehensive modeling system consisting of meteorological (WRF), emission (SMOKE and MOVES), and photochemical (CMAQ) modeling as well as backward and forward trajectory analysis (HYSPLIT). An analysis of the measured time series indicates possible problems with wind measurements.
- The CMAQ results with inputs from SMOKE and MOVES were evaluated using ozone measurements at the Lake Tahoe area (South Lake Tahoe and Echo Summit) and in Sacramento (T-street). At South Lake Tahoe and Echo Summit the model shows a correct order of magnitude and gradual increasing trend during the episode, but underestimates the ozone concentration extremes. It is encouraging that the model at the Sacramento station showed favorable comparison with respect to the ozone peaks and diurnal variation.
- The CMAQ model results were evaluated for the South Lake Tahoe station using EPA recommended statistical measures: the mean bias (MB), the normalized mean bias (NMB), the root mean square error (RMSE), and the normalized mean error (NME).

The model statistics were within the EPA recommended values for NMB for all runs, while the values for NME are right at or above the recommended value. The emissions which do not have significant impact on the simulated ozone (area, point, and to some extent off-road) all have parameters similar to the baseline results. The impact can be seen for the mobile emissions (except for off-road emissions) and biogenic emissions. Halving of the emissions generally worsens the statistics, which indicates that the emissions are most likely not overestimated. Doubling the emissions, however, produces smaller errors which indicate that the emissions, at least in the southern part of the Lake Tahoe Basin, are possibly underestimated. The reduction of emissions for the whole period yields a change in the bias of only 1 ppbV. Obviously, even large reductions in the emissions would not significantly impact ozone peak reductions in the simulations.

- It is important to note that the magnitude of the ozone peaks was quite similar for all three stations in the region.
- Spatial distribution of the simulated ozone shows that the whole region was characterized by elevated ozone concentrations, especially over the western Sierra ridges and the Tahoe area.
- A number of sensitivity tests were conducted to examine the effect of variable emissions on the simulated ozone concentrations. The strategy was to reduce by half each of the main emission categories (area, point, mobile, biogenic) and analyze the effect of reduced emissions on the ozone concentrations simulated by the CMAQ model. These results can provide guidance on deciding on the efficiency of emission control strategies to eliminate exceedances or elevated ozone concentrations in the Lake Tahoe area.
- The main result from the sensitivity runs was that only the reduction of mobile and biogenic emissions had a noticeable impact on the simulated concentrations. We further separated on-road and off-road emissions using MOVES and found out that the main effect is due to on-road emissions. However, even for reduction by half of the mobile (on-road) and biogenic emissions, differences with respect to the control run were only several ppbV considering the entire domain, which is very small. A question remains whether the emissions are underestimated or the model does not respond well to the emission changes, or both. According to the time series at all three stations, the emissions and their temporal variation appear to be underestimated. The simulated ozone peaks were lower by 30, 31, and 35 ppbV for the South Lake Tahoe, Echo Summit and Sacramento stations, respectively. The correlation coefficients were 0.49, 0.60, and 0.82 for the South Lake Tahoe, Echo Summit and Sacramento stations, respectively. It appears that the model was not sensitive enough to large changes in the emission reductions.
- Model sensitivity to input emissions was further investigated by doubling all input emissions. Even the double emissions did not produce same magnitude of the ozone peaks. Due to reduced NO_x, urban areas such as Sacramento showed increased ozone concentrations due to lack of ozone titration by NO_x.
- A general conclusion from the sensitivity tests is that the main features of the ozone episode in the Tahoe area have to be considered within the regional pool of ozone and ozone pre-cursors and that the local effects might have a minor role. It appears that the

efficient method in this urban area is not to reduce mobile emissions, but to reduce VOCs, while in the Lake Tahoe area, reductions in both mobile and biogenic emissions can lead to reductions of ozone concentration peaks. However, the reductions in ozone peaks were quite small for large reductions of the emissions.

- It is important to note that stations in the Tahoe basin show modest reduction in ozone concentrations in the sensitivity runs where the mobile emissions were reduced. However, the mobile emission reductions show no improvement in reducing ozone concentrations at the Sacramento T-street station and even increase them. The tests with double emissions generally show even lower concentrations at the T-street station compared to the baseline run. Consequently, control strategies must be region specific since the urban area appears to have the characteristics of a VOC limited region, while the Tahoe station shows characteristics of a weakly NO_x limited area. However, during some conditions, input of locally emitted NO in the basin can contribute to lowering ozone peaks.
- To understand possible regional characteristics and transport, an analysis of forward and backward trajectories was performed using the HYSPLIT model. The trajectory analysis shows that the period of the highest ozone concentrations was associated with the crossmountain westerly transport from the Sacramento valley toward the Lake Tahoe region. The period of the highest ozone concentrations was also associated with low wind conditions, strong subsidence, and a well-mixed lower portion of the atmospheric boundary layer.
- An analysis of synoptic conditions supports the conclusions from the trajectory analysis. In the beginning of the episode, the ridge from the north and the trough from the south developed a pressure field with weak gradients over the central portion of the West Coast. This pressure system setup supported weak winds dominantly from the west during the period of peak ozone concentrations in the Tahoe area on 11 and 12 August.

Management Implications:

- Based on this study, control strategies need to consider measures for the non-uniform reduction of regional emissions in order to improve air quality in the Tahoe area and selective measures for particular emission categories.
- The control should focus on on-road emissions and biogenic sources as the major components impacting ozone concentrations in the Tahoe area.
- The reduction in the surrounding areas should be focused on VOCs, while in the Tahoe area, reduction of both mobile (primary) and VOCs (secondary effect) should be considered.
- Continuous monitoring should be extended to other sides of Lake Tahoe in addition to the Salt Lake Tahoe station. Special attention should be placed on the western ridges of the Tahoe basin where the model predicts significant concentrations during ozone episodes. The continuous monitoring should include major ozone pre-cursors including VOCs and NO_x.

- Good spatial coverage of meteorological monitoring (surface and upper air) is also needed as a crucial element to provide accurate inputs for the models and models' evaluation.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

2. CLIMATE CHANGE

Projects: 28, 29, 30, 44, 45, 49, 58, 68, 85, 86

P028, ROUND 8, LEAD INSTITUTION: UC DAVIS

Predictive modeling of cheatgrass invasion risk for the Lake Tahoe Basin. Brian L. Anacker, Susan P. Harrison, Hugh D. Safford, Samuel Veloz.

Objectives:

We examine the relationship between climate and the invasion of cheatgrass in an effort to forecast if climate change and disturbance will trigger further cheatgrass establishment and spread in the Lake Tahoe Basin.

Findings:

- Drier sites, especially those highly disturbed (e.g., close to roads and urban areas), were more suitable for cheatgrass than wetter, undisturbed sites. These results combined to suggest that cheatgrass in the LTB is controlled primarily by precipitation and proximity to dispersal corridors and disturbances, but temperature, especially average minimum winter temperatures, are also important for determining when cheatgrass establishment can initially occur.
- There are large areas within the LTB that are climatically suitable for cheatgrass, but do not yet contain the species.
- The binary predictions of the hierarchical model show less area as being suitable for cheatgrass, but also have the highest degree of underprediction (false negatives).
- Our climate forecasts suggest climatic suitability for cheatgrass will continue to be high for the LTB into the next 20 years and up to 60 years.

Management Implications:

- The most effective way to reduce the impact of invasive species is to identify new occurrences and eradicate them. In the beginning of an invasion, there is a window of opportunity where eradication is possible and economically feasible.
- Our spatially explicit model of invasion risk for the LTB, available as a GIS, is a tool that allows managers to predict where invasion is currently most likely.
- It is imperative to carry out pre-project inventory of invasion in these sites and to monitor the effects of these projects on cheatgrass invasion after treatment. Burned

areas should also be monitored for cheatgrass presence. Quick action should be taken if cheatgrass establishment is documented.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P029, ROUND: 8, LEAD INSTITUTION: NORTHERN ARIZONA UNIVERSITY.

Modeling the influence of management actions on fire risk and spread under future climatic conditions. Matthew Hurteau, George Koch, and Malcolm North.

Objectives:

The purpose of this study was to quantify the influence of predicted changes in climate on live tree carbon stocks, as a function of species-specific carbon stock changes, in a Sierran mixed-conifer forest by accounting for both biotic and abiotic influences on growth. Additionally, we sought to determine the carbon stock implications of treatments implemented to reduce the risk of high-severity wildfire and their interaction with climate impacts on growth.

Findings:

- Outputs were produced for numbers of trees, basal area, stand density index, and carbon stock.
- In the recursive partitioning analysis, the most influential factors were general circulation model (GCM), forest type, and simulation period. The partitioning based on GCM was a function of the temperature and precipitation projections specific to each GCM-emission scenario combination. The partitioning based on simulation period was a function of projected climate over a specific time period.
- The projected late-century reduction in winter precipitation, an important source of moisture for tree growth, was greatest from the Geophysical Fluid Dynamics Lab coupled model (GFDL) under the A2 emission scenarios. While all projections were for increasing temperature throughout the century, the greatest increases were from National Center for Atmospheric Research Community Climate System Model (CCSM3) and GFDL.
- The partitioning based on GCM and emission scenario indicates that the level of increasing temperature and decreasing precipitation were more influential on forest carbon stock than simulation period, slope, or forest type. Slope was influential only for CCSM3 and GFDL-A2 where the dominant vegetation was not white fir.
- As expected, mean live tree carbon stocks varied by treatment intensity over the baseline period. The burn-only treatment resulted in the smallest initial mean decrease in live tree carbon stocks (11.7 Mg C /ha), while the thin-only (24.8 Mg C /ha) and thin and burn (33.2 Mg C /ha) had a much larger mean impact on live tree carbon, relative to the control. Over the historical simulation period, the rate of increase in carbon stock size was greater in the thin-only than in the control. This increase resulted in a much smaller difference in mean thin-only carbon stocks (203.8 Mg C /ha), relative to the control (214.7 Mg C /ha) following 29 years of growth.

- Relative to baseline, all treatments had increased live tree C with the largest mean gains made by the burn-only (14.5%) and thin and burn (16.9%). These two exceptions are a function of the smaller increase in temperature and decrease in precipitation projected by the National Center for Atmospheric Research Parallel Climate Model (PCM1) and relatively small increase in warming and large mid-century increase in precipitation under the Centre National de Recherches Météorologiques Coupled global Climate Model (CNRM-A2). Under GCM by emission scenarios where carbon stocks increased relative to the baseline period, the thin and burn and burn-only treatments generally had a larger increase in live tree carbon relative to their baseline conditions, than did the control or thin-only. However, in absolute terms the control and thin-only treatments consistently had larger live tree C stocks and in some cases these two treatments differ significantly by the end of the simulation period.
- White fir and ponderosa pine are the dominant species on the west and east sides of the Tahoe Basin, respectively, and had the largest changes in live tree carbon stocks of the five species modeled. Mid-century, both white fir and ponderosa pine had declines in live tree carbon, relative to the baseline, for GFDL-A2 and PCM1-A2. During the same period, both species had increases, relative to baseline, for PCM1-B1 and CNRM-A2.
- Given the limited contribution to total basal area, in general the changes from baseline were much smaller for red fir, incense-cedar, and sugar pine. In most cases, red fir and incense-cedar live tree carbon stocks tended to decrease relative to baseline and sugar pine tended to increase regardless of GCM, emission scenario, or time period.

Management Implications:

- The large influence of GCM on carbon storage suggests that reducing uncertainty in modeling forest growth response to wildfire mitigation treatments will require further refinement of climate projections. However, our results also suggest that there may be some capacity to leverage treatments to improve adaptive capacity for forest C sequestration as evidenced by the scenarios where there was little difference between control and thin-only treatments by the end of the simulation period (e.g. mid-century CNRM-A2).
- Our results show that changes in species-specific carbon stocks varied by GCM and emission scenario and that trade-offs between species caused a smaller reduction in stand-scale forest carbon stocks than would have occurred had all species been similarly impacted.
- Our results indicate that species-specific growth sensitivity to climate and the resultant carbon stock changes vary considerably as a function of the climate projections for a given emission scenario.
- Our results suggest that stand dynamics following treatment are sensitive to projected climate. While changing climate may alter how effectively different species can capture additional resources released by density reduction treatments, improving projections of the effect size of treatment under changing climate will require additional data from forest stands with a range of densities that have experienced climate variability over an extended period.

- Furthermore, our findings highlight the need to overcome the scale mismatch between GCMs and the typical forest management unit. Recent research suggests the substantial influence of local terrain on mediating climate, making even downscaled climate projections too coarse to capture the fine scale climate variability that can influence tree growth.
- Our results also indicate that given the variability in climate projections among models, species-level modeling using only one or two climate projections is unlikely to capture much of the uncertainty due to the combination of this variability and the problems of model scale.
- In the case of red fir the inclusion of latitude as a model parameter resulted in a less parsimonious model, however latitude was retained in the final model to account for the latitudinal gradient that is present in this species' distribution. While this approach facilitates the inclusion of climatic and topographic information, parameters which are typically absent from growth- and-yield models, the models are empirically-based and may be incapable of predicting growth response to conditions outside the range used for their development, including extreme climatic events such as prolonged, acute drought-stress.
- Had our study included increasing wildfire probability, the effects of management treatments may have been more pronounced because of the influence of these treatments on changing fire behavior and tree mortality rates. However, our results do indicate that under several of the projected climate scenarios (e.g. CNRM-B1, GFDL-B1, and PCM1-A2) the results of the simulated management actions suggest no interaction between climate and management. Understanding interactions among climate, wildfire frequency, and forest growth deserves further research.
- The majority of the growth-and-yield models do not account for the effects of changing climate on forest growth, potentially leading to an incorrect estimate of the future baseline condition. Incorrect baseline estimates detract from the economic viability of a project if carbon stock difference between the baseline condition and the project is reduced to the point that the project value is insufficient to cover the cost of investment.
- As our results indicate, the potential exists for a weakening of the carbon sink strength in these mixed-conifer forests. The strength of this positive biogeochemical feedback to warming may be enhanced by increased wildfire frequency and climatically driven mortality. Forest structural manipulations, such as thinning and prescribed burning, can reduce water, nutrient, and light competition and the risk of stand-replacing fire. However, the current variability in downscaled global climate projections adds considerable uncertainty to projecting how management actions to alter forest structure and composition and climate will interact in the future. Additional investigation into the effects of climate on regeneration and mortality is needed. Better characterization of these processes will help improve projections of stand dynamics under changing climate.
- Given the variation in species-specific carbon stocks in response to the range of emission and climate scenarios used to drive these simulations, our results suggest that an equitable distribution of basal area between species may provide the best hedge against this uncertainty.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

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Hurteau, M. D., Robards, T. A., Stevens, D., Saah, D., North, M., & Koch, G. W. 2014. Modeling climate and fuel reduction impacts on mixed-conifer forest carbon stocks in the Sierra Nevada, California. *Forest Ecology and Management*, 315, 30-42.

P030, ROUND: 8, LEAD INSTITUTION: UC DAVIS

The effects of climate change on Lake Tahoe in the 21st century: meteorology, hydrology, loading and lake response. Robert Coats, John Reuter, Michael Dettinger, John Riverson, Goloka Sahoo, Geoff Schladow, Brent Wolfe Mariza Costa-Cabral.

Objectives:

The goal of this present study was to provide water resource agencies and decision-makers with a scientifically justified assessment as to what extent climate change needs to be considered in ongoing efforts to protect Lake Tahoe.

The purpose of this research was to investigate the likely effects of climate change on Lake Tahoe, while assessing the implications of hydrologic changes associated with climate change for (1) changes in loads of sediment and nutrients to Lake Tahoe, (2) design and effectiveness of Best Management Practices (BMPs) and (3) lake response to warming.

Findings:

- Output from General Circulation Models or GCMs (often referred to as Global Climate Models) used to study changes in global climate do not nearly have the degree of spatial resolution required for a quantitative analysis of future meteorological conditions for topographically complex landscape such as the Tahoe basin.
- Typically, GCM output is provided at approximately 20 locations throughout the states of California and Nevada combined. Using downscaling techniques, the spatial coverage and therefore resolution was increased significantly to 12-16 grid points for the Tahoe region.
- A sophisticated statistical downscaling methodology (constructed analogs method) was applied to the A2 and B1 emissions scenarios of the GFDL (Geophysical Fluid Dynamics Laboratory Model) and the PCM (Parallel Climate Model) GCMs to produce a simulated data record for the 21st Century (2000-2099).
- The A2 and B1 scenarios were chosen to bracket projected emission scenarios with A2 considered a high emission condition and B1 a lower, albeit still increasing emission condition.
- Compared to historical observations (1950-1999) the level of agreement for temperature and precipitation within the study area of the Lake Tahoe Basin was very good. The anomaly correlations for maximum temperature and daily root-precipitation ranged from 0.70-0.95.

- Lake modeling also requires output for meteorological variables such as shortwave and longwave radiation, and surface wind speeds. In comparison to historical data, downscaling worked well for these variables and was adequate for our modeling purposes.
- In an attempt to ensure that the downscaled GCM data was as representative of conditions in the Tahoe Basin as possible, it was further refined using a quantile mapping process so that the modeled historical precipitation related to the nearest in-basin SnoTel meteorology gage. The resulting meteorological output for future conditions represents a deliverable that was used to inform watershed and lake modeling. However, this output is now also available for other researchers studying the effects of climate change on forest vegetation, wildfires and other terrestrial processes. The team used the output of the GCMs, as appropriate, and the two emissions scenarios, downscaled to a 12 km grid scale. The daily output (temperature, precipitation, wind and radiation) was used to drive an existing numerical lake clarity model (DLM), and (after —disaggregation of daily to hourly values) to drive an existing watershed model (LSPC++) that calculates runoff, sediment and nutrient loads. In addition, the Pollutant Load Reduction Model (PLRM) was used to assess the effect of changes in hydrology on the design and operation of BMPs, such as treatment basins.
- Down-scaled climatic data from two General Circulation Models (GFDL and PCM) and two emissions scenarios (B1 and A2) were used to evaluate projections of 21st century hydrologic conditions in the Tahoe Basin. The meteorological data were corrected for bias and adjusted to local temperature, precipitation and wind data, and the results used to drive a distributed hydrology model and a lake hydrodynamic model. The output from the hydrology model has been used to analyze future projected trends in annual precipitation, the relative fraction of precipitation falling as snow, and the Palmer Drought Severity Index.
- For the Upper Truckee River, the hydrology model was also used to analyze the trend in timing of the annual hydrograph centroid, the shifts in the flow-duration curves and flood frequency curves, and the trend in the annual minimum 5-day low flow. The results show:
 - An upward trends in Tmax and Tmin, with trends for the GFDL > PCM, and trends for the A2 > B1;
 - no strong trends in annual precipitation amount, except for declining precipitation for the GFDL A2 case toward the end of the century;
 - a continuing shift from snowfall to rain, toward earlier snowmelt and runoff during the water year, for both scenarios;
 - a downward shift in the flow-duration curve for the A2 scenario in the last third of the century;
 - declining minimum 5-day low-flow for the A2, but not for the B1 case;
 - some increases in drought severity especially toward the end of the century;

- dramatic increases in flood magnitude in the middle third of the century, especially with the B1 scenario.
- These changes will create stresses on both terrestrial and aquatic ecosystems in the Basin, and pose serious challenges to resource managers, especially in the latter half of this century. These challenges include increased risk of wildfire, increased tree mortality from insects and disease, increased erosion and sediment yield, and losses of aquatic habitat.
- Climate change resulted in a shift in the distribution of snowfall towards rainfall. The LSPC modeled time series for snowpack under the A2 emission scenario showed a 55-60 percent reduction during the last one-third of the century (2067-2099) relative to that seen in the period 1967-1999.
- During 2000-2066 the modeled values were intermediate at 20-30 percent reduction. Under the B1 emission scenario a 35-40 percent reduction in snowpack was predicted between 2034 and 2099.
- The beginning and end dates for the snowpack period in the Lake Tahoe Basin are predicted to change in the 21st Century. During the period 2067-2099 – under the GFDL A2 emissions scenario - it is expected that the start of the snowpack could be three weeks later than the 1967-1999 historic baseline; peak snowpack could occur two weeks earlier; and that the end of the snowpack could be five weeks later weeks later.
- The estimated durations of the snowpack under the GFDL A2 emissions scenario are 232 days (2002- 2033), 226 days (2034-2066) and 184 days (2067-2099). These compare to a baseline condition (1967-1999) of 248 days.
- Water yield to Lake Tahoe declined under both the A2 and B1 emission scenarios. Under the GFDL A2 emissions scenario, flow declined by about 5-10 percent between 2034 and 2066. A further decline in flow, approximately 15-30 percent of the baseline, was seen between 2067 and 2099. The GFDL B1 emission scenario showed less of a difference than the A2 model run.
- The watershed model indicates that sediment load may stay uniform or increase slightly (up to 5 percent) relative to baseline loads.
- The modeled trends also suggest that nutrient loading should generally decline in association with the predicted decreasing water yield to the lake. For the first two-thirds of the 21st Century, sediment and nutrient loads are predicted to decline by about 5-10 percent. Thereafter (until 2099) total N and total P loads could drop by 75-80 percent.
- In all, the output from the watershed model suggests that pollutant loading to Lake Tahoe should not increase as a result of climate change, but that some decline may be possible. It is noteworthy that it was beyond the technical scope of this project to ascertain the quantitative impact of rainfall-mediated erosion on loading. Runoff concentrations used in the watershed model are based on current conditions where both snowmelt and rainfall cause pollutants to enter runoff. Theoretically, since rainfall has more erosive energy, some of the loads could be underestimated.

- Historically, the percentage of precipitation that falls as snow ranges between 50%-60% for elevations in the Tahoe basin where most development has occurred (predominantly around the lake margins at elevations ranging from 6,230 feet to 6,600 feet). At the end of the 21st century, the modeling analysis predicts that the percentage of precipitation that falls as snow will decline to an annual range of 30%-40% or even less for developed areas in the Tahoe basin.
- The net result of this potential shift in precipitation patterns is more rain and less snow, which could increase the frequency and magnitude of peak flows in stormwater runoff. This simulated trend of increasing temperature appears to be the most likely factor that may impact the effectiveness of water quality improvement projects (WQIPs) and private parcel best management practices (BMPs).
- Typical standards for national practice for design of stormwater treatment facilities target capture and treatment of 80-90 percent of the average annual runoff volume. The results of modeled simulations showed that increases in stormwater runoff caused roughly a 10 percent decline in treatment performance for WQIPs and BMPs with storm water treatment facilities sized using the 20-year 1-hour design standard for the Tahoe Basin (i.e. one inch of rain in one hour). However, at the end of the simulation period, capture remains above about 80 percent of average annual runoff. This indicates that while performance may be reduced, load reductions consistent with current national stormwater management practice would still be achievable if storm water treatment facilities are sized using the 20-year 1-hour design standard for the Tahoe basin.
- Two representations of a storm water project area were developed to compare pollutant load performance with and without stormwater quality improvements: 1) a Baseline Condition with modeling assumptions reflecting current land use conditions, maintenance practices, and pollutant sources; and 2) an Improved Condition with modeling assumptions reflecting implementation of a hypothetical WQIP that addresses all pollutant sources from public lands and complete implementation of BMPs for all private parcels within the project area. The Improved Condition resulted in roughly an 80-85 percent reduction in fine sediment particles (FSP) loading relative to the Baseline Condition at the beginning of the simulation period.
- The simulated results for the Improved Condition showed a modest decline in performance for FSP load reductions (i.e. increase in average pollutant load) as a result of climate change. However, the Improved Condition continues to provide more than 80 percent FSP reduction relative to the Baseline Condition throughout the entire simulation period.
- The Lake Clarity Model was developed for use in the Lake Tahoe TMDL to quantify the impact of pollutant loads and load reduction on transparency. This model includes a variety of modules such as a hydrodynamic sub-model, water quality and ecology sub-model, optical sub-models, and most recently a fully calibrated and validated dissolved oxygen sub-model. This combined model was used to evaluate the potential impacts of climate change on lake mixing and associated ramifications.
- Measured data from Lake Tahoe has shown that since 1968, the lake mixes (circulates) completely to the bottom (~500 meters) on the average of once every four years. Using

output from the GFDL A2 emissions scenario the Lake Clarity Model suggests that by the middle of the 21st Century (after about 2050) Lake Tahoe will cease to mix to the bottom, with a mixing depth of only 100 m as the most commonly seen value. A similar, albeit not as severe, outcome is seen for the GFDL B1 emissions scenario. As the surface water heats, the resulting density difference between the warmer surface water and the colder deeper water will be too strong for the wind energy to overcome. Indeed, this change in density can already be seen in the measured historic data.

- When the lake fails to completely mix, the bottom waters are not replenished with oxygen and eventually dissolved oxygen at these depths will fall to zero. When this occurs both soluble reactive phosphorus and ammonium-nitrogen (both are readily available for algal growth) are released from the deep sediments resulting in an increase in nutrient loading that would not have happened under the lake's current deep mixing regime. The model shows this as a new and significant source of nutrients, heretofore not seen in Lake Tahoe. By the 2075 or there about the model indicates that under the GFDL A2 scenario dissolved oxygen below 200 m could reach a sustained level of zero year round. At the same depths, oxygen concentrations could drop to levels (< 6 mg/L) that are inhospitable to salmonids even earlier. The model also suggests that intermittent periods of anoxia in the deepest waters could occur within the next 20 years. Under the GFDL B1 scenario, deep-water anoxic will also occur, albeit not as sustained as seen in the GFDL A2 scenario; this results from the observation that while complete mixing will be less frequent than historically observed, it will occur.
- Based on published results for soluble phosphorus (SRP) and ammonium release from anoxic Lake Tahoe sediments, the annual loading of SRP under sustained conditions of lake stratification (no deep mixing) and anoxic sediments would be twice the current load from all other sources. Loading of ammonium under these conditions would increase the amount of biological available nitrogen that enters the lake by 25 percent. This effect on the nutrient loading budgets to Lake Tahoe could have a dramatic and long-lasting impact on the food web and trophic status of Lake Tahoe.
- The resulting annual Secchi depth in the later portion of the 21st Century will be in the range of 15-20 m as compared measured values of 21-22 m since 2000. Should the nutrients release from the bottom sediments periodically mix or otherwise become entrained into the upper waters we expect that the impact on algal growth below the Secchi depth should be significant, with an attendant impact of lake food web dynamics and trophic status.
- The lake model suggests that climate change will drive the lake surface level down below the natural rim after 2086 for the GFDL A2 but not the GFDL B1 scenario.

Management Implications:

This project represents the first attempt to evaluate water quality and water resources at Lake Tahoe under the anticipated conditions of climate change. The results indicate that continued climate changes could pose serious threats to the characteristics of the Lake that are most highly valued. Future water quality planning must take these results into account.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P044, ROUND: 9, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Ecological genetics of western white pine (*Pinus monticola*) from the Lake Tahoe Basin.

Patricia E. Maloney, Detlev R. Vogler, Andrew J. Eckert, Camille E. Jensen, Annette Delfino Mix, and David B. Neale.

Objectives:

Our objectives were to, (1) evaluate genetic variation for phenotypic traits related to growth, phenology, water-use efficiency, and patterns of resource allocation existing within and among populations of western white pine at a spatial scale of 1,300 km², (2) determine the genetic structure and diversity of extant western white pine populations, and (3) identify interactions between soil and climatic factors that influence standing levels of genetic variation for western white pine.

Findings:

Phenotypic variation within and among populations

- Families (maternal trees) accounted for a significant portion of the observed phenotypic variance. As such, mean narrow-sense heritabilities (h^2), estimated using global linear mixed models, were moderate to high ($h^2 = 0.1160 - 0.5898$) for most traits.
- Bud flush and $\delta^{13}\text{C}$ had the highest h^2 values for western white pine. However, there was considerable variation among populations around the mean h^2 for each phenotypic trait. For example, population-level heritabilities for $\delta^{13}\text{C}$ (mean $h^2 = 0.3314$) ranged from 0.0 to greater than 1.0 across populations of western white pine.
- Populations accounted for a statistically significant portion of the observed phenotypic variance. Western white pine had consistent levels of population differentiation for the measured phenotypic traits, as five of six traits had statistically significant population effects, with values for Q_{ST} ranging from 0.0179 (bud flush in 2012) to 0.1724 ($\delta^{13}\text{C}$).

Environmental correlations with genetic variation

- Standing levels of genetic variation were structured spatially for western white pine, with geographic variables (PCNM axes) accounting for 21.30% of the observed genetic variance across all phenotypic traits.
- Both climate and soil variables (PCs) were also important drivers (i.e., statistically significant) of genetic variation with climate variables explaining 20.16% and soil variables explaining 13.53% of the observed genetic variance across traits for western white pine.
- When combined, climate and soil variables jointly explained more than 26.71% of the phenotypic variance across traits for western white pine.
- Environmental correlations with standing levels of genetic variation were apparent for western white pine after correcting for spatial autocorrelation. For western white pine, environmental PCs composed of soil and climate variables, conditioned on spatial effects, predicted upwards of 10% or more of the variance in multivariate phenotypes.

In each case, the first three RDA axes were statistically significant ($P < 0.05$) and comprised approximately 80% or more of the total effect, with 12 of the 14 environmental PCs needed to capture these effects.

- The first RDA axis was dominated by height, bud flush in the first year, $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$, with environmental PC5 and PC7 driving most of the correlation structure. Mixtures of soil and climate variables dominated these two environmental PCs, with PC7 having a larger contribution from climate variables.
- In contrast, the second RDA for western white pine was largely dominated by bud flush in the second year, with environmental PC7, PC11, and PC14 being the most important contributors to this axis.
- As with RDA axis 1, PC7 and PC11 were dominated by mixtures of climate and soil variables, although environmental PC14 was almost exclusively determined by silt, sand, and clay percentages.
- The third RDA axis for western white pine was dominated by $\delta^{13}\text{C}$ and height, with environmental PC8 driving most of the correlation structure. This environmental PC was loaded strongly by maximum temperature in July, soil water capacity, and cation exchange capacity.
- For western white pine, an effect of soil type was found for bud flush in 2011, bud flush in 2012 root:shoot, and $\delta^{13}\text{C}$. Seedlings from non-granitic (e.g., volcanic) soil types had lower height growth, early bud flushing in 2011 and late bud flushing in 2012, lower root:shoot ratios, more negative $\delta^{13}\text{C}$, and lower $\delta^{15}\text{N}$, whereas seedlings from granitic soil types had greater height growth, late bud flushing in 2011 and 2012, higher root:shoot, less negative $\delta^{13}\text{C}$, and higher $\delta^{15}\text{N}$.

Genetic structure and diversity

- Genetic diversity measures (HO and HE) ranged from 0.231 to 0.259 and 0.245 to 0.272, respectively.
- Mean expected heterozygosity was higher in the LTB (mean $HE = 0.261$) than what was reported by Kim et al. (2011) in a range-wide sampling of western white pine (mean $HE = 0.235$).
- The inbreeding coefficient (FIS) ranged from 0.025 to 0.146; most values reported here are within range of zero and appear to be in Hardy-Weinberg equilibrium.
- The drift parameter (ci) ranged from 0.006 to 0.024, with the highest value of ci at Incline Lake (0.024), followed by Meiss Meadow (0.022).

Management Implications:

- We have shown that there is significant segregating genetic diversity for western white pine within the 1,300 km² of the LTB. As shown by previous studies, it is this segregating genetic diversity that can allow rapid responses to novel selection pressures through re-assortment of adaptive alleles across loci determining a quantitative trait.
- For western white pine this segregating genetic diversity appears to have been structured by natural selection in the past; hence, if change continues to occur in the

environmental variables that were important selective forces in the past, it is reasonable to hypothesize that these traits will continue to be important components of biotic responses to ongoing and future changes.

- Our results also emphasize the importance of considering comprehensive environmental datasets including both climate and soil when studying phenotypic variation and evolutionary potential, so that models constructed to understand future responses use appropriate environmental predictors of fitness-related genetic variation.
- Our information provides a perspective on evolutionary potential in the face of ongoing environmental change, indicating that a more spatially nuanced view is needed for gene conservation activities within the LTB and potentially other regions with similarly complex landscapes, steep environmental gradients, and existing genetic diversity.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P045, ROUND: 9, LEAD INSTITUTION: UC DAVIS

Hydrologic Characterization and Modeling of a Montane Peatland, Lake Tahoe Basin, California. Wes Christensen.

Objectives:

This study examines the groundwater system supporting Grass Lake, the largest peatland in the Sierra Nevada Mountains and how climate change might affect the Lake, located south of Lake Tahoe, California.

Findings:

- The average seasonal stream flow (ASSF) values for 2011 are 1.9 (First Creek) to 2.7 times (West Freel Meadows Creek, Freel Meadows Creek, Waterhouse Creek) higher than the 2010 values.
- The ASSF out of Grass Lake in 2011 was 2.2 times higher than the 2010 value.
- In 2010 stream flow for the four streams entering Grass Lake proper fell below 1.0 cfs between late June (Waterhouse Creek) and late July (Freel Meadows Creek).
- In 2011 stream flow for the four streams entering Grass Lake fell below 1.0 cfs between late July (West Freel Meadows Creek and Waterhouse Creek) and mid-August (Freel Meadows Creek).
- Despite the similarity in late-season stream flow into Grass Lake between the two years, late-season stream flow out of Grass Lake dropped to 0.6 cfs by September 10 in 2010 and maintained flows as high as 8.0 cfs into October in 2011.
- Stream flow data collected on May 20 indicates that peak flow in Grass Lake Creek was at least 23.0 cfs ($\pm 30\%$).

- The highest stream flow recorded for First Creek was 4.7 cfs on June 7th. Peak discharge in Freel Meadows Creek (14.8 cfs) and West Freel Meadows Creek (3.3 cfs) occurred on June 7 and June 8, 2010, respectively.
- The highest values of discharge for Freel Meadows Creek (33.1 cfs), First Creek (11.4 cfs), and West Freel Meadows Creek (4.8 cfs) were recorded on June 26, 2011. The highest value of discharge for Grass Lake Creek (70.6 cfs) was recorded three days later on June 29, 2011. The highest value of discharge for Waterhouse Creek (4.0 cfs) was recorded on July 7, 2011.
- A seasonally based surface water budget shows no measurable difference between the total seasonal stream flow into and out of Grass Lake in 2010 or 2011. This is attributed to the large errors (30%) associated with measuring stream flow in these steep, dynamic mountain streams and the uncertainty in the range of ET flux. Groundwater contributions cannot be estimated using a seasonally based water budget.
- The magnitude of groundwater inflow is estimated to be 0.8 to 2.6 cfs after August 13, 2010 and exceeds total stream inflow (0.4 cfs) by September 10, 2010. Groundwater contributions are not detectable before August 13, 2010 due to errors in estimated flow rates.
- Surface water outflows from the peatland exceed surface water inflows by mid- August in 2010 and late-July by 2011. Persistently positive VHGs in many of the piezometers suggest groundwater discharge from the coarse sediment beneath the peat for much of the season.
- Groundwater flow into the peatland after August 16, 2011 was over 8.4 cfs and was the dominant component contributing to the water budget of the peatland.
- Simulations with a rain dominated precipitation regime show lower pressure heads and unsaturated conditions throughout the peatland. The maximum pressure heads simulated in the peatland for the rain dominated regime occur at the end of the wet season (end of May). These maximum pressure heads are comparable to those occurring at the end of the water year (Oct) in the “fully saturated” snow melt dominated simulations.
- The pressure heads and degree of saturation decrease through the dry season (June-Oct) as ET fluxes remove water and the surrounding watershed continues to drain. In simulations using the model calibrated to 2010 heads, pressure heads less than -0.4 m occur to the west of First Creek and to the east of Freel Meadows Creek by the end of the water year. In simulations using the model calibrated to 2011 heads, this same area experiences pressure heads less than -0.7 m. This suggests a large portion of the peatland may be susceptible to desaturation under a rain dominated regime.
- The upper peatland experiences pressure heads as low as -1.5 m using the 2010 calibrated parameters and -2.7 m using the 2011 calibrated parameters. In all cases, the pressure head in the peatland is less than zero by the end of the water year, indicating unsaturated conditions and the potential for peat decomposition.

Management Implications:

- This study suggests a rain dominated precipitation regime may lead to desaturation of the Grass Lake peatland.
- The most significant drying is expected to occur in the eastern and western portions of the peatland, resulting in approximately half of the peatland experiencing saturation levels 70% or less of total saturation by the end of the water year. This is expected to lead to increased aerobic decomposition near the edges of the peatland.
- The predicted increase in temperature is expected to further increase the rate of peat decomposition. The center of the peatland maintains saturation levels above 80% of total saturation in all simulations, suggesting this area is least susceptible to aerobic decomposition and may contain the longest history of peat accumulation despite changes in the precipitation regime.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Christensen, W. (2013). *Hydrologic characterization and modeling of a montane peatland, Lake Tahoe Basin, California*. ProQuest, UMI Dissertations Publishing.

P049, ROUND: 10, LEAD INSTITUTION: PORTLAND STATE UNIVERSITY

Management options for reducing wildfire risk and maximizing carbon storage under future climate changes, ignition patterns, and forest treatments. Loudermilk, E. Louise, Stanton, Alison E., Scheller, Robert M., Weisberg, Peter J., Yang, Jian, Dilts, Thomas E., Skinner, Carl.

Objectives:

Our objectives for this project were, 1) to evaluate the emergent responses of multiple interacting processes, namely climate change and wildfire regime, on total forest carbon and succession dynamics, and 2) to evaluate the long-term effects of fuel treatments in mitigating wildfires and sequestering forest carbon (C), in a contemporary and climate change context, within the regional landscape of the Lake Tahoe Basin, CA and NV.

Findings:

- Our study illustrated the potential for continued forest growth and sequestration of above and below ground C across the LTB, which remained a C sink (Net Ecosystem Productivity > 0), despite any potential shifts in climate in the coming decades. This was a landscape legacy effect from the Comstock Era logging in the 1880's and the resulting regeneration and growth of the forest into the next century.
- Effects from future changes in climate in the LTB included reduced establishment ability of the subalpine and upper montane tree species; stimulated growth of particular conifers, aspen and re-sprouting shrub species; and enhanced wildfire activity. Changes in the wildfire regime had the strongest impact on forest response.
- An increase in wildfire activity (area burned) in a changing climate caused higher mortality rates across the LTB and lower C sequestration potential by year 2110.

- Altered mortality patterns, caused by increased wildfire activity under A2 climate, had a stronger effect on overall productivity and C storage potential than climate change effects (e.g., growth, establishment) on individual species.
- In a changing climate, increased wildfire activity was caused by a reduction in fine fuel moisture across a longer growing season.
- Wildfire activity was further enhanced under future-climate scenarios, especially towards the end of the 21st century, by projected increases in natural and anthropogenic ignition sources.
- Continuous fuel treatments reduced area burned and fire severity across the LTB, regardless of climate or fuel treatment scenario applied.
- Projected increases in ignitions under the A2 climate dramatically reduced the ability of the forest to sequester C, but continuous fuel treatments moderated the reduction.
- The forest continued to sequester C in all fuel treatment scenarios, although at a lower rate than without fuel treatments.
- Continuous fuel treatments strongly suppressed target species (e.g., white fir and incense cedar) in managed areas and improved the regeneration environment for more shade-sensitive species (e.g., Jeffrey pine, sugar pine).
- As wildfire ignitions increase, mainly towards the end of the 21st century, mitigation feedbacks from fuel treatments may become more difficult but be possibly more essential, as more area treated would intersect with more wildfires. This in turn would cause earlier net C gain from fuel treatment application, than fuel treatment simulations using contemporary climate.

Management Implications:

- Forested landscapes are subject to increasingly diverse and often competing demands from society. In the Lake Tahoe Basin (LTB), managers must balance forest health objectives to restore fire-adapted ecosystems and protect wildlife habitat with fuels management objectives to reduce the threat of wildfire and protect communities. In the near future, these objectives may also include storing carbon (C) or limiting C emissions.
- Managing the forested landscape in the LTB to meet the multiple goals of improved forest health, reduced fire risk, and atmospheric C regulation presents new challenges, especially in the context of changing climate regimes and altered disturbance regimes. Faced with the prospect of increasing regulations of carbon emissions, managers may be forced to balance the use of forest treatments for reducing fire risk against the implications for carbon sequestration.
- Properly balancing the spatial arrangement of management activities in order to achieve multiple objectives on the landscape requires more information about the inherent trade-offs among these objectives and improved awareness of the opportunities for optimizing management at the landscape scale.

- This research demonstrates an operational method for explicit consideration of potential trade-offs among management objectives for reducing fire risk, improving forest resiliency to climate induced changes in drought and wildfire regimes, and sequestering C or reducing C emissions. Our modeling approach provided an avenue to analyze the emergent outcomes of interactions among climate, wildfire, forest succession, and nutrient cycling between above and belowground nutrient pools. This research illustrated the influence of multiple landscape-level processes and disturbances, including active management that interact over long spatial and temporal scales to drive forest carbon and species dynamics.
- Our research suggests that increases in fire weather, ignitions, and wildfire activity from climate change may exert the strongest influence on forest species response and C storage potentials and emphasizes the need to incorporate these processes when addressing questions about climate change on forest response. The response of individual species to climate change may be unique within forested regions, but effects on overall landscape dynamics may be more distinctively influenced by feedbacks associated with climate-induced disturbances like wildfire.
- The future response of forest ecosystem C cycling in many forested systems worldwide may depend more on landscape legacies related to land use or major disturbances than on projected climate change alone. This is especially true in the LTB, where a landscape legacy effect of increasing C storage through the coming century is an apparent result of past intensive logging and subsequent fire suppression.
- Despite these legacies, simulated fuels treatments were effective at moderating the effects of wildfire in the LTB under a contemporary climate scenario and climate change intensified the moderating effects in some instances. Although fuels treatments may reduce C storage in the short term, the benefits of reduced fire risk and improved forest species balance provide compelling evidence that fuels treatments will likely remain an important and perhaps critical component of forest management in the coming decades.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P058, ROUND: 10, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Evaluation of montane forest genetic resources: implications for conservation, management, and restoration of whitebark pine (*Pinus albicaulis*) in the Lake Tahoe Basin. Detlev Vogler.

Status: Draft Report

Objectives:

- Determine adaptive genetic variation in whitebark pine for ecologically important plant traits (disease resistance, water-use efficiency, drought adaptation, phenology, and growth) across the Lake Tahoe Basin.

- Determine the underlying genes that control adaptive phenotypic traits using genotype-phenotype associations.

Findings:

Objective 1. Determine adaptive genetic variation in whitebark pine for ecologically important plant traits (disease resistance, water-use efficiency, drought adaptation, phenology, and growth) across the Lake Tahoe Basin.

- Heritable genetic variation for 4 of 5 fitness related traits (water-use efficiency, leaf nitrogen content, root:shoot ratio, and bud flush, low for height growth) exists for whitebark pine in the Lake Tahoe Basin.
- Genetic variation in whitebark pine is structured among populations and along environmental gradients.
- The genetic variation in whitebark pine is correlated with climate, soil and geography.
- These patterns suggest that whitebark pine is locally adapted in the Lake Tahoe Basin.

Objective 2. Determine the underlying genes that control adaptive phenotypic traits using genotype-phenotype associations.

- Heritable genetic variation for phenotypic traits can be decomposed into the actual loci (SNPs) that create it and these loci appear to be under the effect of spatially divergent natural selection.
- These SNPs can be used to track frequencies of “adaptive” alleles in natural populations.
- SNPs associated to root:shoot biomass and $\delta^{13}\text{C}$ were more likely to be associated to climate than randomly chosen SNPs.
- We also discovered 223 additional SNPs, none of which were associated to a measured phenotype, that were correlated to at least one climate variable.
- Considered collectively these 223 SNPs had reasonable discriminatory power (75% success rate) to distinguish groups of populations classified by climate.

Management Implications:

Ecological genetic studies such as ours can provide information to resource managers to guide conservation activities such as cone collections and seed banking. Given that white pine species are locally adapted and genetically diverse reforestation and restoration source material can be provided from within the Lake Tahoe Basin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Maloney, P.E., D.R. Vogler, A.E., Eckert, C.E. Jensen, and A. Delfino Mix. In Revision. Ecological genetics of three white pine species from the Lake Tahoe Basin, USA: Implications for conservation and evolutionary potential. *Ecological Applications*.

Lind, B.M., C.J. Friedline, P.E. Maloney, D.R. Vogler, D.B. Neale, and A.J. Eckert. Genetic architecture of fitness-related traits within whitebark pine (*Pinus albicaulis*). For submission to *Genetics*.

P068, ROUND: 11, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Restoration strategies for whitebark, western white, and sugar pine in the Lake Tahoe Basin: ecological and epidemiological considerations. Detlev Vogler & Patricia Maloney

Status: Active, final report in preparation.

Objectives:

Develop practical, effective, and science-based restoration strategies for whitebark, western white, and sugar pine in the Lake Tahoe Basin.

Findings:

- Season of planting, fall versus spring, and caging were tested to determine best planting time and if seedling protection was warranted. Seedling survival was two times greater in fall plantings versus spring plantings in the Lake Tahoe Basin. Protective caging was generally not warranted.
- Restoration planting survival for sugar pine seedlings were 16% at the Tunnel Creek/Sand Harbor location and 51% at Sugar Pine Point State Park. Five hundred sugar pine seedlings were planted (total 1,000) at each location and seedlings were watered in 2013, at both sites. Due to low survival at Tunnel Creek/Sand Harbor 500 seedlings were sown in 2014 and in fall 2016 these 2-year sugar pine seedlings will be out-planted at Tunnel Creek/Sand Harbor (and will be supplemented with watering in the summers of 2017 and 2018 to improve survival rates) and supplemental seedlings will also be out-planted at Sugar Pine Point State Park as well.
- Restoration plantings for western white pine at Blackwood Canyon and whitebark pine at Rifle Peak occurred in October 2013 yielding seedling survival of 57% and 24%, respectively, with approximately 1,000 seedlings of each species out-planted. In 2014 supplemental restoration plantings were made at both Blackwood Canyon and Rifle Peak, planting an additional 300-500 seedlings at each location. In fall 2016 we will out-plant the remaining western white pine (~300) and whitebark pine (~200) seedlings at each restoration site.

Management Implications:

Use of local and genetically diverse planting material is advised and in high-risk stands, for white pine blister rust, deploying $\leq 33\%$ blister rust resistance is recommended. Supplemental watering of restoration plantings is recommended at dry east shore locations in the Lake Tahoe Basin. Restoration plantings need continued monitoring.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

D.R. Vogler, A. Delfino Mix, and P.E. Maloney. White pine conservation and restoration handbook: A resource for land manager's. To be published as a USDA FS General Technical Report.

P085, ROUND 12, LEAD INSTITUTION, PACIFIC SOUTHWEST RESEARCH STATION

Using provenance test data to inform ecological restoration in the Tahoe Basin. Jessica Wright.

Status: This project is currently active.

Objectives:

It is the goal of this project to provide information from four decades of provenance tests of ponderosa, Jeffrey, and sugar pine that will help guide the creation of resilient forests.

Findings:

Management Implications:

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P086, ROUND 12, LEAD INSTITUTION, PORTLAND STATE UNIVERSITY.

Drought Stress and Bark Beetle Outbreaks in the Future Forest: Extending an Existing Model to Inform Climate Change Adaptation. Loudermilk, E. Louise; Kretchun, Alec M.; Scheller, Robert M.; Hurteau, Matthew D.; Weisberg, Peter J., Skinner, Carl; Belmecheri, Soumaya.

Objectives:

Our primary objectives were to evaluate climate change effects associated with drought stress (reduced forest productivity), bark beetle outbreaks, and management mitigation options across the forested landscape of the Lake Tahoe Basin, CA and NV, USA. In addition, we compared in situ estimates of scaled ANPP from tree-ring data with model outputs across a coincident 20-year period (1987-2006) to climate to investigate model accuracy of forest productivity, as influenced by moisture sensitivity and bark beetle outbreaks. This research was an extension of our previous SNPLMA project (P049, which assessed the impacts of climate change on wildfire and above and below ground forest C dynamics and the effectiveness of fuel treatment options for reducing fire emissions and maintaining forest C). This research leveraged the spatial data, model parameterization, and analysis for P049, while incorporating drought-impact growth estimates from site-level data collected from another SNPLMA project (P029).

Findings:

- Under baseline climate, bark beetles do not significantly reduce total ecosystem carbon over the simulated century beyond the reductions cause by fuel treatments
- Projected increases in bark beetle activity in the A2 climate (high emissions scenario) generally increased C emissions due to heightened tree mortality in the latter half of the century compared to simulations assuming a contemporary climate. In addition, these outbreaks caused greater uncertainty in forest composition and carbon dynamics.
- Bark beetle outbreaks and wildfire activity did not overlap significantly in our simulations, regardless of climate scenario applied. This is in large part due to wildfires

generally occurring near the WUI, and BB outbreaks occurring basin-wide, including more remote and high elevation areas.

- In the A2 climate, fuel treatments remained effective at reducing wildfire activity, but were not particularly effective at reducing bark beetle outbreaks, due to the great magnitude of bark beetle outbreaks and their widespread distribution throughout the basin.
- A Log Odds Ratio analysis on Net Ecosystem C Balance indicated that bark beetles significantly increased the probability of the landscape becoming a C source after mid-century with climate change.
- The effects of bark beetles and fuel treatments had compensatory effects on species interactions, where, e.g., fire tolerant or less targeted species (by beetles or management) regenerated in areas affected by these disturbances. Under high emissions, this compensatory capacity was reduced in the latter half of the century, when effects from bark beetles were severe and forest recovery lagged behind outbreak frequency and intensity.
- The beetle outbreak area varied by species, with the fir engraver causing the most damage. The damage potential of the fir engraver was reduced when fir populations declined from significant beetle kill under high emissions.
- Under high emissions climate, fir engraver outbreaks were 35% greater in area when fuel treatments were not simulated, indicating that simulated fuel treatments have the capacity to reduce outbreak size of fir engraver.
- Two significant drought periods occurred during the historical study period of 1987-2006; these droughts caused reductions in median ANPP when estimated by both increment coring and LANDIS-II, particularly in the sites with the highest potential productivity.
- Moisture sensitivity and bark beetles both caused reductions in aboveground productivity, moisture sensitivity via slowed growth and bark beetles via mortality, particularly in older larger tree cohorts.
- LANDIS-II captured the underlying dynamics of tree growth well. Scenarios that included bark beetle outbreaks and moderate moisture sensitivity matched the increment core productivity estimates best.

Management Implications:

- Managing for fuels may substantially reduce outbreak area by reducing host density and altering forest structure.
- Conversely, climate change and insect outbreaks may reduce the need for fuels management by eliminating a recurring source of ladder fuels, namely white fir.
- Similarly, areas of ponderosa pine plantations in the Modoc National forest which were thinned prior to a MPB outbreak showed significantly lower mortality rates than untreated areas.

- Work in other parts of the western US has also shown reductions in beetle-caused mortality in conifer forests as a result of thinning treatments, though outbreaks that reach 'epidemic' levels may nullify the benefits of such preventative measures.
- Developing strategic approaches to managing in these future conditions is essential.
- Field applications used in the basin, primarily forest thinning, are intended to reduce fire risk but may also have the potential to reduce drought stress and potential beetle-related mortality. This may be particularly important in a changing climate, where higher temperatures may exacerbate these conditions.
- Management strategies to reduce outbreaks need to be preemptive, whereby forests are thinned to create a more resilient forest structure. Beetles would be forced to travel farther between trees and are less likely to find suitable hosts because the remaining trees are often less drought stressed.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

3. FOREST FUELS AND VEGETATION MANAGEMENT

Projects: 6, 8, 9, 12, 17, 18, 19, 20, 32, 33, 34, 36, 51, 67, 78, 83, 91

P006, ROUND: 7, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Nutrient emissions from prescribed fire in the Lake Tahoe Basin: Implications from field and laboratory observations. P. Verburg, A. Shackelford, L.-W. A. Chen, D. Zhu, R. Susfalk, B. Fitzgerald.

Objectives:

This study assesses the carbon (C) and nitrogen (N) release as affected by fuel moisture during a prescribed fire near Incline Village, NV following mechanical thinning. The field component of this study involved a pre- and post-fire fuel inventory to estimate C and N losses under fall fuel moisture conditions. The laboratory component of the study further investigated effects of moisture on nutrient release and speciation.

Findings:

- Results from the field study showed that total fuel reductions were close to 90% and C and N losses closely followed patterns in fuel mass reductions.
- Soil extractable ammonium (NH₄⁺) increased immediately following fire, but no clear trends were observed for extractable nitrate (NO₃⁻).
- The laboratory combustion experiment showed that increasing fuel moisture caused increases in total particulates, including PM_{2.5} and C and N species, and gaseous ammonia (NH₃) emissions for several fuel types.
- Nutrient emission factors were highest for litter and leaves.

- We calculated atmospheric emissions for a hypothetical moist burn combining field and laboratory data. These calculations showed that under moist conditions particulate, and NH₃, emissions per unit fuel consumed will increase but this may be partially offset by a lower amount of fuels consumed compared to dry conditions.
- When comparing our data with model predictions by CONSUME 3.0, our data suggested a higher impact of moisture on particulate emissions compared to CONSUME.

Management Implications:

- Conducting fuel treatments when fuel moisture is low will likely maximize fuel consumption while minimizing air quality impacts. However, dry burns not only increase fuel consumption, which will reduce C sequestration; they also favor conversion of fuels to CO₂, which is an important greenhouse gas.
- Although we did not specifically test this in our study, broadcast burns may lower C sequestration compared to pile burns, since broadcast burns can cause significant consumption of litter and duff compared to piles that have a much smaller footprint. As a result, while more C is being released under dry conditions, air quality impacts may be lower under these conditions suggesting a trade-off between short-term C sequestration and air quality management objectives.
- In addition, high consumption of litter and duff may negatively impact short and long-term nutrient availability by removing a pool of easily mineralizable N.
- Our emission factors can help to better inform existing models that estimate fuel reduction and emissions following prescribed fire such as CONSUME to allow for more accurate predictions of C and N emissions from prescribed fire.
- The fuel inventories prepared in this study can be added to existing Fuel Characteristic Classification System fuelbeds, and thus provide additional information on the variability in fuel loads in the Lake Tahoe Basin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Chen, L. W., Verburg, P., Shackelford, A., Zhu, D., Susfalk, R., Chow, J. C., & Watson, J. G. 2010. Moisture effects on carbon and nitrogen emission from burning of wildland biomass. *Atmospheric Chemistry and Physics*, 10(14), 6617-6625.

P008, ROUND: 7, LEAD INSTITUTION: NORTHERN ARIZONA UNIVERSITY

Restoring sugar pine in the Tahoe Basin: regeneration ecology and recruitment dynamics of sugar pine under various stand structures. Kristen Waring and Natalie Angell.

Objectives:

The objectives of this study were to:

- To compare competition variables and tree characteristics at the individual tree-scale between true saplings (TS) and pygmy trees (PYG) in stands of differing site productivity and management history.
- To identify the best predictors of tree status (TS vs. PYG) to develop a predictive model for use by managers.
- To define relationships between canopy closure, stand structure and sugar pine height growth rates in stands with differing management histories.
- To identify the most important stand, microsite, and individual tree attributes explaining past growth rates and develop models to predict stand structures that promote these attributes at the stand and individual seedling/sapling level.

Findings:

- Age structure was typically comprised of one or two cohorts with a few stands having remnant stems from pre-Euro-American settlement (prior to 1850). Overstory basal areas (live tree and total) varied considerably between stands and management types, with the highest live tree basal area approximately four times greater (59.4 m² ha⁻¹) than the lowest (14.3 m² ha⁻¹).
- For total basal area, the largest value (68.5 m² ha⁻¹) was approximately 3.5 times larger than the lowest value (19.1 m² ha⁻¹). The median live and total basal areas were 42.6 and 45.3 m² ha⁻¹, respectively.
- Tree density also varied widely among stands (overstory = 108.1 - 632.5 (trees ha⁻¹) and understory = 420.4 - 5585.4 (trees ha⁻¹)), as did stand density index (247.3 - 1473.9).
- No definite trends occurred in site index between stands; all stands were classified into fair and poor site productivity classes.
- Out of 130 trees measured across all stands, 38.5% (n = 50) were classified as TS and 61.5% (n = 80) as PYG).
- Regarding site productivity, there was a fairly even split between TS and PYG in poor (46.0% and 52.5%, respectively) and fair (54.0% and 47.5%, respectively) site productivity classes.
- Regarding management, 18.0% of TS were sampled in managed stands and 82.0% in unmanaged stands.
- There was a slight negative relationship of height growth by age for TS and PYG (data not shown). The average age of TS was 33 years and 75 years for PYG (data not shown).
- Within each management type, there were no significant differences in competition characteristics between TS and PYG. For tree attributes the only significant differences were in unmanaged stands where TS had significantly higher mean crown surface area and height growth than PYG. The small sample size for height growth (TS = 3, PYG = 6) likely contributed to the non-significant results.

- Within each site productivity class (fair and poor), there were significantly higher means for PYG in the competition characteristics of live tree, total basal area, and azimuth to closest shade tree in poor quality sites, and canopy closure in fair sites at the individual tree level. For tree characteristics mean height growth was the only significant individual tree attribute, with significantly higher means for TS than PYG in both site productivity classes.
- Tree height growth was a significant positive predictor ($p = 0.0005$) of a tree being a TS. The larger the value of a tree's height growth, the greater the probability of it being classified as a TS. No other variables significantly predicted whether a tree was TS or PYG ($p > 0.05$, data not shown).
- We found significantly higher basal areas (live only and total), canopy closure, height growth and total height of sugar pine seedlings in unmanaged stands than in managed stands for. The converse is true for saplings, with managed stands having significantly higher mean basal areas (live and total), canopy closures and sapling height than unmanaged stands. The mean height growth rate was also higher for managed than unmanaged stands, although the difference was not statistically significant.

Management Implications:

- Treatments that create a variable horizontal spatial pattern, such as modified group selection or variable density thinning, are the management strategies most likely to meet the multiple objectives of lowering density, reducing fire hazard, maintaining aesthetics, and providing for the establishment and recruitment of sugar pine.
- Prescribed burning is also likely to result in a similar spatial heterogeneity and create desirable seedbeds for sugar pine germination.
- Leaving residual, large sugar pine in the openings provides a nearby seed source while maintaining some structural heterogeneity in the openings.
- We recommend that a variable density thinning in both the groups and matrix would be more suitable for stands in the Lake Tahoe Basin.
- Variable density thinning provides for a less regular spatial pattern and more flexibility in species preferences.
- Growth of sugar pine saplings is likely to be enhanced near openings or with reduced canopy cover and stand density.
- These practices in concert with planting of white-pine blister rust resistant seedlings may help sugar pine recruit into the overstory, increasing the genetic and structural diversity of the stand.
- Multiaged management that creates two or more age classes may provide for multiple resource objectives and create sustainable stand structures that provide for continuous crown cover over time, thus avoiding some of the negative perceptions associated with more aggressive even-aged treatments.

- When integrated with topographic-scale variability, a range of multiaged approaches can be used to design stand structures that accommodate the role of fire, sensitive wildlife habitat and heterogeneous stand structures.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Angell, N. J. 2011. *Determinants of Pygmy Sugar Pine in the Lake Tahoe Basin, USA* (Doctoral dissertation, Northern Arizona University).

P009 A, ROUND: 7, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Population biology of sugar pine (*Pinus lambertiana* Dougl.) with reference to historical disturbances in the Lake Tahoe Basin: Implications for restoration. Patricia E. Maloney, Detlev R. Vogler, Andrew J. Eckert, Camille E. Jensen, David B. Neale.

Objectives:

Our goal was to determine current population and genetic characteristics of *P. lambertiana* given the history of Comstock logging, fire suppression, and *C. ribicola* in the Lake Tahoe Basin. Given the diversity in forest conditions across the Basin our objectives were to determine:

- The current population structure and trends of sugar pine in the Basin;
- The genetic structure and diversity of extant sugar pine populations;
- Relationships between stand and sugar pine population characteristics with historical disturbances (logging, fire suppression and white pine blister rust (WPBR)); and,
- Landscape-scale frequency of WPBR resistance (Cr1). Any restoration strategies to potentially mitigate these anthropogenic disturbances will require information on current population, genetic, and stand conditions in the Lake Tahoe Basin.

Findings:

- Comstock-era logging was evident in 9 of the 10 sites; only D.L. Bliss State Park, located north of Emerald Bay, did not exhibit obvious, significant harvesting. Fire suppression was also evident in most stands, with forest stands characterized by high densities of shade tolerant species like white fir.
- Despite the confounding effects of recent stand treatments, we found a moderate and negative relationship between sugar pine survivorship and white fir basal area ($r^2 = 0.31$, $F_{1,10} = 3.57$, $P = 0.09$, slope estimate = 0.01). White pine blister rust was found in 90% of the sites and ranged from 0% to 48%. The highest rust levels were found at Carnelian Bay (30%), Sugar Pine Point State Park (41%), and Granlibakken (48%). No rust was found on sugar pine in the Glenbrook population.
- Sugar pine densities were highest at Crystal Bay, D.L. Bliss State Park, Heavenly, and Glenbrook, respectively, and lowest at Sugar Pine Point State Park and Tunnel Creek. Basal area of sugar pine was highest at Granlibakken, followed by Glenbrook, D.L. Bliss, and Sugar Pine Point State Park.

- Sugar pine cone production and recruitment varied considerably from site to site. High cone production was found at Glenbrook, Carnelian Bay, Granlibakken, and Sugar Pine Point State Park.
- High reproductive output did not always correspond to higher numbers of recruitment, with the exception of the Glenbrook population, with 835 recruits per hectare. Cone production at Granlibakken was high (1183 cones ha⁻¹) but only 25 seedlings and saplings were found per hectare. D.L. Bliss State Park had moderate cone production (685 cones per ha) and the second highest number (262) of seedlings and saplings per hectare.
- Evidence of cone-damaging insects was found at all sites. Sugar pine mortality was moderate, ranging from 1–10%. The highest mortality levels were at Granlibakken and the Sand Pit. High mortality at Granlibakken corresponded with very high rust incidence.
- Variation in fecundity, which is a function of cone production and the number of recruits that successfully established, was found among populations. Overall fecundity was highest at Glenbrook, due to a combination of good cone production and successful recruitment. Despite high cone production at Sugar Pine Point State Park and Granlibakken, both populations had moderate to low fecundity, possibly due to stand conditions and high WPBR incidence.
- Survivorship varied due to differential mortality between size classes and populations. Mean survivorship probabilities were >0.850 for 8 of 10 sugar pine populations, but were substantially lower for Sugar Pine Point State Park (0.621) and Granlibakken (0.729). In both latter populations survivorship was low in size classes 2 (0.1–5.0 d.b.h.), 4 (10.1–20.0 d.b.h.), and 5 (20.1–40.0 d.b.h.). Mean survivorship probability and WPBR incidence were significantly and negatively related ($r^2 = 0.46$, $F_{1,10} = 6.72$, $P = 0.03$, slope estimate = 0.04).
- Estimated growth rate (k) for 6 of the 10 sugar pine populations was $k \geq 1.0$, indicating that these populations are stable, if not slightly growing. Sugar Pine Point State Park, Tunnel Creek, Granlibakken and Crystal Bay had $k < 1.0$, indicative of populations that may be in decline. All upper limit confidence intervals for k were greater than 1, suggesting stability in most populations. However, for most populations the lower confidence interval was < 1.0 ; whether this is cause for concern is difficult to assess, given that k was estimated from a one-time sampling.

Management Implications:

- Restoration strategies to mitigate anthropogenic influences should be based on strong evidence of negative population and genetic effects, as well as an assessment of risk factors for a population (e.g., how much disease at a site, frequency of resistance, and frequency of infection periods).
- Of the 10 sugar pine populations evaluated in the Lake Tahoe Basin only three appear to be in need of restoration.
- Restoring population numbers, disease resistance, and genetic variation may require out-planting seedlings that are genetically diverse and WPBR-resistant, as well as forest

treatments (e.g., thinning and/or prescribed fire) that promote natural sugar pine regeneration.

- Despite recent prescribed fire treatments at Sugar Pine Point State Park, this location still may require restoring sugar pine numbers, as well as genetically diverse and WPBR-resistant material. Even though frequency of Cr1 (0.125) is moderate at Sugar Pine Point State Park, the remaining 87% of the individuals are susceptible and under strong disease pressure (WPBR incidence = 41%).
- Deploying resistance at least to present levels (0.125) would be advisable.
- Given recent thinning and prescribed fire treatments at Tunnel Creek, a similar strategy, as stated above, of restoring sugar pine numbers by facilitating recruitment and planting genetically diverse and resistant seedlings may be warranted.
- Future fuel treatments of thinning and prescribed fire are proposed at Granlibakken (D. Fournier pers. comm., USDA Forest Service) and will be key to promoting natural sugar pine regeneration. Because this sugar pine population is in a high-risk site and very little disease resistance has been found, deploying WPBR-resistant material from nearby locations is warranted. Frequency of Cr1 being deployed should be within the range of frequencies currently found in the Lake Tahoe Basin (0.045– 0.125). Deploying resistance will have positive effects on sugar pine survival in high-risk sites, despite the risk that virulence to Cr1 may evolve in the pathogen.
- The primary goals of forest restoration treatments (e.g., thinning and/or prescribed fire) is to generally increase tree size and shift forest composition toward fire tolerant pine species, particularly in historically pine-dominated communities. We have shown from our study that it is not only about restoring numbers of sugar pine or desirable forest conditions (e.g., reduced stem densities and representation of fire intolerant species) but also restoring genetic diversity and moderate levels of disease resistance, so rarely considered.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Maloney, P. E., Vogler, D. R., Eckert, A. J., Jensen, C. E., & Neale, D. B. 2011. Population biology of sugar pine (< i> Pinus lambertiana</i> Dougl.) with reference to historical disturbances in the Lake Tahoe Basin: Implications for restoration. *Forest Ecology and Management*, 262(5), 770-779.

P009 B, ROUND: 7, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Ecology of whitebark pine populations in relation to white pine blister rust infection in subalpine forests of the Lake Tahoe Basin, USA: Implications for restoration. Patricia E. Maloney, Detlev R. Vogler, Camille E. Jensen, Annette Delfino Mix.

Objectives:

For over a century, white pine blister rust (WPBR), caused by the introduced fungal pathogen, *Cronartium ribicola* J.C. Fisch., has affected white pine (Subgenus *Strobus*) individuals,

populations, and associated forest communities in North America. We surveyed eight populations of whitebark pine (*Pinus albicaulis* Engelm.) across a range of environmental conditions in subalpine forests of the Lake Tahoe Basin, California and Nevada, to determine how WPBR is influencing host fecundity (i.e., female cone production and recruitment), survival, and current population trends.

Findings:

- Whitebark pine is a dominant component in these subalpine forests and relative densities ranged from 0.94 to 0.99.
- Because whitebark pine tends to form clusters in subalpine environments, as a result of seed caching behavior, densities ranged from 446 trees per ha to 797 trees per ha. Highest whitebark densities occurred in westside locations on the West Shore Peaks and Dick's Pass, and the lowest densities in eastside locations such as Rifle Peak and Snow Valley Peak. Across locations mean basal area was 23.3 m² per ha. In 2009 mean number of cones per ha was 2456 and ranged from 960 at Rifle Peak to 4632 at Freel Peak.
- Recruitment varied from location to location with a mean of 139 seedlings and saplings per ha and a range from 44 to 296.
- White pine blister rust was found at all locations. Disease incidence (number of WPBR-infected whitebark pine trees/all white-bark pine trees in a population) ranged from 1% at Freel Peak to 65% at Rifle Peak.
- Average number of branch cankers per population ranged from 0.06 to 4.99.
- Disease severity as measured by stem girdling category (1 = 61/3 of stem girdled; 2 = >1/3–2/3 girdled; and 3 = >2/3-completely girdled) ranged from a high of 1.35 at Rifle Peak and a low of 0.02 at Freel Peak, with three of eight populations having stem girdle categories P1.0.
- Cumulative whitebark pine mortality was low, ranging from 1% to 4%. Incidence of MPB was also low, ranging from 0% to 4%. The primary causes of mortality at our sites were MPB, WPBR, and likely drought stress, and their interactions.
- Multi-size structure was found for whitebark pine, with good representation in size classes 10.1–20.0 and 20.1–40.0cm. High proportions of large diameter trees (>40.1 cm) were found at Dick's Pass, Freel Peak, Heavenly, and Mt Rose (6.5%, 7%, 9%, and 13%, respectively). Relatively high proportions of trees in the smallest diameter class, 0.1–5.0 cm, were found at Freel Peak, Mt Rose, and Rifle Peak.
- Estimated growth rates (k) for 7 of the 8 whitebark pine populations were P1.0, indicating that these populations appear to be stable. Mt Rose had a k < 1.0, indicative of a population that may, or may not be, in decline.
- There is no conclusive evidence at this point in time to say that these eight populations are either in decline or growing – currently they appear stable based on the criteria used for this one-time sampling.

Management Implications:

- Field studies and methods that incorporate both ecological and disease condition assessments are necessary to identify whitebark pine populations that may require intervention and restoration.
- Restoration of whitebark pine requires considerable effort and can be costly. We have designed a restoration trial to evaluate important components of outplanting strategies (including season of planting, favorable microhabitat conditions for planting, determine herbivore pressure, and diverse seedling material) to develop effective and successful restoration protocols. Our ultimate goal is to maintain whitebark pine numbers on the landscape, both currently and in the future.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Maloney, P. E., Vogler, D. R., Jensen, C. E., & Delfino Mix, A. 2012. Ecology of whitebark pine populations in relation to white pine blister rust infection in subalpine forests of the Lake Tahoe Basin, USA: Implications for restoration. *Forest Ecology and Management*, 280, 166-175.

P009 C, ROUND: 7, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

The multivariate underpinnings of recruitment for three *Pinus* species in montane forests of the Sierra Nevada, USA. Patricia E. Maloney.

Objectives:

In the present study, the following specific questions were addressed:

- Are white pine recruitment pulses correlated with regional patterns in precipitation and temperature?
- Are local stand conditions more influential than broad scale environmental conditions to white pine recruitment in the Sierra Nevada?

Findings:

- This study demonstrates that local biological and environmental conditions as well as regional climatic conditions influence white pine recruitment in the mountains of the Sierra Nevada, but the strength and importance varies by species across elevational forest types.
- This study identified recruitment pulses for sugar pine starting around 1996, and upper montane forests appear to have the most consistent pulses of western white recruitment and overall higher numbers of regeneration.
- Unlike the two lower elevation species, whitebark pine recruitment is low and steady from 1970 to 2000 with no observed new recruits beyond 2001.
- There were no strong relationships between precipitation and recruitment for these species.

- However, these above patterns with nighttime temperature are correlative only and thus causation is not implied, but the patterns and potential response of increases in reproductive output parallel those studies investigating elevated CO₂ on seed production, and warrants mention.
- Source strength, represented by number of reproductive sugar pine trees and sugar pine density, was the best predictor of sugar pine recruitment.
- Regional patterns of increasing nighttime temperature show a positive correlation with sugar pine and western white pine. This positive response may be due to an increase in seed production as a result of increasing atmospheric CO₂.

Management Implications:

Gaining a better understanding of the multiple factors and complex interactions influencing recruitment success is fundamental, as this important stage in a plants life cycle can have significant consequences on forest community dynamics, genetic architecture, and adaptive potential.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Maloney, P. E. 2014. The multivariate underpinnings of recruitment for three *Pinus* species in montane forests of the Sierra Nevada, USA. *Plant Ecology*, 215(2), 261-274.

P012, ROUND: 7, LEAD INSTITUTION: BMP ECOSCIENCES

Analysis of 15 Years of Data From the California State Parks Prescribed Fire Effects Monitoring Program. Alison E. Stanton and Bruce M. Pavlik

Objectives:

The central objective of this study is to analyze the existing Fire Management Handbook (FMH) dataset to evaluate the effects of prescribed fire treatments on vegetation composition and structure, fuel loading, and potential fire behavior in mixed conifer stands. A portion of the monitoring data from three years post-fire has been previously analyzed to evaluate specific short-term effects of prescribed fire. The larger dataset now available provides the opportunity to investigate longer term effects. A secondary objective is to evaluate the effectiveness of the California State Parks (CSP) fire monitoring program and provide recommendations for future monitoring efforts.

Findings:

Forest Structure and Composition

- Prescribed fire reduced the density of live trees (>2.5 cm DBH) an average of 46% in the year following fire. By ten years, the density was 65% lower.
- Significant tree mortality occurred only in pole-size (15-30 cm DBH) and sapling (2.5-15 cm DBH) size classes.
- On average, 73% of tagged trees pre-burn were white fir <30cm DBH.

- Reduced tree density after fire did not shift the proportion of white fir, which still accounted for 75% of all trees ten years post-fire.
- Average tree size significantly increased by about five cm (QMD) the year after fire.
- Snag density increased significantly in the first five years following fire, but returned to pre-fire levels by ten years post-fire.
- Average basal area (BA) and seedling density did not change in response to fire.

Fuel Accumulation

- The pre-treatment surface and ground fuel load was significantly reduced an average 67% by prescribed fire.
- With an average rate of accumulation of 0.542 kg/m² for all fuel components combined, the surface and ground fuel load would be expected to equal the pre-fire fuel load by 2010.
- Prescribed fire significantly reduced fine surface fuels (FWD) and the subsequent rate of accumulation was nearly zero.
- Prescribed fire significantly reduced the rotten component of coarse surface fuels (CWD) but did not reduce the sound component, which accumulated to nearly three times pre-fire levels within ten years.
- The duff layer comprised the largest portion of the total pre-treatment fuel load and showed the largest response to prescribed fire with the greatest reduction in average loads following fire and the greatest accumulate rate in subsequent years.

Understory Vegetation Response

- Pre-fire understory vegetation was sparsely distributed on the landscape with an average cover of only 16%.
- Prescribed fire significantly reduced understory cover by an average of 58% the year following fire, mainly due to a decline in shrub cover.
- Understory percent cover recovered to pre-fire levels by ten years post-burn, likely due to a significant increase in the nitrogen fixing shrub whitethorn (*Ceanothus cordulatus*).
- Sub-shrub percent cover appears to have been significantly reduced in all years by fire, but forb cover did not show any response.
- Species richness did not decline in the year following fire, but was significantly greater five and ten years later, when sample plots had on average three to four more species than before the burn.

Management Implications:

A new monitoring plan is warranted over additional post-treatment sampling of the existing FMH plots.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P017, ROUND: 8, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Lake Tahoe Upland Fuels Research Project: Investigating the effects of fuels reduction treatments on forest structure, fire risk, and wildlife. Patricia N. Manley, Dennis D. Murphy, Bruce M. Pavlik.

Objectives:

With this study, we aimed to understand the changes to plant and animal communities in response to conventional fuels reductions treatments in the Lake Tahoe Basin Management Unit (LTBMU). Specifically, our objectives were to:

- Describe changes in forest structure following hand and mechanical treatments.
- Predict changes in fire behavior following fuel treatments.
- Understand how fuels treatments may change community composition and abundance of small mammals, birds, and ants.
- Understanding how these elements respond to treatments is essential for addressing key management questions identified in the Sierra Nevada Forest Plan Amendment (SNFPA).

The data for this project has been collected across a range of treatment types and intensities, in both west shore mixed conifer and east shore Jeffrey pine/red fir forests. The resulting dataset represents the first comprehensive monitoring effort in the Lake Tahoe Basin specifically designed to examine changes in plant and animal communities and fuel loading in response to fuel management activities.

Findings:

- Mechanical fuels reduction treatments resulted in more open forest with fewer smaller diameter trees.
- Treatments successfully reduced both proportion of area killed and large tree mortality under modeled fire conditions.
- There is little evidence to support the removal of large proportions of basal area for fuel reduction.
- Small mammal community richness and evenness shifted negligibly following treatment.
- Measures of bird community richness and evenness were largely unchanged following treatment.
- Ant community richness did not differ between pre- and post-treatment forests.

Management Implications:

- Our results indicate that implementation of conventional fuels reduction treatments is consistent with maintenance of bird, small mammal, and ant community diversity over short time frames.
- Reduction of surface fuels resulted in greater tree resiliency to future wildfires over the lifespan of these treatments.
- While wildlife communities were largely unchanged, we observed substantial changes in abundance of several species following treatments, as well as a slight increase in overall mammal abundance and a slight decline in bird abundance.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P018, ROUND: 8, LEAD INSTITUTION: USFS-PACIFIC NORTHWEST RESEARCH STATION

FCCS fuelbeds for the Lake Tahoe Basin Management Unit. Rodger D. Ottmar and Hugh Safford.

Objectives:

Specific objectives of the project were:

- Consult with Lake Tahoe Basin Management Unit (LTBMU) ID-team to determine critical fuelbed types, fuelbed pathways, and fuelbeds that will represent past, current and future vegetation states of the LTBMU.
- Build fuelbeds using previously collected data and scientific and gray literature.
- Run each fuelbed for fuelbed characteristics, fire potentials, fire behavior, and total carbon.
- Use CALVEG existing vegetation layer to map the Fuel Characteristic Classification System (FCCS) fuelbeds for the LTBMU.
- Prepare required quarterly progress reports.
- Complete a final report with fuelbed handbook, pathway diagrams, FCCS predicted fire outputs, and FCCS fuelbed files.
- Complete FCCS fuelbed map for the LTBMU.
- Prepare a draft manuscript(s) to be submitted to a refereed journal.
- Present a minimum of one conference and one mini-workshop

Findings:

- This project has provided a robust set of fuelbeds that represent the past, current and potential future conditions of major forest and rangeland types, management activities, and natural disturbances occurring within the LTBMU.
- Each FCCS fuelbed developed for the LTBMU represents a relatively uniform unit on the landscape that is a unique combustion environment. These fuelbeds provide realistic physical fuel properties for a range of applications in fire, fuel, smoke, wildlife habitat, and carbon assessments.
- Each fuelbed can be customized with collected data to improve the representation of a particular fuelbed.
- The FCCS fire potentials calculated for each fuelbed represent the capacity of a specific fuelbed to support a surface fire and crown fire, and to consume and smolder fuels at benchmark environmental conditions.
- The FCCS predicts actual surface fire behavior of reaction intensity (btu ft⁻² sec⁻¹, flame length (ft), and rate of spread (ft min⁻¹) for specific environmental variables of moisture content, wind speed and slope.
- Each fuelbed contains over 300 input variables and fire and carbon prediction outputs.
- The LTBMU is unique in that the CALVEG layer contains specific classes that allowed a detailed cross-walk to be developed and enabled more fuelbeds to be assigned to the landscape than many mapping projects in the west.

Management Implications:

- Users can assess the effects of human and natural disturbances on a range of fuelbed characteristics. These can lead to a rigorous framework for planning, decision making, and policy analysis.
- Because the fuelbed list was developed from important fuelbed types and pathways, the fuelbeds will be especially beneficial for fuel treatment planning and evaluating the effectiveness of the fuel treatments through space and time.
- These fuelbeds can be used to evaluate the landscape for fire potential, smoke production, fuel loading, carbon storage, and wildlife habitat across time and space.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P019, ROUND: 8, LEAD INSTITUTION: HUMBOLDT STATE UNIVERSITY

Developing fuels treatments for balancing fuel reduction, soil exposure, and potential for erosion in the Tahoe Basin. Dr. Andrew P. Stubblefield, Dr. J. Morgan Varner, Dr. Eric E. Knapp, Nick Harrison, Erin Banwell.

Objectives:

The goal of this research was to understand erosion thresholds in order to determine the optimal levels of surface fuel retention with mechanical mastication and prescribed fire treatments that maximize fire hazard/ fire severity reduction goals while minimizing the threat of erosion and sedimentation. We sought to understand current static conditions and seasonal changes in fuel moisture in order to link fuel moisture with timing of prescribed fire, and the pattern of the resulting burn. Finally we compared our field erosion measurements against predictions made using a popular modeling tool, the Watershed Erosion Prediction Project (WEPP) in order to support the use of this tool in the Lake Tahoe Basin.

Findings:

- Drastic differences in sediment yield were observed between fuels treatments that exposed large patches of bare soil and those that retained fuels on the soil surface.
- Masticated treatments characterized by even distributions of surface fuel and limited patches of exposed soil mitigated severe erosion by trapping sediment and increasing infiltration.
- In prescribed fire plots, heterogeneous patches of unburned or less severely burned islands of surface fuel were present to mitigate erosion in a similar manner.
- Area of plot surface exposed to prescribed fire was a significant predictor of sediment yield (ANOVA, $p < 0.001$). A distinct threshold was observed with severe erosion potential occurring when the burned area within each plot exceeded 54%. Highest sediment yields were generally found on bare volcanic soils.
- The WEPP model results replicated the general trend of the field erosion data for prescribed burn treatments, showing a threshold of burn severity above which erosion rates increased dramatically. However the WEPP model put the threshold higher than was observed in the 2 x 5 meter field erosion plots.
- In spite of the mechanistic links to fire effects, little information is available on the composition, bulk density, mineral content, depth, and loads of forest floor fuels.
- Forest floor moisture followed predictable patterns across the Tahoe Basin. Litter, woody fuels, and cones consistently had the lowest moisture contents of the sampled fuels.

Management Implications:

A better understanding of the complexity of forest fuels will help land managers manage fire in Tahoe Basin forests and inform the understanding of fuels dynamics in other temperate coniferous forests.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Banwell, E. M. 2011. *Forest floor characteristics and moisture dynamics in Jeffrey pine-white fir forests of the Lake Tahoe Basin, USA* (Doctoral dissertation, Humboldt State University).

Harrison, N. M. 2012. *Understanding the effects of soil exposure in fuels treatments that balance fuel reduction and erosion control in the Tahoe Basin* (Doctoral dissertation, Humboldt State University).

Identifying spatially explicit reference conditions for forest landscapes in the Lake Tahoe Basin, USA. Alan H. Taylor, R. Stockton Maxwell, Carl Skinner, Hugh Safford.

Objectives:

The overall goal of this project was to develop spatially-explicit reference conditions for pre-Comstock forest landscapes and associated fire regimes for the Lake Tahoe Basin that can be used by land managers in the ecosystem restoration planning and implementation process. An understanding of the spatial variability in pre-Comstock forest characteristics is essential for understanding if and how planned stand-level activities (mechanical fuel treatments, prescribed burning, etc.) scale up and contribute to restoration of functioning forest landscapes (i.e., wildlife habitat, forest health, hydrologic conditions, etc.).

Findings:

- Contemporary basal area was greater in the present day forest than in the modeled pre-Comstock forest. However, previous work suggested that the basal area in the reference Red Fir and Lodgepole Pine forest types were greater than or equal to the contemporary period, and reported that the species composition and diameter distributions differed between the contemporary and reference stands, stating that reference red fir and lodgepole pine trees were larger in diameter than contemporary trees and there were few reference trees < 30 cm in diameter.
- All forest types saw some increase in percent coverage at the expense of the Red Fir forest type, which decreased by 38.9%.
- The change in percent cover of the Red Fir forest type was the greatest change in forest composition in the entire basin.
- The biggest increase was in the Subalpine forest type; however, this result was likely spurious and a consequence of forest definition.
- As expected, the White Fir and Lodgepole Pine forest types expanded coverage in the contemporary period.
- The visual comparison between our modeled point fire return interval (PFRI) and the fire return interval departure (FRID) map showed three trends: 1) minimum and maximum fire frequencies were similar for both maps; 2) fire frequency decreased with increasing elevation; and 3) the modeled PFRI had a more continuous transition from one frequency category to the next rather than the abrupt transitions in the FRID map.
- The contemporary fuel models provided by the Fuel Characteristic Classification System (FCCS) for medium and large diameter trees for each of the forest types had heavier fuel loadings than the pre-Comstock fuel models. The expected fire behavior from these heavier fuel models would likely be more severe with greater potential for crown fire and mortality of larger diameter stems.
- The visual comparison between our modeled PFRI and the FRID map showed three trends: 1) minimum and maximum fire frequencies were similar for both maps; 2) fire frequency decreased with increasing elevation; and 3) the modeled PFRI had a more

continuous transition from one frequency category to the next rather than the abrupt transitions in the FRID map.

Management Implications:

- ArcGIS layers of pre-Comstock forest structural types (and subtypes), fire return interval, and surface fuels that are available as .kmz files viewable in Google Earth.
- Stand Visualization System (SVS) and EnVision simulations of pre-Comstock forest structural types.
- Spreadsheets containing density (stems/ha) and basal area (m²/ha) by species and 30 cm bin for each main forest structural type and subtype.
- Summary tables of data reported above.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Alan H. Taylor, Anna M. Vandervlugt, R. Stockton Maxwell, Robert M. Beaty, Catherine Airey & Carl N. Skinner. *Changes in forest structure, fuels and potential fire behaviour since 1873 in the Lake Tahoe Basin, USA*. In Applied Vegetation Science, 2013.

P032, ROUND: 9, LEAD INSTITUTION: USFS-PACIFIC NORTHWEST RESEARCH STATION

Evaluating alternative fuel treatments in the South Shore wildland urban interface area.

Morris Johnson and Roger Ottmar.

Objectives:

The goal of this project was to develop fuels data and management alternatives needed to reduce fire hazard in the South Shore Project of the Lake Tahoe Basin Management Unit by linking the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) and the Fuel Characteristic Classification System (FCCS) tools.

Findings:

Simulation results show that thinning treatments reduced the forests susceptibility to support crown fire initiation through changing canopy metrics, which increase active crown fire and burn severity.

Management Implications:

This project will help managers in developing local and regional fire hazard assessments and would be an invaluable analysis tool for an interdisciplinary team designing alternatives for NEPA documents.

Publications:

In progress.

Fuel Management in the Lake Tahoe Basin: Effects of fuels treatments on small mammals, birds, and forest structure. Patricia N. Manley, Ph.D., Traynor G. Biasioli, Angela M. White, Ph.D.

Objectives:

With this study, we aimed to understand the changes to plant and animal communities in response to conventional fuels treatments in the Lake Tahoe Basin Management Unit (LTBMU). Specifically, our objectives were to:

- Understand how fuels treatments may change community composition and abundance of small mammals and birds, including examination of novel variables focused on treatment intensity.
- Describe changes in forest structure following fuels treatments.
- Understanding how these elements respond to fuels treatments is essential for addressing key management questions identified in the Sierra Nevada Forest Plan Amendment (SNFPA).

Findings:

- Fuels treatments resulted in more open forest with fewer small diameter trees. Post-treatment tree species composition was less fir-dominated and included a greater proportion of pines. In the understory, treatments reduced shrub cover, but did not significantly impact either coarse woody debris volume or herbaceous cover.
- Small mammal community richness and evenness shifted negligibly following treatment. Overall abundance of mammals increased significantly following treatment.
- Measures of bird community richness and evenness were largely unchanged following treatment. Pooled abundance of all bird species did not change significantly after treatment.
- We observed significant responses to treatment in 12 species of birds and 2 species of small mammals, with a majority of these species responding positively to treatment. Likewise, the majority of these species had not been adequately investigated in prior fuels treatment studies, highlighting a distinct lack of prior research in the Sierra Nevada.

Management Implications:

- Our results indicate that implementation of conventional fuels reduction treatments is consistent with maintenance of bird and small mammal community diversity over short time frames, and may result in overall increases in community abundance, particularly for small mammals.
- This observed increase in abundance may provide enhanced foraging opportunities for predator species within the basin, though this will vary based on the prey specificity of local predators.

- Individual species showed a variety of responses to fuels treatments, but the majority of species which responded significantly to treatment were more abundant following treatment implementation.
- Further research is needed to investigate longer-term impacts of fuels treatments on wildlife communities, and to identify differences in wildlife response to non-conventional fuels treatments, such as those focused on enhancing forest structural heterogeneity.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Beth Gardner, Rahel Sollmann. *Development of hierarchical spatial capture-recapture models to understand the effects of fuel reduction on small mammals in the Sierra Nevada*. Final report to Pacific Southwest Research Station Davis, CA. March, 2013.

P034, ROUND: 9, LEAD INSTITUTION: USFS-ROCKY MOUNTAIN RESEARCH STATION

Integrated decision support for cost effective fuel treatments under multiple resource goals.
Woodam Chung and Greg Jones.

Objectives:

The objectives of this project were:

- To develop an integrated decisions support system for optimizing fuel treatment locations in time and space to achieve multiple management objectives while meeting resource and operational constraints;
- To develop applications of the system for the Lake Tahoe Basin;
- To deliver the system to end users.

Findings:

- OptFuels combines the vegetation simulation capabilities of the Forest Vegetation Simulator, the landscape fire behavior modeling functionality of the Minimum Travel Time algorithm in FlamMap, and a heuristic algorithm for scheduling fuel treatments.
- In addition to fuel treatment optimization by the heuristic algorithm, users also have the option of entering their own treatment alternatives for analyzing effects on fire behavior and conducting trade-off analyses.

Management Implications:

This integrated system provides land managers with a streamlined ability to develop spatiotemporal fuel treatment alternatives and assess trade-offs among various alternatives and no action.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Chung, Woodam; Jones, J Greg; Krueger, Kurt; Bramel, Jody; Contreras, Marco. 2012. Optimizing fuel treatments over time and space. Submitted to the *International Journal of Wildland Fire*.

Schmidt, David; Bramel, Jody P.; Chung, Woodam; and Jones, J. Greg. 2012. An inventory-based process for assigning surface fuel models to projected forest stands. In review for *Fire Ecology*.

Jones, J. Greg; Chung, Woodam; Bramel, Jody; Schmidt, David; and Krueger, Kurt. 2012. Planning Fuel Treatments for Multiple Fire Events. In review for the *International Journal of Wildland Fire*.

P036, ROUND: 9, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Nest site selection and influence of woodpeckers on recovery in a burned forest of the Sierra Nevada. Gina L. Tarbill.

Objectives:

The objectives of this study were:

- To determine what habitat characteristics have the greatest influence on nest site selection by each of three primary cavity excavators.
- To determine the relative influence of the three primary cavity excavators on bird and small mammal community recovery.

Findings:

- A total of 169 nests were found for focal species in 2009 and 2010 combined. In 2009, 15 Black-backed woodpecker nests, 37 Hairy woodpecker nests, and 20 White-headed woodpecker nests were found. In 2010, 24 Black-backed woodpecker nests, 41 Hairy woodpecker nests, and 26 White-headed woodpecker nests were found.
- Eleven detections of secondary cavity use occurred between March and August, 2010. Eighty-one percent of cavities monitored had some secondary cavity use detected. A total of 53 detections were observed at all nests, of which 70% were birds and 30% were small mammals. Nine species of secondary cavity users were detected. Western bluebirds (*Sialia mexicana*) and chipmunks (*Tamias* species) were detected at the most nests overall.
- All three woodpeckers created cavities that were used by both birds and small mammals. Cavities created by both White-headed woodpeckers and Black-backed woodpeckers were utilized by six species. Hairy woodpecker nests had the lowest secondary cavity user diversity, with only 4 species utilizing these cavities.
- Nest webs indicate that species preferred cavities excavated by a particular species of woodpecker, excluding Mountain bluebirds, which equally utilized White-headed and Hairy woodpecker nests. Northern flying squirrels, House wrens, and Northern flickers exclusively utilized cavities excavated by Black-backed woodpeckers, while White-breasted nuthatches were only detected in cavities excavated by White-headed woodpeckers. Chipmunks preferred White-headed woodpecker cavities (67%). Douglas

squirrels preferred cavities excavated by Hairy woodpeckers (60%). Both Mountain chickadees and Western bluebirds preferred White-headed woodpecker cavities (50%), although they used cavities excavated by all three species.

- Nest trees of Black-backed woodpeckers had mean DBH of 35.3cm (s.d.=9.44), mean height of 17.47m (s.d.=8.07), mean decay of 1.7 (s.d.=1.17), and mean percent scorch of 88.3% (s.d.=20.4).
- Nest trees of Hairy woodpeckers had mean DBH of 40.25cm (s.d.=8.82), mean height of 17.7m (s.d.=8.13), mean decay of 1.7 (s.d.=1.66), and mean percent scorch of 89% (s.d.=16.1, range=35 to 100%).
- Nest trees of White-headed woodpeckers had mean DBH of 39.2cm (s.d.=10.6), mean height of 7.8m (s.d.=5.9), mean decay of 3.1 (s.d.=1.3), and mean percent scorch of 97.3% (s.d.=10.4).

Management Implications:

Woodpeckers play an important role in post-fire habitats by rapidly colonizing these areas and creating cavities that are used by many other species that rely upon them for nesting, denning, roosting, and resting. Woodpeckers select habitat based on excavation ability and foraging preferences, resulting in differences in selection between species. These differences result in differential use by secondary cavity users, with some species of woodpecker influencing recovery more strongly than others. Because woodpeckers may act as keystone species, factors that influence nest site selection for woodpeckers may influence the structure and composition of cavity- dependent communities. Understanding the relationships between woodpeckers, cavity- dependent communities, and habitat is crucial for forest management and conservation.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Tarbill, G. L. 2010. *Nest site selection and influence of woodpeckers on recovery in a burned forest of the Sierra Nevada* (Doctoral dissertation, Master's Thesis, California State University, Sacramento).

P051, ROUND: 10, LEAD INSTITUTION: HUMBOLDT STATE UNIVERSITY

Stocking guidelines for aspen restoration: predicting treatment persistence after successive conifer removals. John-Pascal Berill, Christina M. Dagley.

Objectives:

This report introduces the Aspen Stocking Assessment Model and provides examples of its use in simulating aspen-conifer stand development before and after restorative thinning. Tree data collected in 2 1/2 acre (one hectare) plots around the Lake Tahoe Basin were used to initiate the model. Different diameter-limit thinning prescriptions (i.e., cut all conifer below a defined size) were simulated by removing records for smaller (cut) trees from the plot data and then recalculating density and average tree size for input into the Aspen Stocking Assessment Model. This approach ensured that model simulations were based on realistic pre- and post-thinning values.

Findings:

- The Aspen Stocking Assessment Model forecasted a 15-year treatment persistence, after which time the stand had returned to pre-treatment stand density index (SDI), and a second thinning was scheduled. For the second treatment, we compared three alternatives: 20, 24, or 30 in. (50, 60, or 75 cm) DBH limit thinning, and again forecast growth of each tree species using the Aspen Stocking Assessment Model. These treatments had 23-, 29- and 40-year persistence, respectively. The heaviest thinning treatment generated ~28 US short tons ac⁻¹ (~64 metric tons ha⁻¹) of dry cut wood.
- Treatment persistence, defined here as the time taken for stands to return to their pre-treatment crowding levels, varied according to pretreatment stand density, species composition, and thinning intensity.
- The Aspen Stocking Assessment Model indicated that 36 years after the 24-inch DBH limit thinning, once the stand had again exceeded pre-treatment SDI, the new cohort of regenerating conifers collectively represented only 14% of stand density; the remainder being aspen or large residual conifers that had grown larger than 30 in. (75 cm) DBH.
- Thinning the stand again by cutting only the young conifers (i.e., cut 14% of SDI) would have short treatment persistence.
- Therefore – after two successive thinning treatments with progressively higher DBH limits - any subsequent prescription calling for thinning more than 14% of SDI would necessarily involve cutting/killing some conifer >30 inches DBH.

Management Implications:

The Aspen Stocking Assessment Model is a flexible, transparent spreadsheet-based model that allows the user to schedule restoration thinning and ‘grow’ aspen-conifer stands forward in time, before and after multiple thinning treatments.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Berrill, J. P., & Dagley, C. M. 2012. Geographic patterns and stand variables influencing growth and vigor of *Populus tremuloides* in the Sierra Nevada (USA). *International Scholarly Research Notices*, 2012.

Berrill, J. P., & Dagley, C. M. 2014. Regeneration and Recruitment Correlate with Stand Density and Composition in Long-Unburned Aspen Stands Undergoing Succession to Conifer in the Sierra Nevada, USA. *Forest Res*, 3(119), 2.

P067, ROUND: 11, LEAD INSTITUTION: INTEGRATED ENVIRONMENTAL RESTORATION SERVICES, INC.

Adaptive management handbook and tools for vegetation management and estimation of pollutant loading from forested catchments. Michael Hogan, Mark Grismer.

Objectives:

- Measure impacts of Tahoe Basin-specific vegetation management practices on pollutant generation and transport in forested catchments.
- Develop and test cost-effective mitigation measures to minimize the effects of vegetation management practices on pollutant generation and transport in forested catchments.
- Empirically test the priority hypotheses associated with objectives #2 and #3 with resources available. Data collection efforts will focus on validating the hypotheses for forest land surface conditions and management actions assumed to have the greatest relative water quality risk with respect to FSP given the observed range of conditions.
- Work closely with WEPP model developers to integrate field data and link field assessment protocols to hillslope- and catchment-scale pollutant loading estimates for top priority vegetation management treatments in the Tahoe Basin.

Findings:*Pile burning:*

- Runoff velocities from burn scars roughly doubled following pile burning (without mitigation).
- Unmitigated burn scars generally had higher turbidity and higher surface runoff velocities than piles where duff was replaced post-burn.
- Different levels of mitigation treatment yielded different reductions in runoff velocities compared to unmitigated burn scars (Ward Canyon):
 - 16% reduction with duff removal and replacement only
 - 35% reduction with loosening only
 - 100% reduction (no runoff) with duff removal and replacement plus loosening.
- Removing and replacing duff on burn scars has proven to be the most effective and important treatment for reducing sediment transport. At Ward Canyon, removal and replacement of duff with hand-loosening of burn scars led to at least a 95% reduction in turbidity in runoff (measured with runoff simulator), from more than 1000 NTU (burned, unmitigated) to generally less than 50 NTU (duff removed/replaced + hand loosening).
- Field trials at several sites suggest that hand-loosening burn scars alone (without adding surface cover) can slow runoff velocity but still tends to produce very high turbidity in runoff consistent with unmitigated burn scars (>1000 NTU).
- Vegetation re-establishment tends to be very slow in unmitigated piles; mostly conifer seedlings.
- Charcoal (and in some cases, ash) were still visible on soil surface up to 6 years post-burn on unmitigated piles.

- Highest post-burn vegetation cover and lowest amount of bare soil observed in piles where duff was salvaged and replaced.
- Applying perennial grass seed mix (in addition to duff salvage and replacement) yielded the highest vegetation cover of all mitigation treatments tested.
- Application of native grass seed mix reduced short-term establishment of conifer seedlings (i.e. ladder fuels) after burning, which may help to extend the amount of time before follow-up thinning is required.

Mechanical Treatment:

- Soil compaction tends to increase as the number of vehicle passes increases. At three different North Tahoe sites, 6 passes with a rubber-tired harvester/forwarder led to 38-69% reductions in cone penetrometer depth-to-refusal (DTR); 4 passes led to a 79% reduction in DTR (Highlands only); and 2 passes led to a 3-32% reduction in DTR. This data suggests that 4-6 passes was the threshold for lasting compaction at these sites (Highlands, Skylandia).
- A soil's resistance to compaction can be very site-specific. At another site (Granlibakken), as few as 1-3 passes by a harvester/forwarder led to a 67% reduction in penetrometer DTR, which was the same change in compaction as that measured at an adjacent plot with 5-10 equipment passes (65% reduction). Another plot at the same site with 50-100 passes exhibited the greatest compaction—an 83% reduction in penetrometer DTR.
- Soil compaction from equipment operations can persist for long periods of time. Penetrometer DTR at a landing near Truckee averaged only 1.8 inches 15 years after the fuels reduction project was complete (Waddle Ranch).
- As the number of equipment passes increases, the width of the travelway (impacted area) tends to increase. Increasing the number of passes from 2 to 6 increased travelway width by 75% (Highlands) and 142% (Granlibakken).
- With other site and soil factors being equal, equipment tends to produce less compaction where a robust mulch/duff layer is present and more compaction where soil is bare.
- Operating equipment over a slash mat can minimize soil compaction when heavy slash layers are used, but thinner slash mats tend to get crushed and provide minimal soil protection, especially with increasing machine passes.
- Higher soil moisture levels tended to correspond to greater compaction with the same number of machine passes.
- The addition of 2-3 inches of wood chip mulch reduced runoff velocity by 60% and runoff distance by 54% compared to bare/unmitigated conditions.

- Incorporation of wood chips into the soil by hand tilling led to the same reduction in runoff velocity as mulching (60%) but a more substantial reduction in runoff distance of 85% due to much high infiltration rates.
- Incorporation of wood chips into the soil also led to a large (779%) increase in penetrometer depth and 230% increase in soil wetting depth during runoff simulation.
- Wood chip mulch has been observed to be displaced by concentrated runoff when not incorporated into the soil, particularly in dirt roads.
- Mulching alone can provide hydrologic and sediment reduction benefits in lower-angle conditions and that incorporating wood chips into soil via physical loosening provides the greatest and longest lasting improvements.

Roads and Travel Management:

- Applying a layer of compacted asphalt grindings (1.5" depth) to an unpaved haul road reduced turbidity in runoff by approximately 10 times with no measurable change in infiltration rate.
- Applying 1 inch of gravel to high-use unpaved road segments on the west shore of Lake Tahoe reduced sediment yield by 94 times (from 138,947 to 1,484 lbs/acre/in) on a graded road and by 10 times (from 4,227 to 408 lbs/acre/in) at an ungraded road.
- Applying a layer of wood chips (3" depth) to an unpaved, recently used road reduced turbidity in runoff by approximately 10 times with no measurable change in infiltration rate.
- Wood chip mulch was applied to an inactive dirt road in the Homewood Creek watershed (west shore Lake Tahoe) at several depths (1", 2", 4"). Rainfall simulation showed wood chip mulch reduced sediment yield by an average of 17 times compared to bare soil conditions (from 868 lbs/acre/in to 51 lbs/acre/in). Deeper mulch depths (2-4") resulted in the greatest sediment reductions of 21-22 times.
- Pine needle mulch was applied to an inactive dirt road in the Homewood Creek watershed (west shore Lake Tahoe) at several depths (1", 3", 5"). Rainfall simulation showed that pine needle mulch reduced sediment yield by an average of 5 times compared to bare soil conditions (from 868 lbs/acre/in to 176 lbs/acre/in). The 5" mulch depth resulted in the greatest sediment reduction of nearly 7 times.
- Vegetative treatments that do not improve soil physical structure (e.g. hydroseeding) can temporarily reduce sediment yield; however, long-lasting sediment reductions tend to be associated with treatments that improve soil infiltration rates through loosening and soil amendment incorporation, which also tend to support robust native vegetation.
- Road decommissioning treatments – including soil loosening and wood chip incorporation, fertilizing, seeding, mulching – tested in the Homewood Creek watershed resulted in sediment reductions of more than 100 times (compared to untreated dirt roads) and foliar plant covers ranging from 3-18%. Three roads treated using these techniques resulted in NO RUNOFF and therefore no sediment yield, even at rainfall rates of 4.7 inches per hour.

- Runoff simulation conducted on a graded section of road directly adjacent to an ungraded section indicated that grading increased sediment yields by 33 times. Where road grading is necessary, application of gravel road base can substantially reduce sediment yield in runoff.

Management Implications:

Pile Burning:

- Avoid building piles in drainageways or other areas that are hydrologically connected to stream channels. When building piles in known flow areas, plan for post-burn mitigation treatment.
- Salvage duff from burn pile footprints and replace after burning whenever possible.
- Cover burn scars with at least 3 inches of duff after burning.
- Hand-loosen and seed burn scars with native grasses (in combination with duff addition) for greatest erosion protection and to expedite vegetation recovery.
- Piles comprised of large-diameter fuels should be considered higher priorities for post-burn mitigation treatment.
- Revisit burn piles at least once the season after burning to assess stability and recovery trajectory.
- Photo document burn scars immediately following burning and in subsequent years to track recovery trajectory and learn from different management strategies.

Mechanical Treatment:

- Assess and document soil conditions prior to implementation (compaction, soil cover, duff depth, soil moisture).
- Assess and document soil conditions during and after project implementation to determine if and where mitigation treatments are needed.
- Use stratified entry approach: use main travel way to enter and exit project area; use spur access off main travel way and specify a maximum number of trips per spur where mitigation is not intended to be required post-project (4 trips is a good starting point).
- De-compact main travel way when demobilizing (use separate bucket or ripper attached to masticator head).
- Spread wood chips and/or masticator shreds over bare soil areas.
- Incorporate wood chips into soil in compacted areas for greatest hydrologic benefits and erosion resistance.
- Minimize or eliminate pivot turns (operators can make arced turns).
- Aim to conduct mechanized thinning treatment once soil moisture is less than 10%. If operating equipment during higher soil moisture conditions is necessary, concentrate

trips to main travelway(s) and implement appropriate post-treatment mitigation measures (such as soil decompaction and mulching).

- Identify legacy sites (e.g. old landings, skid trails) that can be decommissioned as part of forest fuels reduction projects.

Roads and Travel Management:

- Create a base map showing flow paths (not just streams) and legacy erosion source areas such as old roads and landings. Use this to create an access plan including protection/avoidance areas, temporary BMPs, and post-project mitigation areas.
- Use stratified entry approach: use main travel way to enter and exit project area; use spur access off main travel way and specify a maximum number of trips per spur where mitigation is not intended to be required post-project (4 trips is a good starting point).
- Require contractors to submit GPS tracking data to document equipment travelways. Use this information to determine if and where mitigation may be required, and if other contract conditions were met (e.g. stream buffer restrictions).
- Spread wood chips and/or masticator shreds over bare soil areas.
- De-compact main travel way when demobilizing (use separate bucket or ripper attached to masticator head).
- Incorporate wood chips into soil in compacted areas for greatest hydrologic benefits and erosion resistance.
- Minimize or eliminate pivot turns and associated displacement of duff and topsoil (operators can make arced turns).
- Assess and document soil conditions during and after project implementation to determine if and where mitigation treatments are needed.
- Aim to conduct mechanized thinning treatment once soil moisture is less than 10%. If operating equipment during higher soil moisture conditions is necessary, concentrate trips to main travelway(s) and implement appropriate post-treatment mitigation measures.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Drake, Kevin, P067: Adaptive Management Handbook and Tools for Vegetation Management and Estimation of Pollutant Loading from Forested Catchments. Integrated Environmental Restoration Services, June 2015.

Forest Management Guidebook, A publication of Integrated Environmental Restoration Services, June 2015

Assessment of fire hazard/risk in the Wildland Urban Interface “WUI” and stream environment zones “SEZs”. David Saah.

Findings:

As with much of the Sierra Nevada Range, fire, whether ignited by lighting or from indigenous burning, was common in the Lake Tahoe Basin prior to the late nineteenth and early 20th centuries. There continues to be a relatively stable number of ignitions per year, with the majority of these ignitions being human caused. The vast majority of these fire starts are controlled before they can grow to an acre or more in size, resulting to a near absence of fire on the landscape over the 20th century. While there have been several fires over 100 acres in size in the last decade, current policies focused on fire exclusion and difficulties implementing large scale prescribed burning have essentially removed fire as an ecosystem process at a landscape scale from the Lake Tahoe Basin over the last century. As has been noted in several previous studies, the historic and contemporary fire history and fire management within the Lake Tahoe Basin reflects larger trends seen across the Sierra Nevada Region.

- Areas that were treated within the Wildland Urban interface (WUI), riparian areas, or otherwise, consistently had a lower probability for passive or active crown fire for both 2010 and 2020. These findings are consistent with findings in the existing literature from both local and regional studies in similar coniferous vegetation types.
- Treatments greater than 15 years old consistently had a lower potential for passive or active crown fire when compared with areas that were not treated at all.
- Full implementation of the 10 Year Plan as reflected in the proposed and planned treatment units and areas would result in decreased conditional burn probability within the WUI and would generally increase the WUI area modeled as having flame lengths less than 4 feet in 2020.
- Given the existing riparian vegetation GIS dataset, we were unable to clearly distinguish differences in fire hazard between coniferous and deciduous dominated riparian vegetation types, though treatments in both types were effective at reducing the potential for active and passive crown fire.

Management Implications:

- An approach to fire and ecosystem management that recognizes that large fires may occur is important in designing a fuel treatment network to mitigate them and planning for a future vegetation structure and distribution, which can incorporate their potential beneficial effects over the long term.
- Continued collaborative incorporation of local knowledge from fire managers and others with on the ground experience with local fire conditions, WUI protection and evacuation procedures, resource managers with detailed understanding of local ecological conditions, and other scientists with local expertise is critical to the continued long term planning and success of any fuel management strategy.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P083, ROUND: 12, LEAD INSTITUTION: USFS-ROCKY MOUNTAIN RESEARCH STATION

Incorporating project-level analysis and enhanced decision support into the OptFuels fuel treatment planning system for the Lake Tahoe Basin. J. Greg Jones (retired), Nate Anderson, Jody Bramel, and Woodam Chung.

Objectives:

The objectives for this phase of the project were to:

- Add functionality to OptFuels for users to enter treatment unit polygons with assigned treatments for project alternatives and analyze the effectiveness of those proposed treatments to modify fire behavior and reduce the risk from future wildland fire.
- Construct a Lake Tahoe Basin-wide OptFuels database and develop a streamlined process for clipping and building OptFuels models that are tailored to specific planning areas.
- Enhance the fuel treatment information provided by OptFuels that can be used in designing projects to meet various forest management objectives.
- Enhance the capability of OptFuels to predict wildfire effects on erosion and water quality and on various values at risk both with and without fuel treatments across user-specified fire scenarios.
- Deliver the enhanced OptFuels system to end-users.

Findings:

The following tools were created:

- Custom project layers based on existing stand polygons or by using the default data using a 'click and drag' GIS interface.
- Model a treatment scenario based on user-defined stands and treatment types.
- Provide the capability to parameterize and run the OptFuels model and analyze outputs directly from the custom ArcGIS toolbar.
- 'Compare Outputs' tool showing the difference in Arrival Time, Flame Length, and Expected Loss between No Action and Treatment.
- The fuel treatment information was enhanced to provided by OptFuels so it can be used in designing projects to meet various forest management objectives.
- OptFuels to predicts wildfire effects on erosion and water quality and on various values at risk both with and without fuel treatments across user-specified fire scenarios.
- Provide the capability to Graph Sediment by Arrival Time.
- Delivered the enhanced OptFuels system to end-users.

Management Implications:

- This integrated system provides land managers with a streamlined ability to develop spatiotemporal fuel treatment alternatives and assess trade-offs among various alternatives and no action.
- Trade-offs can be assessed in terms of effects on fire behavior including flame length and fire arrival time across the landscape, expected loss to values at risk, and sediment loading in stream channels if wildfire were to occur.
- Forest vegetation is modeled through time and can also be compared across treatment alternatives, including no action.
- In addition to fuel treatment optimization by the heuristic algorithm, users have the option of entering their own treatment alternatives for analyzing effects on fire behavior and conducting trade-off analyses.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Chung, W., Jones, G., Krueger, K., Bramel, J., & Contreras, M. 2013. Optimising fuel treatments over time and space. *International Journal of Wildland Fire*, 22(8), 1118-1133.

Schmidt, David; Bramel, Jody P.; Chung, Woodam; and Jones, J. Greg. 2012. An inventory-based process for assigning surface fuel models to projected forest stands. Unsuccessfully submitted to *Fire Ecology*, currently modifying for submittal to another journal.

The OptFuels website (<http://www.fs.fed.us/rm/human-dimensions/optfuels/>) has been updated with the latest installers and supporting documentation, including a User Guide document and a 'Quick Start' Tutorial.

P091, ROUND: 12, LEAD INSTITUTION: HUMBOLDT STATE UNIVERSITY

Ecosystem Response to Aspen Restoration. Dr. John-Pascal Berrill, Dr. Christa M. Dagley.

Objectives:

There is a need for monitoring of ecosystem responses to thinning and pile burning in aspen stands. Analysis of monitoring data would inform the design of thinning and pile-building prescriptions; specifically, maximum thinning intensity, maximum burn pile size, and minimum safe distance from live aspen trees of any size.

Findings:

This project was active as of June 2015.

Management Implications:

In progress.

Publications:

In progress.

4. HABITAT IMPROVEMENT

(Projects: 7, 22, 47, 50, 53, 59, 90, 92, 99)

P007-A, ROUND: 7, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Fire history of coniferous riparian forests in the Sierra Nevada. Kip Van de Water, Malcolm North.

Objectives:

Objectives of this study were to determine whether adjacent coniferous riparian and upland forests burned historically with different frequencies and seasonalities, and whether these relationships varied by forest, site, and stream characteristics.

Findings:

- Riparian fire return intervals (FRI) ranged from 8.4 to 42.3 years under a liberal filter (mean 16.6), and 10.0 to 86.5 years under a conservative filter (mean 30.0).
- Upland FRI ranged from 6.1 to 58.0 years under a liberal filter (mean 16.9), and 10.0 to 56.3 years under a conservative filter (mean 27.8).
- Riparian and upland fire return intervals were significantly different in only one quarter of the sites we sampled.
- Riparian and upland areas did not burn with different seasonalities, and fire events occurred primarily during the late summer-early fall dormant season in both riparian and upland areas (88% and 79% of scars, respectively).
- FRI was shorter in forests with a higher proportion (>22.7–37.6%) of fire-tolerant pine (*Pinus* spp.), sites east of the Sierra crest, lower elevation sites (<1944 m), and riparian zones bordering narrower, more incised streams (width/depth ratio <6.2).
- Upland areas exhibited a greater degree of fire–climate synchrony than riparian areas.

Management Implications:

- Our study suggests that coniferous riparian forests in the Sierra Nevada historically experienced frequent fire, often at intervals not significantly different from the adjacent upland forests. This relationship, however, does vary as a function of forest, site, stream and climate conditions. Managers should take into account local conditions when developing treatment prescriptions for riparian areas, considering how forest, site and stream characteristics would have likely influenced fire return intervals and subsequent fire effects.
- Riparian areas surrounded by forests with a high proportion of fire-tolerant pine species (about one-third of the basal area or greater), especially those east of the Sierra crest, likely experienced more frequent fire than riparian areas in other forest types, and could be treated similarly to upland areas. Less intensive treatment, such as hand thinning and pile burning small trees, should be considered for riparian areas in other forest types.

- Riparian areas at higher elevation typically experienced longer fire return intervals under the C10 filter and therefore could be treated less intensively than the adjacent upland areas.
- Riparian areas at lower elevations could be treated similarly to upland areas.
- Riparian areas bordering small incised headwater streams historically experienced fire at frequencies similar to those of upland areas, and could thus be treated the same.
- Wider streams likely acted as an effective barrier to fire under some conditions, resulting in longer fire return intervals in adjacent riparian areas which could receive less intensive treatment than adjacent upland areas.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Van de Water, K., & North, M. 2010. Fire history of coniferous riparian forests in the Sierra Nevada. *Forest Ecology and Management*, 260(3), 384-395.

Van de Water, K., & North, M. 2011. Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; a comparison of current and reconstructed conditions. *Forest Ecology and Management*, 262(2), 215-228.

P007-B, ROUND: 7, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; a comparison of current and reconstructed conditions. Kip Van de Water, Malcolm North.

Objectives:

Objectives of this study were to compare stand structure, fuel loads, and potential fire behavior between adjacent riparian and upland forests under current and reconstructed active-fire regime conditions. Current fuel loads, tree diameters, heights, and height to live crown were measured in 36 paired riparian and upland plots. Historic estimates of these metrics were reconstructed using equations derived from fuel accumulation rates, current tree data, and increment cores. Fire behavior variables were modeled using Forest Vegetation Simulator Fire/Fuels Extension.

Findings:

- Riparian forests were significantly more fire prone under current than reconstructed conditions, with greater basal area (BA) (means are 87 vs. 29 m² /ha), stand density (635 vs. 208 stems/ha), snag volume (37 vs. 2 m³ /ha), duff loads (69 vs. 3 Mg/ha), total fuel loads (93 vs. 28 Mg/ha), canopy bulk density (CBD) (0.12 vs. 0.04 kg/m³), surface flame length (0.6 vs. 0.4 m), crown flame length (0.9 vs. 0.4 m), probability of torching (0.45 vs. 0.03), predicted mortality (31% vs. 17% BA), and lower torching (20 vs. 176 km/h) and crowning indices (28 vs. 62 km/h).
- Upland forests were also significantly more fire prone under current than reconstructed conditions, yet changes in fuels and potential fire behavior were not as large.

- Under current conditions, riparian forests were significantly more fire prone than upland forests, with greater stand density (635 vs. 401 stems/ha), probability of torching (0.45 vs. 0.22), predicted mortality (31% vs. 16% BA), and lower quadratic mean diameter (46 vs. 55 cm), canopy base height (6.7 vs. 9.4 m), and frequency of fire tolerant species (13% vs. 36% BA).
- Reconstructed riparian and upland forests were not significantly different. Our reconstruction results suggest that historic fuels and forest structure may not have differed significantly between many riparian and upland forests, consistent with earlier research suggesting similar historic fire return intervals.
- Under current conditions, however, modeled severity is much greater in riparian forests, suggesting forest habitat and ecosystem function may be more severely impacted by wildfire than in upland forests.

Management Implications:

- Results suggest that coniferous riparian forests in the northern Sierra Nevada historically had forest structure, composition, fuel loads, and fire behavior similar to adjacent uplands. However, both riparian and upland stands currently appear to be more fire prone than their historic conditions, with riparian areas significantly more so than adjacent upland areas.
- While active management of riparian forests is becoming more common, riparian forests could be considered a high priority for restoration and fuel reduction treatments, with objectives similar to adjacent upland forests.
- If reintroduction of an active fire regime similar to historic conditions is desirable, treatments might focus on reducing basal area and stand density by removing small fire-intolerant tree species, and reducing surface fuel loads, especially the duff layer. Such treatments may reduce flame lengths, probability of torching, crowning index, and probability of mortality to their historic range of variability, which was likely similar for many adjacent riparian and upland forests.
- However, prescriptions should take local conditions such as species composition, precipitation regime, elevation, stream channel size and incision into account, which may have historically influenced the relationship between riparian and upland fire regimes. This will produce heterogeneity at the landscape scale, while restoring forests conditions that will facilitate resilience under changing climatic conditions.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Van de Water, K., & North, M. 2010. Fire history of coniferous riparian forests in the Sierra Nevada. *Forest Ecology and Management*, 260(3), 384-395.

Van de Water, K., & North, M. 2011. Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; a comparison of current and reconstructed conditions. *Forest Ecology and Management*, 262(2), 215-228.

P022, ROUND: 8, LEAD INSTITUTION: PACIFIC SOUTHWEST RESEARCH STATION.

The Effect of Ski Resorts on Population Dynamics of the Pacific Marten in the Lake Tahoe Region of California and Nevada, 2009 – 2011. Keith M. Slauson and William J. Zielinski.

Objectives:

The overall goal of this study was to determine whether ski resorts have a net negative, neutral, or positive effect on Pacific marten populations in the Lake Tahoe region. Specifically, we gathered information necessary to evaluate the influence of ski resorts on:

- Loss and fragmentation of forest habitat;
- Marten movement;
- Marten seasonal occupancy and space use;
- Marten abundance and survival;
- Marten age structure and sex ratio;
- Proportion of females that reproduce.

Findings:

- Martens were detected on all 6 study areas, with a total of 17 (13M:4F) individuals detected on the ski areas and 23 (14M:9F) on the control areas. While the number of male martens detected differed by only 1, the proportion of the stations used by male martens were lower at the resorts compared to the controls. More than twice the number of female martens were detected on controls ($n = 9$) versus ski areas ($n = 4$), yielding sex ratios (M:F) of 1.56 for controls versus 3.25 for ski areas. Females were detected at 62% more stations on controls than ski areas.
- During the winter season we identified 36 used and 75 unused apparent marten movement paths between adjacent stations. Overall, martens showed highly significant selection ($p = 0.0001$) for movement paths with lower cumulative minimum ski run crossing distances.
- The mean cumulative minimum ski run crossing distance at movement paths used by martens was 3-times lower, 17.5 m versus 54.8 m, than present at unused movement paths. There were no significant differences between the mean cumulative crossing distances between males and females during winter ($p = 0.39$) or between adult and sub-adult males ($p = 0.87$), adult and sub-adult females ($p = 0.63$), and adult males and females ($p = 0.97$).
- During the spring-summer seasons from 2009-2011, we identified 39 used and 82 unused apparent movement paths. Only 18 (46%) of the movement paths used in the spring-summer were also used in the winter season. However, despite the high level of non-overlap between movement path use between seasons, the characteristics of both movement paths and single ski run crossings varied little between seasons. During the spring-summer season martens also showed highly significant ($p = 0.0004$) selection for movement paths with lower cumulative minimum ski run crossing distances.

- The high degree of sensitivity for run crossing widths significantly reduced the functional habitat connectivity on ski versus control study areas, but these effects were confined to within the operations area boundaries. The resulting landscape structure on ski areas, due to the interconnected networks of ski runs and roads, has greatly influenced the apparent movements of martens at ski areas.
- Effective isolation of habitat patches in operations areas occurred once stations were more than a single ski run >20 m wide or by a combination of run crossings > 30 m within a 500 m linear distance.
- Both males and females showed significant selection for the largest available patch sizes of remnant forest habitat within ski operations areas during the spring-summer season.
- Winter density estimates were 33% higher in controls (5.64 martens/1000 ha, var = <0.01) than ski areas (4.25 martens / 1000 ha, var = <0.01). This difference is largely driven by the difference in the density of females, which was 2.3 times higher in controls (2.3 females/1000 ha) versus ski areas (1 female/1000 ha). During the winter, the density of males was not significantly different between controls (3.59 males /1000 ha) versus ski areas (3.25 males/1000 ha).
- Annualized spring-summer total marten density estimates were nearly equivalent between controls (6.83 martens/1000 ha) and ski areas (6.75 martens/1000 ha). For adult males (1.92-ski versus 2.22-control/1000 ha), adult females (0.83 versus 0.94 females/1000 ha), and subadults (4.00-ski versus 3.67-control/1000 ha) all differed by <15% between ski areas and controls.
- The cumulative age structure of the entire study population was overall skewed to younger age classes of 1 and 2 year old martens. Males and females both had median ages of 2 years, but males typically exhibiting older annual maximum ages of 5-7 years versus 3-5 for females.
- There were no significant differences in the cumulative age structures between treatment-level and operations-level comparisons for both sexes pooled, males only, and females only. The largest difference among any age classes occurred at the operations-level for males, where higher proportions of sub-adult males (1-2 years old) and lower proportions of adult males (>2 years old) occurred in the ski operations areas versus outside the operations areas.
- The overall observed population sex ratio was 1.9 males to a single female. There were no significant differences between the sex ratio for the treatment- or operations-level comparisons.

Management Implications:

The overall results of our study suggest that winter ski recreation at developed ski areas may be compatible with the maintenance of marten populations in the Lake Tahoe region of the Sierra Nevada. However, ski area development and winter ski recreation activities do have negative, sex-specific effects on martens. Our results suggest that marten conservation within ski areas will be best achieved by considering the following suggestions:

- Maintain reproductive habitat and its use by adult female martens.

- Maintain or enhance suitable reproductive habitat within ski operations areas by maintaining or increasing the sizes of habitat patches.
- Maintain habitat connectivity between reproductive habitat in ski operations areas and outside them to provide year-round habitat to support adult females.
- Maintain or enhance ski run crossings between reproductive habitat within and outside of ski operations areas by maintaining or increasing the proportion of ski runs <15m across. Maintain or enhance sequential run crossings, between suitable patches of reproductive habitat, to not exceed 30m cumulative crossing distances between ski operations boundaries and suitable reproductive habitat.
- Restrict recreational activities in reproductive habitat to the non- denning seasons (fall-winter) to limit their effects on marten reproduction.
- Maintain or enhance habitat connectivity within ski operations areas.
- Maintain or enhance the proportion of ski run crossings < 20m between non-reproductive habitat patches that are >10 ha and the operations areas boundary. Where smaller patches function as potential 'stepping-stones' between patches >10 ha and/or the operations boundary, maintain or enhance the proportions of ski run crossings that are < 20m.
- Evaluate expansion using a variety of spatial criteria for habitat and connectivity that are sex specific (as described above).
- Expansion or habitat altering activities should avoid reproductive habitat, or large (>10 ha) patches of remnant habitat on ski areas.
- Expansion or habitat altering activities should incorporate consideration for how habitat connectivity will be affected and minimize effects reducing habitat connectivity between reproductive habitat and large (>10 ha) remnant patches of habitat.
- Mitigation efforts can be useful, but rarely compensate for the loss or degradation of female denning habitat.
- Mitigation efforts should match or exceed the value of habitat or connectivity lost due to a proposed action.
- Ski area expansions should be considered as a cumulative effect which account for impacts from prior ski development (the seasonal and sex- specific effects found in this study) as well as other threats that may have affected, or will affect, martens or their habitat (e.g., fuel treatments, climate change effects on habitat).
- The scope of inference of this study are limited to ski area development that involves the creation of ski run, road, and development infrastructure with very limited modification to remnant forest habitat within operations areas. Modifications such as thinning of trees to increase space for skiing or removal of logs and rocks to improve surface consistency in remnant forest patches were not included in the ski study areas used in this study. These activities are known to be used elsewhere for ski area development and likely represent additional degradation of habitat suitability.

- The results of this study are applicable to forest habitats within the range of the Pacific marten on west slope and Sierra crest forest types. Due to the difference in effects reported in this study, and work reported previously in eastside forest habitats, marten populations may be responding to ski area development and recreation in different ways in these areas.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P047, ROUND: 10, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Monitoring Desired Conditions for Vegetation and Wildlife Habitat: An Independent Test of Proposed Indicators for Monitoring Vegetation in the Lake Tahoe Basin. Dr. David Saah, Dr. Patricia Manley, Jarlath O’Neil-Dunne, Dr. Qi Chen, Dr. Angela White, Travis Freed, and Jason Moghaddas.

Objectives:

The objective of this study was to help managers identify meaning indicators for upland habitat ecological condition in accordance with vegetation desired conditions identified as part of Tahoe’s Pathway planning process and per a draft “*Healthy Vegetation and Hazardous Fuels Desired Condition Monitoring Plan*” (Greenberg and Dobrowski 2009). The draft monitoring plan identified indicators to characterize vegetation conditions relative to desired conditions as: 1) landscape extent of forest/non-forest types, 2) forest structural class, 3) ecological condition of non-forested lands (e.g., meadows), 4) total burned area, 5) area treated in wildland urban interface that meet flame length standards, and 6) percent of private and public parcels in urban areas that meet defensible space prescription. Absent from the list of indicators was indicator(s) to assess wildlife habitat conditions. We tested the ability of the proposed vegetation indicators to also represent change in probability of wildlife occurrence within habitat. Remote sensing and in-situ field sampling were proposed methods to generate indicator values and as such were reviewed to determine their implementation efficacy for monitoring program managers.

Findings:

Efficacy of methods prescribed in the draft vegetation monitoring plan (Greenberg and Dobrowski 2009):

- Through this project the following GIS data derivative products were assembled from existing sources or otherwise uniquely derived from 2010 LiDAR and WorldView 2 datasets, including: 1) Digital Elevation Model (DEM), 2) Canopy Height Model (CHM), 3) Canopy bulk density, 4) Slope, 5) Aspect, 6) Tree Stems (map of individual tree locations - attributed with a) height to crown base (HTCB), b) crown bulk density, c) dbh, d) height), 7) Tree crown map (perimeter of individual trees), 8) Canopy cover (CC), 9) Fuel model surface, 10) Tree stand boundaries, 11) Existing vegetation type, 12) Distribution of past wildfires, 13) Distribution of past fuel treatments, 14) TARI and SEZ Maps (from SEZ project), 15) Land Cover Database (the National Land Cover Database for 1992, 2001, 2006 and 2011).

- In general, prescribed monitoring plan methods for remote sensing were found to be valid and that LiDAR based change detection is accurate and useful for characterizing the status of vegetation indicators (along with other indicators such as impervious cover), but collecting and processing the information is labor intensive, expensive, and not well suited for annual evaluations.
- Field monitoring procedures proposed in the monitoring plan were found to be valid for non-forested environments. However, managers may find cost savings by leveraging other existing monitoring efforts where vegetation data are collected (e.g., TRPA stream bioassessment program or data collection associated with CRAM - California Rapid Assessment Method)

Use of vegetation indicators to inform characterization of wildlife habitat conditions (White et al. 2014):

- We recorded 57 species of birds for which point count surveys are typically used to monitor their populations. Birds were detected during 1,209 visits to 447 point count stations.
- **Impervious Cover Indicator** – LiDAR derived impervious cover (an indicator not identified in the draft monitoring plan) had the strongest, most consistent effect on the probability of species occurrence – where increased impervious cover resulted in reduced the probability of species occurrence. Dusky Flycatcher (*Empidonax oberholseri*), Hermit Thrush (*Catharus guttatus*), Nashville Warbler (*Oreothlypis ruficapilla*), and Townsend’s Solitaire (*Myadestes townsendi*) were the most sensitive to urbanization (i.e., impervious cover). Species least sensitive (i.e., high occurrence probability) to urbanization included Brewer's Blackbird (*Euphagus cyanocephalus*) and Mourning Dove (*Zenaida macroura*).
- **Extent of Forests/Non-forest Cover Indicator** - The probability of occurrence of 23 species is significantly influenced by the extent of forests/non-forest cover. We concluded that this indicator can quantify the habitat needs of many of the avian species
- **Forest Structural Class Indicator** - Our hierarchical model results suggest that forest structural class could help predict the probability of occurrence for 21 species
- **Field Measurements** - In general, field-based covariates were poor predictors of the probability of occurrence of avian species within the 2011-2012 time period.
- **Change Detection**
- **Forest Vegetation** - The mean change per year in the density of trees (all size classes) increased slightly at control sites, whereas there was a decrease in the density of small (11-24 cm DBH) and medium-sized (24-61 cm DBH) trees per year at sites that had undergone a fuel reduction treatment). Similarly, the mean change in the density of snags/year was reduced at treated sites and increased slightly in controls. The volume of coarse woody debris and the percent shrub cover decreased at both control and treated sites, with a greater reduction in shrub cover at treated sites.
- **Avian Populations** - The average probability of occurrence for the majority of avian species sampled remained relatively constant indicating that their populations were

stable. Change in average vegetation conditions over the timeframe could not explain the observed increase or decrease in the probability of occurrence for any of the species.

Management Implications:

- LiDAR based change detection is accurate and useful for several indicators, including impervious surfaces and vegetation cover, but collecting and processing the information is labor intensive, expensive, and not well suited for use annually.
- It is suggested that one approach to annual monitoring would be to develop algorithm based assessments of change using more frequently available (and less expensive) imagery from a source such as Planet Labs (<https://www.planet.com/data/>). This data may also be used retrospectively, to be able to capture changes as far back in time as the imagery and resolution allows. When integrated with older LANDSAT imagery, this would allow the Lake Tahoe Basin to assess change as far back as 1984.
- The use of multi-species approaches to inform land management can also enhance biodiversity conservation by identifying habitat conditions that support unique suites of species. Management approaches that consider the extent and distribution of habitat conditions across landscapes have the greatest likelihood of conserving and restoring biodiversity and ecosystem functions.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P050, ROUND: 10, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Wildlife habitat occupancy models for project and landscape evaluations in the Lake Tahoe Basin. Angela M. White and Patricia N. Manley.

Objectives:

The goal of this project was to use existing empirical field data that were collected in a systematic manner to develop species distribution maps and habitat occupancy models for forest associated vertebrate species in the Lake Tahoe Basin. These models will facilitate site and landscape-scale evaluations of management treatments, climate change, and other change agents that affect forest structure and composition today and in the future.

Findings:

- We recorded 66 species of birds for which point count surveys are typically used to monitor their populations. Birds were detected during 2937 visits to 1091 point count stations. Eight avian species considered very rare, Hammond's Flycatcher (*Empidonax hammondi*), House Finch (*Haemorhous mexicanus*), Lesser Goldfinch (*Spinus psaltria*), Lazuli Bunting (*Passerina amoena*), Pacific-slope Flycatcher (*Empidonax difficilis*), Purple Finch (*Carpodacus purpureus*), Ruby-crowned Kinglet (*Regulus calendula*), and Savannah Sparrow (*Passerculus sandwichensis*) were observed at fewer than 20 sites.

- In general, mean parameter estimates for abiotic variables suggested that species within the basin may be more restricted by these factors than by variability in forest structure.
- Of the modeled habitat covariates, percent canopy cover significantly influenced the occurrence probability of 35 species (linear and squared combined), DBH for 12 species, percent shrub cover for 22 species (linear and squared combined), and percent herbaceous cover for 19 species.
- Variation in the response across species for each environmental variable underscores both the consistent effect of development and the importance of heterogeneous habitat for maintaining species diversity.
- Of the modeled habitat covariates collected via field sampling methods, percent shrub cover influenced the largest number of species, with the occurrence of nine species negatively and eight species positively influenced by increasing levels of shrub cover.
- A similar number of species were estimated to be positively affected by increasing stem density as were predicted to be negatively affected, although these relationships were rarely significant. The Red-breasted Nuthatch (*Sitta canadensis*) and Hermit Thrush were significantly associated with increasing stem density, while the Green-tailed Towhee (*Pipilo chlorurus*) and Cassin's Finch (*Carpodacus cassinii*) were negatively associated.
- The density of snags was associated with significant changes in the probability of occurrence for three (soft snags) and one (hard snags) species. The probability of occurrence of Hairy Woodpeckers increased at increased densities of hard snags, whereas the Red-breasted Nuthatch was associated with soft snag density.
- We captured 16 species of small mammals during 525 days of trapping at 175 sites, including four small mammal species considered very rare: montane vole (*Microtus montanus*), brush mouse (*Peromyscus boylii*), western gray squirrel (*Sciurus griseus*), and western jumping mouse (*Zapus princeps*).
- As predicted, small mammal species were significantly influenced by elevation with the probability of occurrence for the majority of species being highest at low to mid-elevations.
- Of the modeled habitat covariates, percent canopy cover significantly influenced the occurrence probability of the golden-mantled ground squirrel, percent shrub cover significantly influenced the occurrence probability of the golden-mantled ground squirrel (negatively) and the California ground squirrel (*Spermophilus beecheyi*) (positively), and percent herbaceous cover was positively associated with the occurrence of the long-tailed vole (*Microtus longicaudus*). Increases in the standard deviation in canopy cover were associated with an increase in the probability of occurrence of yellow-pine chipmunks.
- Of the modeled habitat covariates collected via field sampling methods, the small mammal community seemed to be negatively associated with stem and large tree density, but positively associated with diversity in tree size.

- The probability of occurrence of the golden-mantled ground squirrel was the only species to be significantly influenced by tree size diversity. Similarly, the occurrence of lodgepole pine chipmunks was the sole species whose parameter estimate was significant for the density of trees and the yellow-pine chipmunk was the only species significantly associated with the density of large trees.
- Percent shrub cover was significantly associated with a decrease in the golden-mantled ground squirrel and the yellow-pine chipmunk.

Management Implications:

- The results of these models can be used by managers in the Lake Tahoe Basin to better understand how variation in different abiotic and biotic variables can influence the suite of species that currently occur in the area.
- Synthesis of data on bird and small mammal populations in the Lake Tahoe Basin is intended to improve the capacity and confidence of stakeholders tasked with making decisions that could impact biodiversity.
- Management actions that are driven by one or a few focal species are not likely to maintain biodiversity if they result in decreased variability in habitat conditions. An integrated approach that emphasizes conserving a diversity of habitats across environmental gradients and minimizing the extent of urbanization impacts is likely to more effectively conserve and restore biodiversity and enhance ecosystem functioning than a single-species focus.
- The use of multi-species approaches to inform land management can also enhance biodiversity conservation by identifying habitat conditions that support unique suites of species. Management approaches that consider the extent and distribution of habitat conditions across landscapes have the greatest likelihood of conserving and restoring biodiversity and ecosystem functions.
- The results of our model indicate that practices and management approaches that lead to increased homogenization of the forest will have negative impacts on diversity. Management approaches, such as fuel reduction treatments, or the use of prescribed or managed wildland fire, may be designed to restore at least some of the variability within and among stands that existed during an active fire regime, thereby enhancing habitat conditions for conserving biodiversity.
- Because it is difficult to predict how the loss of a particular species would impact ecosystem functioning, many biodiversity targets focus on retaining or restoring the greatest number of species. Ecosystem functioning may not be affected by loss in species richness per se, if loss of a species is ameliorated by the presence of a functionally similar species, therefore, maintaining redundancy in groups of species that fill similar ecological roles (i.e. guilds, functional groups) may improve ecosystem resiliency.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Ecological succession in the Angora fire: The role of woodpeckers as keystone species.

Patricia N. Manley, and Gina Tarbill.

Objectives:

Woodpeckers excavate cavities in trees to use as nests for the brooding and rearing of their young. After fledging, these cavities are abandoned but remain in the environment for use by other species that are unable to excavate cavities but rely on them for reproduction and cover (secondary cavity users). When fire destroys cavities, secondary cavity users may be unable to breed in the burned area until woodpeckers colonize and create new cavities. Therefore, understanding how woodpeckers utilize burned areas is important as they provide a keystone function by creating habitat for other organisms.

Findings:

- This research investigated nest site selection in three species of *Picoides* woodpeckers (*P. arcticus*, Black-backed Woodpecker; *P. villosus*, Hairy Woodpecker; and *P. albolarvatus*, White-headed Woodpecker). Using logistic regression, we determined the factors with the greatest influence on nest presence and found that they differed among the three species.
- The density of small snags (by DBH) was positively associated with the presence of Black-backed Woodpecker nests.
- Nest presence of White-headed Woodpeckers was positively associated with tree decay and negatively associated with tree height and density of small trees.
- Hairy Woodpecker nests were negatively associated with small trees.
- All woodpecker species were more likely to have nests in more highly scorched trees, underscoring the importance of fire in creating habitat for these species.
- White-headed Woodpeckers had highest index of cavity utilization, although Black-backed and Hairy Woodpeckers were important to some secondary cavity users.
- Woodpeckers play an important role in post-fire habitats by rapidly colonizing burned areas and creating cavities that are used by many other species that rely upon them for nesting, denning, roosting, and resting.

Management Implications:

- The Black-backed Woodpecker was a significant contributor to the establishment of bird and small mammal species and communities in areas with high burn intensities, and it appeared to have a more narrow range of suitable habitat conditions for nest site selection compared to the Hairy Woodpecker. Thus, the habitat requirements of the Black-backed Woodpecker serve as a useful threshold for managing burned sites for wildlife recovery.
- Currently, post-fire harvest prescriptions in the Angora fire footprint prescribe the removal of all small snags and retention of approximately 5-10 large snags per hectare

for wildlife use. The removal of most or all small snags within a burned area is likely to render the site unsuitable for Black-backed Woodpecker nesting.

- Management plans with multiple objectives of maintaining species diversity while promoting fire safety may benefit from integrating strategies to maintain a diversity of woodpecker species in burned forests. White-headed Woodpeckers in burned forests will require decayed large diameter snags in open areas. Black-backed and Hairy Woodpeckers will require areas with high densities of small to medium sized snags, especially in highly scorched areas. This management goal may be achieved by leaving large patches of high density small snags and harvesting other areas while leaving larger diameter snags.
- Understanding how wildlife species respond and recover from fires is critical for conservation and management of forest ecosystems. Meeting management objectives in burned areas focus on promoting fire safety while maintaining species diversity.
- The results from this research indicate that management plans that incorporate habitat for multiple woodpecker species would maintain the greatest biodiversity. This management goal may be achieved by leaving large patches of high-density small snags away from urbanized areas and some larger diameter snags in open areas where they pose fewer fire risks.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P053-B, ROUND: 10, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Angora Fire Wildlife Monitoring Project. Patricia N. Manley, Gina L. Tarbill, T. Will Richardson, and Angela M. White.

Objectives:

The objective of this study was to determine the relative influence of burn severity and post-fire restoration activities on wildlife response in the first three years following the fire. This information can be used to guide management of this burned area and future burns if they occur. Management informed by monitoring will ensure that multiple resource objectives are being achieved.

Findings:

- In 2008, 66 bird species were detected across the 40 core sites sampled. Four species were observed on greater than 80% of all sites: Steller's Jay, Mountain Chickadee, American Robin, and Dark-eyed Junco.
- In 2009, 80 bird species were detected across all 66 sites sampled, with 73 species detected in the core sites. All the same species as 2008, with the addition of Western Wood-peewee and Brown-headed Cowbirds, were observed at greater than 80% of sites.

- In 2010, 72 bird species were detected across the 72 sites sampled, with 69 species detected at the core sites. In 2010, the previous species were detected, with the addition of Hairy Woodpecker, at greater than 80% of sites.
- Results from the ANOVA indicate that burn severity and time since fire played important roles in the composition of the bird community after fire.
- Differences were observed in the mean abundance of several species of birds across the burn severity categories. The Evening Grosbeak was the only species that appeared to be negatively impacted by fire, with higher abundance in unburned sites than sites with low, moderate or high burn severity.
- The Mountain Chickadee, Red-breasted Nuthatch, and Yellow-rumped Warbler responded neutrally to low and moderate severity burns, but had significantly lower abundances in high severity burn areas.
- The abundance of many species was significantly higher at sites with some level of burn severity compared to unburned sites. The American Robin, Pine Siskin, and Steller's Jay were found in higher abundance in low burn severity sites than moderate or high burned sites.
- The mean abundance of Black-headed Grosbeak was greater in low burned sites than in both unburned sites and highly burned sites.
- Abundance of Western Bluebird, Mountain Bluebird, and House Wren were all significantly greater in highly burned sites than in unburned, low, or moderately burned sites.
- Black-backed Woodpecker abundance was greater in highly burned sites than in sites of low or no burn and Olive-sided Flycatcher abundance was greater in highly burned sites than unburned sites.
- Abundance of Hairy Woodpecker was greater in high severity sites than moderate or low severity sites. Abundance of Lazuli Bunting was also greater in high severity burns than in moderately and low burned sites, although the results of the post-hoc test were only marginally significant.
- Species richness of birds was higher in sites with high burn severity than low burn severity. The mean total abundance of birds and the mean abundance of 18 species of bird did not differ significantly across all categories of burn severity, indicating a neutral response.
- Only one species had significantly higher average abundance in the first year after fire than the third year: the Western Tanager. Tanagers were also more abundant in the second year post-burn than the third year.
- Total abundance of birds and the abundance of eight species of bird increased from the first year after fire, including Brown Creeper, Cassin's Finch, Chipping Sparrow, House Wren, Lesser Goldfinch, Steller's Jay, White-crowned Sparrow, and Yellow-rumped Warbler. Of these species, abundance of Brown Creepers and Yellow-rumped Warblers was significantly lower in the first year after fire than in either subsequent year.

- Effects of PFH treatment were only significant for three bird species: Brown-headed Cowbird, Common Raven, and White-crowned Sparrow. All had higher abundance in treated sites versus untreated sites.
- With the exception of the Douglas Squirrel, small mammals were found in higher abundance in low to moderately burned sites.
- Higher species richness of small mammals and abundance of Golden-mantled Ground Squirrel were observed at sites that burned at low severity than sites that burned at high severity.
- One species, the Long-eared Chipmunk, had significantly higher abundance in sites of moderate burn severity than both unburned and highly burned sites.
- The only small mammal that appeared to prefer sites that burned at high severity was the Deer Mouse, with higher abundance in high severity sites than moderate or low severity sites.
- Douglas Squirrels were found with higher abundance in unburned sites than sites that burned at any severity.
- The total abundance of six species of small mammal were not significantly different across all categories of burn severity, indicating a neutral response.
- Development and the interaction of development and burn severity did not affect any small mammal species.
- The impact of burn severity on species richness was especially evident in the year one, with lower richness in high severity burn sites than in both moderate and low severity burn sites in any other year. Species richness of small mammals was also higher in moderate severity sites in year two and three and in unburned sites in year two than in high severity sites in year one.
- Post-fire harvest (PFH) treatments were only significant for one species, Montane Vole, which had higher mean abundance in treated sites than untreated sites.
- Results from the ANOVA indicate that burn severity and degree of development affected the species richness and the abundance of two species of ant, but most species responded neutrally to burn severity, PFH treatment, and development.
- No PFH treatment effects were observed in any species of ant. There was no significant interaction effect between burn severity and development for any ant parameter.

Management Implications:

- Results from this study may aid in the management of recently burned forests for multiple objectives, including the maintenance of biodiversity, a reduction in the risk of fire to human life and property, and a reduction in future fire risk.
- This study suggests that treatments in urban areas have minimal negative impacts on burn-specialists. As this is the area of primary concern in reducing risk of future fire and damage to human life and property, implementing PFH in these areas may allow

managers to meet multiple goals of reducing risks and maintaining ecosystem function and biodiversity.

- In the short term, birds seem to respond more favorably to post-fire forest conditions than small mammals, and ecological groups varied greatly in their response to burn severity and other habitat features. This suggests that multi-objective management goals that include biodiversity would ideally include fire management strategies that result in a patchy distribution of low, moderate, and even high severity burns.
- Our study suggests that small mammals are less dependent on snag density and are less likely to be negatively affected by post-fire snag removal than birds. Treatments that aim to reduce risk of damage to property or life created by dead, standing trees, are most effectively focused on the wildland-urban interface areas, and in these areas the impact of treatment on wildlife community recovery is lower because of lower habitat suitability in urban areas.
- For managers aiming to maintain biodiversity and ecosystem functionality, planning post-fire harvest treatments that leave stands of snags that differ in size, species, and density in wildlands will maintain habitat heterogeneity for wildlife communities.
- Ecosystem function and structure may also be maintained by focusing on potential keystone species, such as woodpeckers. Woodpeckers create cavities that are used by other species for denning, resting, roosting, and nesting. These cavities may facilitate the recovery of secondary cavity users, a group which includes several bird species, tree squirrels, chipmunks, and small avian and mammalian carnivores.
- Woodpecker abundance increased with the density of all sizes of snags, suggesting that managers aiming to preserve these keystone species and the community they support will need to maintain habitat with high densities of multi-sized snags.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P059, ROUND: 10, LEAD INSTITUTION: CALIFORNIA NATIVE PLANT SOCIETY

Plant Community Characterization and Ranking of Fens in the Lake Tahoe Basin, California and Nevada. Kendra Sikes, Danielle Roach, and Julie Evens.

Objectives:

One of the goals of our project was to provide detailed survey information to identify new rare plant locations that add to the knowledge base of sensitive species in the region. Another goal was to classify these fen sites for their vegetation type diversity and presence of rare species, and rank them for their ecological integrity and quality. We intend for land managers to use the ranking system to recognize high priority fen sites for maintenance and restoration.

Findings:

- In this project, we produced 15 detailed fen site maps showing a diversity of vegetation types from woody to herbaceous types in fens. This mapping information provides a

more detailed view of the different vegetation types that occur in the Lake Tahoe Basin meadow systems.

- This project has ranked 49 confirmed fen sites in the Lake Tahoe Basin based upon eight Conservation Significance criteria, including inherent diversity considerations and management related criteria. One value of our Conservation Significance ranks lies in the recognition of vegetation diversity and other important botanical, site history, and environmental characteristics in some of the smaller and less well-known fens.
- The most highly rated fens for Conservation Significance are Grass Lake East and Dave Immecker Fen, with several other fens of the South Basin Region being more highly rated than those in any other Fen Region.
- The three subwatersheds (HU-12) of the Truckee River Watershed had the three highest average Conservation Ranks, in addition to being the subwatersheds with the most fens currently recorded.
- The average Conservation Significance rating for fens of the Angora Creek Subwatershed was the highest at 25.0 (based on 10 fens).
- The lowest average rating was 21.0 for both Incline Lake Subwatershed (based on 8 fens) in the Incline Village Fen Region and Fallen Leaf Lake Subwatershed (based on 2 fens) in the South Basin Fen Region.
- If comparing Regions rather than subwatersheds, Incline Village Region shares the same low average Conservation Rank as the Meiss Country Region.

Management Implications:

The combined Conservation Significance ranks can assist land managers in making restoration and other management decisions, by providing a means for direct comparison between sites. Depending on their purpose, managers may want to consider only certain relevant ranking criteria when comparing fens and setting priorities for management.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P090, ROUND 12, LEAD INSTITUTION: UNIVERSITY OF NEVADA-RENO

Understanding the decline of deepwater sensitive species in Lake Tahoe: What is responsible, eutrophication or species invasions? Sudeep Chandra, Eliska Rejmankova and John Reuter.

Objectives:

The goals of this proposal were to: 1) increase our understanding of the biology and ecology of deepwater special status plant and invertebrate communities, 2) determine mechanisms (e.g. decreased water clarity and the introduction of non-native species) that have contributed to declines in these communities over the past 40+ years, and 3) to create a restoration and monitoring plan based on determined mechanisms. Specific objectives and related hypotheses include:

- Increase our understanding of special status aquatic plant (stoneworts, liverworts, and mosses) and invertebrate (Tahoe stonefly and blind amphipod) communities in deepwater “hotspot” areas of Lake Tahoe, and relate the distribution of these communities to depth, subsurface irradiance, substrate type, and availability of organic matter in sediments.
- Increase our understanding of the biology and ecology of special status deepwater plants and invertebrates through seasonal tracking of populations, developmental state, and diet using stable isotopes.
- Develop a P-I curve for commonly encountered deepwater plants in Lake Tahoe and link the curve to historical light data to determine how plant communities have responded to changes in clarity and how they may respond to future changes in water clarity.
- Determine if non-native invertebrate species are affecting special status communities.
- Identify a strategy to conserve and restore habitat for deepwater special status plant and invertebrate communities and develop a monitoring plan to evaluate community response to conservation and restoration strategies.

Findings:

- There is a tight association between *Chara* and *C. lacustra* in Lake Tahoe and it is likely that *C. lacustra* would not be able to maintain populations in the lake without *Chara*. There also is an association between the moss bed at the South Shore Mound and what is perhaps the only remaining extensive population of *Stygobromus* spp. in the lake.
- The Camp Richardson *Chara* bed and the South Shore Mound moss bed are currently the only known areas that harbor healthy populations of endemic invertebrates.
- Although the biology of many of the endemic invertebrate taxa in Lake Tahoe remains unknown, we have made some interesting discoveries about the life history of *C. lacustra*. Few stoneflies develop two reproductive cohorts simultaneously, as does *C. lacustra*, and it is the only stonefly that is known to give live birth.
- We postulate that the ability for *C. lacustra* to give birth to live nymphs is related to the direct dependence on *Chara* beds for habitat and food. Recently-born nymphs are able to cling to the substrate (*Chara*) which will protect and sustain them.
- Moss and *Chara* beds occurred much deeper historically; therefore, it is likely that areas of suitable habitat with silt-dominated substrate that were colonized by plants in the past are now in areas of the lake in which light levels are not sufficient for the growth of extensive plant beds.
- Although we found evidence that non-native species (mysids and crayfish) are directly consuming both *Chara* and *C. lacustra*, it is unclear how much of a negative effect they are having on these plant-invertebrate assemblages.
- The Camp Richardson *Chara* bed maintains an extremely high density of both *Chara* and *C. lacustra*, despite non-native species predation. The negative effects of non-native species on *Stygobromus* spp. populations, however, may be more severe. *Stygobromus*

spp. was one of the most abundant invertebrates in the lake in the 1960s and now it can hardly be found. In the 1960s, its densities were highest in deep areas of the lake in which plants did not grow. This suggests that non-native mysids and crayfish could have affected *Stygobromus* spp. either directly through predation (as we found evidence for in this study) or indirectly through consumption of organic matter the amphipod was dependent upon.

Management Implications:

- Because of the decline in deepwater plant beds in Lake Tahoe, *C. lacustra* has had its habitat severely restricted. Although the stonefly was placed on a list of endangered invertebrates by the International Union for the Conservation of Nature in 1983, was listed as a Species of Concern by the US Fish and Wildlife Service, and was described as “critically imperiled” by the Nevada National Heritage Program in 1998, it has remained difficult to get recognition for this small species that lives at depth in Lake Tahoe. Although we have made headway in understanding the life history of *C. lacustra*, it has now become clear that we must also understand the ecology and biology of the plants that these endemic invertebrates depend on.
- The unique nature of endemic invertebrate and plant populations in Lake Tahoe certainly warrants further attention and study. We suggest the delineation of conservation zones in the area of the South Shore Mound and Camp Richardson plant beds. Further study is needed to investigate the potential for plant growth in deeper areas of the lake and to monitor plant bed growth during periods of increasing water clarity. Finally, a diver’s survey of the lake in areas potentially colonized by *Chara* and moss (e.g., the 30-50 m depth zone) is suggested in order to search for other hotspots of biodiversity on the lake bottom.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P092, ROUND 12, LEAD INSTITUTION: UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Effectiveness of reintroductions and probiotic treatment as tools to restore the endangered Sierra Nevada yellow-legged frog (*Rana sierrae*) to the Lake Tahoe Basin. Roland A. Knapp, Vance T. Vredenburg.

Objectives:

A major factor driving declines of the Sierra Nevada yellow-legged frog (*Rana sierrae*) is a lethal disease caused by the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*; Bd). The primary objective of the proposed study is to evaluate the effectiveness of several strategies to recover *R. sierrae* in the presence of Bd. These include (1) translocation of frogs from donor populations in which frogs are persisting despite Bd infection to nearby suitable habitats, and (2) captive rearing of early life stage frogs collected from persistent populations and their reintroduction back into the wild as adults. Because some of the captive-reared frogs would never have been exposed to Bd (e.g., frogs raised from eggs) and may therefore be very susceptible to Bd infection, in this group of frogs we also tested whether infecting frogs with Bd and subsequently

clearing them of the infection prior to their release into the wild would increase their resistance to Bd. Finally, because the community of microorganisms inhabiting the skin of frogs (i.e., “microbiome”) can affect frog-Bd dynamics, we characterized the skin microbiome of frogs in the persistent donor populations to provide insights into whether the microbiome confers some degree of resistance against Bd.

Findings:

- Translocations and/or reintroductions were conducted at three sites in the Lake Tahoe Basin study area. Translocated adults showed relatively high survival and quickly occupied a wide range of habitats, including lakes, ponds, and streams.
- Bd infection intensities on frogs changed little after translocation, being sufficiently low as to have minimal effect on frog health and survival.
- Translocated egg masses also showed high survival and many tadpoles produced from the egg masses metamorphosed in the final year of the study (2015).
- Survival of captive-reared adults was similar to that of translocated frogs. Additional years of data collection are needed to fully evaluate the effectiveness of the Bd exposure treatment on reintroduction success, but preliminary results suggest that the treatment may have increased frog survival rates.
- Assessment of the translocated/reintroduced populations over several more years will be necessary to determine whether these population become established, but results to date are very encouraging.
- Analyses of the skin microbiome of *R. sierrae* from the donor populations indicated that bacterial communities changed markedly between tadpole and juvenile/adult stages, but within these stages were relatively stable across the summer active season. Several species of bacteria were identified that strongly suppress the growth of Bd in culture, and may confer some degree of resistance to frogs against Bd infection.

Management Implications:

If translocations and/or reintroduction are successful, the study could result in the reestablishment of *R. sierrae* at several locations in the Lake Tahoe Basin and provide the basis for reestablishing additional populations in the future. More generally, the results of this experiment will provide critically needed guidance for similar recovery efforts being planned across the range of *R. sierrae* and the closely related *Rana muscosa* to recover these endangered frogs across their historical range.

Publications: In progress.

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P099, ROUND 12, LEAD INSTITUTION: CONSULTANT

Renewing and refining the Tahoe yellow cress Conservation Strategy: incorporating new science and management tools. Alison E. Stanton, Dr. Bruce M. Pavlik.

Objectives:

Our primary goal was to ensure that the critical work of the Tahoe yellow cress AMWG can continue and that the MOU to implement the Conservation Strategy is renewed by January, 2013. To reach these goals we proposed the following objectives:

- Synthesize results of field based research conducted between 2003 and 2010;
- Update the conceptual model of TYC population dynamics;
- Evaluate and update indicators in the CS;
- Develop a geo-database for data management and analysis;
- Recommend new management tools including restoration and mitigation tools.

Findings:

This project is currently active.

Management Implications:

In progress.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

5. LAKE QUALITY

Projects: 2, 14, 15, 24, 27, 35, 48, 56, 69, 70, 80, 81, 84, 87

P002, ROUND 7, LEAD INSTITUTION: UC DAVIS

Predicting and managing changes in nearshore water quality. S. Geoffrey Schladow, Fabian Bombardelli, Kristin Reardon, Patricio Moreno, Scott Hackley, Alexander Forrest, Francisco Rueda, Andrea Hoyer, Mario Castro, Mario Acosta, Mancia Anguita, Alan Heyvaert, Rick Susfalk, Brian Fitzgerald, and Sudeep Chandra.

Objective: The research undertaken here focused on the following key areas:

- Measurement of the current driven physical processes of the nearshore, in particular sediment resuspension;
- The modeling of wind driven waves across the surface of Lake Tahoe and their impact on sediment resuspension;
- The development of a three-dimensional hydrodynamic model that can be used to understand the currents in the lake and their impact on issues such as transport of contaminants and invasive species;
- A refinement of the three-dimensional hydrodynamic model using a nested grid approach in which small scale within the nearshore zone can be better represented and studied;

- A survey of the algae that coat the rocks of the nearshore zone of Lake Tahoe;
- The invasive species, most of which have their introduction in the nearshore and continue to live there;
- Measurements on the influence of urban runoff on the water of the nearshore.

Findings:

- Nearshore suspended sediment: Measurements showed that there were pronounced fluctuations in suspended sediment concentrations in the nearshore.
- Wave Modeling: The main process for particle resuspension is wave-induced shear stress. Wind waves can significantly affect the process of sediment entrainment into suspension in places where water depth is shallow, inducing changes in water clarity and color, and potentially releasing contaminants that are bound to the sediment. However, it is clear from the simulated data that wave induced shear stress is important only very close to the lake shore where shallow waters are present.
- Three-Dimensional Hydrodynamic Modeling: The model results showed that particles in Lake Tahoe are transported along a counter-clockwise gyre in the northern part of the lake and a clockwise gyre in the southern part of the lake.
- The Nested-grid Approach to Resolve Nearshore Circulation: The results show that the inner model is capable of representing features in the nearshore at high resolution, and in some cases features that do not appear at all in the coarse grid model.
- Periphyton Surveys: The measurements showed two areas of high growth of periphyton along the South Shore: one at Timber Cove where persistent high growth of periphyton occurred during the study and at Kiva Beach where significant growth of stalked diatoms occurred early in the spring.
- Invasive Species: Our movement study indicated that warm water fish move out of the Tahoe Keys during summer and late fall periods suggesting that the Tahoe Keys may be an important source population for the rest of the lake.
- Nearshore Water Quality at Lake Tahoe: The impact of urban runoff on nearshore clarity was observed during four surveys. Urban runoff primarily degraded water 100 to 200 m from the shoreline. It was common that turbidity exceeded 4 NTU with areas that exceeded 10 NTU. Turbidity decreased with increasing distance from shore. Large sediment plumes from the Upper Truckee River (UTR) were infrequent, but they degraded water quality on a regional scale when they occurred. Urban runoff events were more frequent and resulted in a more localized degradation of water quality.
- Urban runoff from the Regan Beach (RB) and Bijou Creek (BC) culverts reached peak discharge values of 26 cfs and 4.3 cfs, respectively. Peak flow in the UTR exceeded 600 cfs. Peak turbidity in urban runoff was typically in the range of 600-1000 NTU compared to a turbidity in the UTR of up to 150 NTU.
- Water Chemistry: Nitrogen species in urban runoff were dominated by inorganic species other than nitrate and ammonium. Phosphorus species in urban runoff were

dominated by particulate forms. Concentrations of total N and P in urban runoff samples (RB and BC) were four to seven times greater than the maximum concentrations observed in surface water (UTR).

- Maximum relative loads observed at urban runoff (RB and BC) sites were 2.5 kg N day⁻¹, 0.4 kg P day⁻¹, and 200 kg sediment day⁻¹. In contrast, the maximum relative loads at peak snowmelt-driven discharge at UTR were 485 kg N day⁻¹, 102 kg P day⁻¹, and 101,000 kg sediment day⁻¹. For each unit of sediment discharged to the lake, urban runoff (RB and BC) contained 260% more N and 100% more P than that in surface runoff from UTR.
- Nearshore Clarity: Background turbidity values measured in pristine nearshore waters around the entire lakeshore increased from their typical 0.15 NTU up to 0.21 NTU in the summer of 2008. Atmospheric deposition from nearby forest fires was attributed as the cause.
- The BC site was characterized by greater turbidity and conductance values during runoff, presumably due to the influence of wash off from Highway 50 and a heavily-used parking lot just upstream of its discharge into Lake Tahoe.
- At UTR, only 16 out of the 55 days of seasonal snowmelt were characterized by peak turbidity values exceeding 20 NTU. Sediment loads at UTR dropped significantly after the maximum snowmelt-driven discharge.
- Nearshore Clarity: Background turbidity values measured in pristine nearshore waters around the entire lakeshore increased from their typical 0.15 NTU up to 0.21 NTU in the summer of 2008. Atmospheric deposition from nearby forest fires was attributed as the cause.
- Warmer water present in the northeastern part of the lake in August 2008 may have increased algal production resulting in an increase in the chlorophyll-containing particles in the nearshore.
- Three sediment pulses from the UTR were observed to degrade the water clarity off of South Lake Tahoe. The largest pulse, starting on 1 May 2009, remained primarily within 300 m of the shoreline, traveled west to RB and increased turbidity in excess of 10 NTU. Elevated turbidity resulting from this sediment pulse decreased to low levels (<0.5 NTU) within 30 days.
- The impact of urban runoff on nearshore clarity was observed during four surveys. Urban runoff primarily degraded water 100 to 200 m from the shoreline. It was common that turbidity exceeded 4 NTU with areas that exceeded 10 NTU. Turbidity decreased with increasing distance from shore.
- Four surveys observed anomalous elevated turbidity readings that may have resulted from the resuspension of sediment caused by moderate to high sustained winds the day of or prior to the survey. Low lake levels present during this study may have increased the likelihood for resuspension to occur.
- Large sediment plumes from the UTR were infrequent, but they degraded water quality on a regional scale when they occurred. Urban runoff events were more frequent and

resulted in a more localized degradation of water quality. These results were collected during a below average water year. Average or above average water years would be expected to degrade water quality to a greater degree for a longer duration.

Management Implications:

- Invasive Species: Our movement study indicated that warmwater fish move out of the Tahoe Keys during summer and late fall periods suggesting that the Tahoe Keys may be an important source population for the rest of the lake. Since the densities of warmwater fishes are currently fairly low compared to other lake ecosystems, a control and management program where fishes have been observed may be effective.
- Food sources, such as crayfish, and ultraviolet light penetration (clarity) are likely to be significant factors affecting the population growth of invasive bass and the competitive advantage of native fish.
- Define the nearshore zone: Currently, there is no consistent definition of what areas comprise the nearshore zone.
- Eliminate the “influenced by stream discharges” terminology in current standards: Given the complexity of trying to delineate sediment sources, we strongly urge that revised nearshore thresholds abandon thresholds based on if they are impacted by a stream.
- Acknowledge that nearshore water clarity reflects local factors: We suggest that revised thresholds recognize local factors, such as urbanization, in place of or in addition to areas influenced by stream discharges. Recognition of urban influences separately from pristine areas would provide greater protection for the more pristine areas around the lake. A regional approach, compared to the current stream influenced approach, would be more realistic for the South Lake Tahoe area where it remains difficult to separate pollutant loads discharged directly into the lake compared to those from the Upper Truckee River. This, however, does not prevent more localized thresholds for specific problem areas, such as for Bijou Creek Or Regan Beach. The Localization of thresholds could also include a temporal component, permitting exceedance for a greater period of time off-shore from urban areas, but more restrictive near pristine areas. Regardless Of form, local factors such as land use, bathymetry, and nearshore currents should be accounted for when developing regional threshold values for different zones around the lake.
- Thresholds based on relative turbidity measurements may be difficult to measure: we suggest that turbidity only be used in situations where values of less than 1 NTU are not required such as monitoring the seasonal impact of the Upper Truckee River and the short-term impact of urban runoff on the nearshore zone. Turbidity should not be used to determine long-term trends in nearshore clarity as that requires measurements down to less than 0.15 NTU. Secondly, we suggest that if turbidity is included in the revised thresholds, that it is based on absolute and not relative (% difference) measurements.
- Use indicators that address threshold objectives: Light transmissometers are more suitable for long-term measurements at background clarity levels whereas turbidity may be more suitable for short-term measurements at non-background conditions.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P014, ROUND: 7, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Assessment of Particle Size Analysis in the Lake Tahoe Basin. Alan C. Heyvaert, Daniel M. Nover, Todd G. Caldwell, Wendy B. Trowbridge, S. Geoffrey Schladow, John E. Reuter.

Objectives:

The main goal of this project was to assemble and analyze available data on particle size characterization reported for samples taken from Lake Tahoe, from Tahoe Basin streams, and from Tahoe area urban runoff. Additional objectives included:

- Conducting a set of comparative tests on the methods currently in use for particle size distribution (PSD) analysis;
- Preliminary investigation on the use of surrogate measurements to complement or replace the explicit measurement of PSD;
- Developing guidance for standardized analysis and reporting of new data by various groups.

Findings:

- Lake concentrations tended to be highest in the upper water column above the Secchi depth and declined below the deep chlorophyll maximum. Spring and early summer particle concentrations increased, coinciding with snowmelt, and then decreased in late autumn and early winter, especially during periods of lake turnover. Annual average stream concentrations showed variable relative differences between sites and years, although relative ranks based on annual average flux were more consistent. Both concentrations and flux were lowest during dry years and highest during peak wet years.
- Fine sediment particle (FSP) concentrations in stormwater samples were generally several orders of magnitude greater than the fine particle concentrations in lake and stream samples.
- Changes in PSD associated with holding times for stormwater samples were evident within a single day, tending toward increasing particle size, a process that continued with increased holding times.
- Data from the Particle Measuring Systems LiQuilaz instrument did not correspond as closely to the DigiSizer or the LS-13320 ($\leq R^2 = 0.78$).
- A standard operating procedure for laser particle size analysis of Tahoe stormwater samples was developed, as well as specific operating parameters for both the LS-13320 and the DigiSizer instruments, and recommended reporting criteria.

Management Implications:

Water clarity in Lake Tahoe has been declining for several decades. Much of this clarity loss has been caused by increased input and accumulation of fine particulates (<16 μm in diameter) in the

lake. Therefore, accurate methods for analysis of fine particle concentrations and particle size distributions in water samples from the lake, streams, and urban runoff are of major importance.

It is intended that these methods be employed to improve management control of fine sediments.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P015, ROUND: 7, LEAD INSTITUTION: UC DAVIS

Monitoring past, present, and future water quality using remote sensing. Todd E. Steissberg, S. Geoffrey Schladow, and Simon J. Hook.

Objectives:

The objective of this project is to utilize remotely sensed (satellite) data to provide a quantitative management tool for lake-wide assessments of water quality and to link changes in water quality to discrete sources at the sub-watershed (e.g. the Incline Creek watershed) scale.

Findings:

- Remotely sensed “measurements” are a combination of measurements and models. Spaceborne radiometers, such as MODIS, measure the spectral distribution of radiance exiting the top of the atmosphere. Only a small fraction of the radiance measured at the sensor is water-leaving radiance. Over oligotrophic waters, such as Lake Tahoe, the atmosphere can contribute as much as 90 – 99% of the signal received by the satellite sensor. In addition, there are influences from factors such as sun glitter, whitecaps, clouds and jet contrails. Therefore, atmospheric correction must be performed on each satellite image to remove these contributions and adjust for atmospheric attenuation. In the open ocean there are well-established methods for atmospheric correction, which benefit from negligible terrestrial contributions to the atmosphere and water. Lake Tahoe by contrast has a more optically complex terrestrial atmosphere, albeit a thinner one due to its altitude, and more optically complex waters, although its low chlorophyll concentrations are similar to the pelagic ocean. Uncertainties associated with the process of atmospheric correction (i.e. how the atmosphere is modeled) are an important limitation on the accuracy of remotely sensed water quality at Lake Tahoe.
- As part of this project a web-accessible database of Tahoe remotely sensed imagery has been created. This is a living database, and images are being added to it as they are acquired by MODIS. These images are atmospherically corrected, using what we believe to be the most appropriate “models” for Lake Tahoe. Instantaneous and monthly averaged Secchi disk depths and chlorophyll *a* values for locations corresponding to the long term UC Davis monitoring stations are calculated, as are similar values for 45 “virtual” offshore, coastal and nearshore stations around the periphery of the lake, and maps of these variables for the entire lake are produced.
- Calibration of the satellite-derived Secchi depth and chlorophyll *a* concentration against the measured data for the lake gave a very good match, with both seasonal variations and year- to-year variations for the 8 years of data used being well represented. Annual average Secchi depth showed a slight bias, with the satellite derived values being about 1 m lower than the measured values. The cause of this bias is currently being studied.

- Lakewide maps of Secchi depth and chlorophyll *a* concentration show significant variations. The largest variations occur closer to shore, and the lowest Secchi depth and highest chlorophyll *a* are frequently seen to be associated with stream mouths and to occur at times of spring runoff.
- Because of the influence of nearshore features such as bottom reflection, and the relatively large pixel size associated with MODIS imagery, the “virtual sampling stations” that were established had their nearshore sites approximately 750 m from shore. While this was sufficient to see the influence of loading from the land, it cannot resolve finer-scale features closer to land such as details of turbidity plumes, distribution of macrophytes and clam beds, and the precise source of pollutants from the intervening zones. That type of information can best be acquired with the concurrent use of high resolution satellite imagery (as was acquired in summer 2010 by TRPA) by NASA airborne hyperspectral sensor in combination with field measurements of bottom reflectance around the nearshore.
- An unexpected finding of comparing the 8-year, monthly averaged Secchi depth around the lake periphery is that Secchi depth is consistently lower on the east side of the lake (from Stateline Point to Tahoe Keys) than on the west side of the lake. This appears to hold true at all times of year, and is most pronounced closest to shore (at the nearshore sampling stations). Consistently the lowest clarity region is between Glenbrook and Marla Bay. The reasons for this are not fully understood, but it is most likely due to mixing and transport processes within the lake (i.e. physical limnology) than on watershed inputs in this region. Chlorophyll *a* on the other hand, did not show as clear a pattern from east to west.
- The images in the report showed clearly that the distribution of clarity and chlorophyll *a* in the nearshore is very often controlled by the transport processes within the lake. This held true for both along shore effects, and onshore-offshore transport. Through a complex and poorly understood combination of upwelling, large-scale circulations, meso-scale spiral eddies, jets and flow reversals, pollutants are redistributed around the lake. This has very important ramifications for near-shore monitoring of water quality. In the first instance, a given measurement site may not be representative of a nearby land-use as water from pristine and polluted areas are potentially transported large distances. Second, as these transport mechanisms are likely to change their spatial and temporal distributions seasonally, annually and inter-annually in response to meteorological and climatic forcing, long-term trends will be difficult to ascertain until the transport is better understood.

Management Implications:

- The intent of this project was to demonstrate the use of remote sensing for measuring water quality parameters at Lake Tahoe. One of the major benefits of this approach would be that a whole-lake view of water quality changes would be possible, even extending into the nearshore where discrete sources of pollutants could be identified.
- Improving our understanding of the dynamics of water quality parameters in the lake will improve our ability to manage them.

- Several regions in the lake merit further study. Water quality in Carnelian Bay was lower than expected at times, while the area adjacent to Blackwood Creek showed minimal impacts near its inflow points, despite its much greater inflows.
- Similarly disproportionate effects were observed along the eastern shore adjacent to the Glenbrook and Logan House Creek inflows, which were the lowest of the streamflows recorded during this study period.
- The inflows along the southern shore appear to have a very large impact on lake-wide water quality. Therefore, this region needs further study to quantify the point- and non-point sources of pollution into the lake and the contribution of sediment resuspension to water clarity.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P024, ROUND: 8, LEAD INSTITUTION: EM CONSULTING

Nutrient and sediment loading predictions for prescribed fire using optimized WEPP model. William Elliot, Drea Traeumer, Erin Brooks.

Objectives:

The objective of this project was to provide temporal and spatial predictions of nutrient and sediment loadings at the hillslope scale for prescribed fire using an optimized Watershed Erosion Prediction Project (WEPP) model. Optimization was performed through calibration and validation efforts using locally-measured data for WEPP's most sensitive erodibility parameters (hydraulic conductivity, interrill erodibility, and bulk density); runoff quantity and quality; and sediment yield and composition. Validation was evaluated through quantitative measures of goodness of fit.

Findings:

Basic results of this study are reflected in the WEPP model refinements tailored for Lake Tahoe, which are available through the PSW web site.

Management Implications:

This project, while specific to prescribed fire, optimized the WEPP model with local data, with results that are expected to be applicable beyond the scope of this project, such as improving WEPP's application to other non-urban fire and non-fire related sources and its application to evaluate best management practices at the necessary smaller-scales for siting, design, cost-benefits, and long-term effectiveness.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Basic results of this study are contained in the following products available on the PSW website.

- Tahoe Basin Sediment Model
- WEPP Online Interfaces

- WEPP Online GIS Interface
- WEPP software and documentation

P027, ROUND: 8, LEAD INSTITUTION: UN RENO

NICHES: Nearshore Indicators for Clarity, Habitat and Ecological Sustainability

Development of nearshore fish indicators for Lake Tahoe. Christine Ka Lai Ngai, Dr. Sudeep Chandra, Joseph Sullivan, John Umek, Betina Chaon, Paul Zander, Hollund Rudolph, Andrew Tucker, Dr. Craig Williamson, Dr. Jim Oris, Amanda Gevertz.

Objectives:

Our assessment of the nearshore fish communities in Lake Tahoe addressed the following objectives:

- Conduct a contemporary evaluation of the nearshore fishery.
- Evaluate a variety of traditional indicators that may be used to determine long-term change.
- Determine an efficient capturing method to assess nearshore fish communities.
- Develop novel metrics including UV transparency and trophic niche (stable isotope techniques) to detect shorter term change to the nearshore habitat.
- Provide recommendations and guidance for establishing a long-term monitoring program for nearshore fish communities of Lake Tahoe.

Findings:

- The potential of using two novel indicators (trophic niche and UV) to measure long- and short-term changes in nearshore fishery was examined. Changes in trophic niche were found.
- All fish species examined, except Tahoe sucker (*Catostomus tahoensis*) demonstrated greater reliance in pelagic food source and all fish species have reduced trophic position.
- UV exposure and in situ incubation experiments show that UV transparency of nearshore sites significantly impacts the survival of warmwater fish larvae and influences whether these potentially invasive fish species are able to establish in nearshore Lake Tahoe.
- Native fish larvae (Lahontan redbside shiner) were at least six times more tolerant of UV exposure than non-native warmwater fish larvae (bluegill and largemouth bass). The observed difference in UV tolerance in native versus non-native fish was used to develop a UV attainment threshold (UVAT, i.e. a water clarity threshold based on water transparency to UV) that is lethal to non-native fish larvae with no observed effect on native fish larvae.

- Measurements of UV transparency around the lake showed that more than half of the sites sampled were in non-attainment of the UVAT, suggesting the potential for widespread warmwater fish establishment.
- Contemporary assessment also suggests that the health of Lake Tahoe's nearshore native fishery is deteriorating.
- Given potential expansion of suitable habitat for non-native fishes as a result of increasing spread of invasive plants, elevated lake water temperature, and reduction in UV transparency, as well as other related threats (e.g. nearshore development), the future of Lake Tahoe's nearshore native fishery may be in trouble.

Management Implications:

A long-term nearshore monitoring and warmwater fish prevention program utilizing ecologically relevant metrics is necessary to help us better understand Lake Tahoe's nearshore native fishery, and assist stakeholders to more effectively manage and restore the lake's precious native biodiversity.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

NICHES: Nearshore Indicators for Clarity, Habitat and Ecological Sustainability; Christine Ka Lai Ngai, Dr. Sudeep Chandra, Joseph Sullivan, John Umek, Betina Chaon, Paul Zander, Hollund Rudolph, Andrew Tucker, Dr. Craig Williamson, Dr. Jim Oris, Amanda Gevertz.

P035, ROUND: 9, LEAD INSTITUTION: USFS-PACIFIC SOUTHWEST RESEARCH STATION

Effects of Pile Burning in the LTB on Soil and Water Quality. Ken Hubbert, Matt Busse, Steve Overby.

Objectives:

The specific objectives were to:

- Produce an inventory of current pile conditions in the Lake Tahoe Basin (LTB).
- Determine the soil heat pulse associated with pile burning for the range of pile sizes and fuel types found in the basin.
- Identify the importance of pile size as a factor controlling soil heating.
- Assess the efficacy of water applications (mopping up) to limit soil heating while allowing for adequate fuel consumption.
- Determine the short-term (2 year) effect of pile burning on soil fertility and soil physical properties associated with erosion potential (water infiltration rate, water repellency, porosity).
- Identify pile conditions (size, fuel type) that lead to soil sterilization.

- Assess nutrient transport toward streams from burn piles located in or near riparian zones.

Findings:

- Hand-built pile burn units were scattered across the LTB and ranged widely in size and fuel composition. Burn piles of three kinds were found, often interspersed within a treatment unit:
- Piles dominated by large wood (defined as being greater than 22.5 cm, or 9 inches, in diameter and classed as 10,000-hour fuels) were common,
- Piles containing a mixture of slash sizes and a small amount of large wood (less than 10% of the pile) were also common, and
- Piles containing only small diameter slash only (defined as being less than 7.5 cm, or 3 inches, in diameter and classed as 1-hour, 10-hour, or 100-hour fuels), were less common.
- Average diameter of 781 piles was 3 meters (10 feet), with the maximum diameter approaching 9 meters (30 feet).
- Ground coverage of piles was moderate, averaging 8% of the land surface. Complete conversion of a lodgepole pine stand to burn piles – presumably the upper limit of ground coverage for a pile-and-burn operation – resulted in 15-34% ground coverage.
- Burning of hand-built piles of various sizes and fuel types did not result in extreme soil temperatures unless large wood (10,000-hour fuels) was the dominant fuel type. Even then, extreme heating above 400 ° C was limited to the surface 10-cm (4-inch) soil depth.
- Pile size was of minor importance. The soil heat pulse did not increase significantly for piles ranging from two to seven meters in diameter (6.5 to 23 feet in diameter). Thus, decisions regarding pile size and arrangement can be made based on safety issues and cost effectiveness, not soil heating.
- Soil temperatures declined precipitously from the pile center to the pile edge. Roughly one-half of the ground surface area beneath piles reached maximum heating, whereas the soil on the outer half of the pile perimeter remained considerably cooler.
- Mopping up piles with water was an effective option for limiting soil heating beneath piles that contained a high percentage of large-diameter wood (greater than 22.5 cm [or 9 inch] diameter; classed as 10,000-hour fuels). Waiting for eight hours after ignition before mopping up resulted in near complete fuel combustion and only a minor soil heat pulse.
- Soil physical properties were altered moderately (water repellency, porosity) to severely (water infiltration) by pile burning. As a consequence, some localized erosion may be expected in the first few years after burning before surface litter or plant cover return. It is unlikely that this will create erosion problem in the LTB, however, because of the scattered, discontinuous arrangement of pile burn scars across treatment units.

- Burning of wood piles and slash piles did not produce a detrimental change in soil fertility indices (total soil carbon, nitrogen, phosphorus, pH, inorganic nutrients, or visual observations of fine roots production).
- Pile burning did not sterilize the soil. Ample evidence of surviving soil microorganisms was noted regardless of the severity of heating. The results suggest that short-term changes in soil microbial populations and their nutrient cycling processes will not be severe at any soil depth beneath burn piles.
- A strong spike in soil nitrates and sulfates was found within burn scars in the late spring following the initial snowmelt after burning. Consequently, the potential exists for a short-term nutrient pulse in surface and subsurface water following pile burning.
- Nitrate concentrations in overland flow were low in 2010 regardless of sample location. Although the concentrations were higher in 2011, they decreased two-fold moving downslope from the pile burn. This reduction in nitrate concentration with distance from the burn piles is attributed to the filtering effect of ground cover. Subsurface flow of nitrates also decreased about two-fold going downslope from burn piles, although the differences were not statistically significant due to high pile-to-pile variability.
- Overland flows in 2010 also exhibited a decrease in phosphate concentration downslope from the burn piles. Interestingly, the phosphate concentrations were substantially lower for burn pile samples, compared to the control samples.
- Phosphate concentrations were higher in surface and subsurface flow in 2011 compared to 2010, and they did not decrease with distance from burn piles. Collectively, the phosphate concentrations ranged from 1 to 4 mg/l, which is below the EPA threshold for water quality.
- Little movement of sulfate in overland flow was detected downslope from the burn piles, as sulfate concentrations at seven meters downslope of the piles were equivalent to, or lower than, at the control sites. Subsurface movement of sulfates also declined with distance from the burn piles.

Management Implications:

We conclude that overland and subsurface movements of nitrates, phosphates, and sulfates were not excessive in 2010 or 2011, and that they may be a minor factor when pile burning in SEZs, particularly when ground cover is present.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Busse, Matt D., Carol J. Shestak, and Ken R. Hubbert. 2013. Soil heating during burning of forest slash piles and wood piles. *International Journal of Wildland Fire* 22.6: 786-796.

P048, ROUND: 10, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Lake Tahoe Nearshore Evaluation and Monitoring Framework. Heyvaert, A.C., Reuter, J.E., Chandra, S., Susfalk, R.B., Schaldow, S.G. Hackley

Objectives:

Two overarching management objective statements were developed to support achieving the desired condition. The first is for preserving ecological and aesthetic characteristics of the nearshore:

- Maintain and/or restore to the greatest extent practical the physical, biological and chemical integrity of the nearshore environment such that water transparency, benthic biomass and community structure are deemed acceptable at localized areas of significance.

This report proposes that the nearshore ecology and aesthetic objective will be evaluated on the basis of three separate indicators (with associated metrics) that collectively provide assessment of:

- Nearshore clarity;
- Nearshore trophic status (nutrients and algal growth that indicate the degree of eutrophication);
- Nearshore community structure (biological composition).

The other objective is for sustaining conditions suitable for human health in the nearshore zone:

- Maintain nearshore conditions to standards that are deemed acceptable to human health for purposes of contact recreation and exposure.

The focus for this objective is specifically on health risks associated with recreational exposure and not on attendant risks associated with water provided from the nearshore for municipal or domestic supply. Existing state and local programs enforce potable water supply standards. They also provide criteria for tracking the presence of pathogens and toxic compounds that may affect conditions for human health, which serves as the indicator for this objective.

Findings:

- A nearshore water quality conceptual model was completed.
- A process was developed and utilized to evaluate 17 nearshore attributes for use in a coordinated monitoring program. Four broad categories were selected; Clarity, Trophic Status, Community Structure, and Human Health considerations to ensure a balanced, comprehensive evaluation of nearshore conditions.
- Ten metrics were selected to represent the four categories for monitoring purposes.
- For each metric, monitoring locations and frequencies in Lake Tahoe were identified.
- Background measurements for each metric and for each location were determined.
- Interim thresholds were developed for each metric, with the expectation that additional monitoring would be necessary to confirm the original threshold estimates.
- Finally, a comprehensive monitoring plan was developed for the suite of 10 metrics.

Management Implications:

- Conditions in the lake will continue to change over time as a consequence of changing patterns in land use, recreational activities, climate, species distributions, and other as yet potentially unidentified factors. A regular program of data collection allows the

stakeholder community to detect and evaluate these changes in the context of natural variability and desired conditions.

- Ultimately, the findings and recommendations of this project are expected to support several agency statutory and programmatic needs by: 1) providing baseline information to support assessment of relevant state and TRPA standards; 2) supporting the development of products for the Tahoe Monitoring and Evaluation Program; 3) tracking the effectiveness of the Tahoe TMDL Program and other EIP efforts related to nearshore condition; and 4) contributing to detection and management of aquatic invasive species in the nearshore.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P056, ROUND: 10, LEAD INSTITUTION: UC DAVIS

Potential for pathogen growth, fecal indicator growth and phosphorus release under clam removal barriers in the Lake Tahoe Basin. Mitsunori Odagiri, Alexander Schriewer, Geoff Schladow, and Stefan Wuertz.

Objectives:

The overall objective of this study was to evaluate impacts of the rubber barrier installation on microbial and chemical water quality. Specific questions addressed here were:

- Whether fecal indicator bacteria (FIB) such as total coliforms, fecal coliforms, *Escherichia coli* and enterococci re-grow under the barrier;
- Whether artificially added human pathogens (*Campylobacter jejuni* and *Salmonella enterica*) re-grow and/or persist,
- Whether alternative fecal indicator bacteria such as universal-, human-, dog- and bovine-associated Bacteroidales re-grow;
- How much nutrients (ammonium, phosphate and dissolved organic carbon (DOC) would be released under the barrier as a result of decaying Asian clams.

Findings:

- The study aimed to evaluate impacts of rubber barrier installations on water quality in Lake Tahoe. A microcosm study was performed, mimicking environmental conditions under the rubber barriers in the laboratory. We found the following results:
- FIB (fecal indicator bacteria) did not increase under the rubber barriers at winter temperatures in any of the cases studies, whereas sporadic increases in FIB, especially total coliforms, were observed in some cases at summer temperatures.
- The model pathogens *Campylobacter jejuni* and *Salmonella enterica* did not significantly increase in numbers under the barriers at either winter or summer temperatures as measured by DNA. The pathogen decay rate constants at summer temperatures, however, were lower than those reported under ambient water conditions elsewhere, indicating that these pathogens persisted longer under rubber barriers.

- Host-associated Bacteroidales DNA did not increase at either winter or summer temperatures, whereas universal-Bacteroidales DNA showed a slight increase at summer temperatures.
- Dissolved Organic Carbon (DOC) release rates were the highest followed by ammonium and phosphate at both winter and summer temperatures. Nutrient release rates at summer temperatures were one order of magnitude higher than at winter temperatures. Release rates of ammonium and phosphate estimated at summer temperatures were 10 to 1000 times higher than release rates from sediment reported in Lake Tahoe, suggesting that dead Asian clams were possible sources.

Management Implications:

In conclusion, considering the fact that no FIB increase was observed and lower nutrient release rates were measured at winter-like conditions, installation of rubber barriers during winter could minimize the impacts on water quality, but this could also lead to a longer lead time before achieving 100% Asian clam mortality.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Mitsunori Odagiri, Alexander Schriewer, Geoff Schladow, and Stefan Wuertz, Potential for Pathogen Growth, Fecal Indicator Growth and Phosphorus Release under Clam Removal Barriers in the Lake Tahoe Basin. Final Report (P 056), June 2012.

P069, ROUND: 11, LEAD INSTITUTION: UC DAVIS

Potential for Pondweed control in Lake Tahoe using bottom barriers. Allison Gamble, Thomas Barr, Brant Allen, Katie Webb, John Reuter, Marion Wittmann, Sudeep Chandra, and Geoff Schladow.

Objectives:

- Profile five sites around the South Shore of Lake Tahoe with existing curlyleaf pondweed populations.
- Select three of the profiled sites to deploy three types of bottom barriers over adult curly-leaf pondweed populations and turions to determine the impact of anoxia.

Findings:

- As hypothesized in the literature, while a standing condition of anoxia in a water body may be an important mechanism inhibiting sprouting of turions and growth of curly-leaf pondweed, this appears to be fundamentally different than establishing a temporary condition of anoxia for the purpose of inhibiting turion sprouting.
- Since turions are produced each year, bottom barriers would have to be installed annually, and then with only a 20-30 percent reduction in sprouting (i.e. incomplete control/management).

- We did not find evidence to suggest that once the barriers were removed that in situ turion germination would not occur in the treated plots, provided the appropriate environmental conditions were present.
- Bottom barriers have been used to control plant growth and biomass in Emerald Bay; however, since these barriers affect photosynthesis by blocking light, a distinction between material that are porous or non-porous to dissolved oxygen is not an issue.
- In contrast the use of nonporous material is essential if the objective is to inhibit turion sprouting.

Management Implications:

- Based on our experiments we see no reason to recommend the large-scale application of non-porous bottom barriers for managing existing curly-leaf pondweed populations in Lake Tahoe that employs control of turion sprouting as a primary mechanism.
- In reference to aquatic macrophyte control applied to infested waterbodies in general, previous studies concluded that benthic bottom barriers alone cannot eradicate 100 percent of the turions on their own, but that non-porous benthic bottom barriers could possibly be used in conjunction with other integrated methods for eradication of *Potamogeton crispus* turions. Such combined treatments may be able to selectively take advantage of the anoxic conditions that will enhance efficacy. This study does not recommend the use herbicide or other toxics for treatment of curly-leaf pondweed in the open waters of Lake Tahoe. Rather, we provide comments on ‘combined treatments’ to inform future discussions on this matter should the need arise.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Allison Gamble, Thomas Barr, Brant Allen, Katie Webb, John Reuter, Marion Wittmann, Sudeep Chandra, and Geoff Schladow, Potential for Pondweed Control in Lake Tahoe using Bottom Barriers, June 2013.

P070, ROUND: 11, LEAD INSTITUTION: UN RENO

Science to assist policy decisions regarding the prevention of invasive species: testing the survival and growth of quagga mussel in Lake Tahoe. Sudeep Chandra, Kumud Acharya.

Objectives:

The proposed research will directly assess the habitat suitability of Lake Tahoe and its watershed to support the establishment of quagga mussel by testing the survivability of veliger to sub-adult stage using Lake Tahoe water. This information will be important for supporting the current efforts related to inspection and washing of boats entering Lake Tahoe.

Findings:

This project is ongoing.

Management Implications:

In progress.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P080, ROUND: 12, LEAD INSTITUTION: UNIVERSITY OF CALIFORNIA DAVIS

Remote Sensing of Lake Tahoe's Near Shore Environment. Shohei Watanabe, Erin L. Hestir, S. Geoffrey Schladow.

Objectives:

The goal of this research was to investigate the extent to which remotely sensed data could be used to retrieve fine particles, chlorophyll, and colored dissolved organic matter (CDOM) concentrations from the water column in the near shore, and to map the distribution of periphyton (attached algae), aquatic macrophytes (submerged plants), and clam beds in the near shore of Lake Tahoe.

Findings:

- An algorithm for deriving fine sediment, chlorophyll, and CDOM concentration in the water column in the near shore water regions using remote sensing imagery, proved to be very difficult. Absorption analyses showed that the values of optically significant components are extremely low relative to the values found in other inland water bodies, and the available instruments (US Geological Survey, Sacramento) frequently had issues with samples below their levels.
- Algorithms for underwater substrate detection were developed but their application proved to be difficult due to influence (and lack of resolution) of water-borne constituents above the bottom surface as discussed previously, even though the lake water is very clear. Discrimination between sand and macrophyte would be feasible until the bottom depth reaches approximately 10 m. Detection of rocks from sand would also be feasible in a similar depth range.
- Clam beds usually exhibit a patchy distribution in sand, and hence the possibility of separation would be low due to the similarity in spectral shape between sand and clam beds, and site to site variability of spectra within these substrate types.
- Separation of rocks from macrophyte would also be feasible. In general, with present technology, it appears that only larger patches of macrophytes are sufficiently distinguishable from remotely sensed datasets. It will require higher sensitivity and high spectral resolution data (e.g., hyperspectral airborne sensor, PRISM by NASA-JPL) for other substrate types to be distinguishable.

Management Implications:

- Estimation of the concentrations of optically significant components in water of the lake proved to be difficult due to low concentration and low variability. CDOM, non-algal suspended solid, and algal particle all showed extremely low level of absorption relative to other natural water bodies. CDOM was almost at detection limit of the instrument and could not be quantified reliably. Also, spatial variability was quite low among our samples, in that statistical model development was not feasible.

- The development of a cost-benefit analysis for using remote sensing for nearshore monitoring is not meaningful at the present time. The lack of adequate discrimination of different bottom types with current remote sensing products and the noise inherent in the in-water constituent concentrations means that the full suite of benefits are not presently available.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Shohei Watanabe^{1,2}, Erin L. Hestir, Susan L. Ustin, S. Geoffrey Schladow, Remote Sensing of Lake Tahoe's Near Shore Environment.

P081, ROUND: 12, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Evaluating Field and Laboratory Data for Developing Surrogate Indicators to Monitor Fine Sediment in the Tahoe Basin. Alan Heyvaert, John Reuter, Masoud Kayhanian, and Nicole Beck.

Objectives:

The primary goal of this project was to investigate use of turbidity as a surrogate or proxy indicator of fine sediment particle (FSP <16 µm) concentrations in Tahoe Basin stormwater runoff. The main objective was to provide Tahoe Basin agencies and the science community with analytical protocols and techniques that convert from turbidity measurement to FSP as mass concentration and FSP as particle concentration.

Development of these conversion routines was essential because the Lake Clarity Model and the TMDL rely on particle numbers (FSP: number/liter) for estimating fine sediment loading and reduction targets, while the Pollutant Load Reduction Model uses a mass concentration of fine sediment particles (FSP: mg/liter) in its routines for estimating load reductions associated with BMP implementation.

Furthermore, it was recognized that if dependable relationships could be developed, measuring turbidity would provide continuous or real-time information on FSP compared to discrete single sample collection and analysis. This approach also represented a potential for cost savings in TMDL and Lake Tahoe Interagency Monitoring Program (LTIMP).

The overall approach taken in this project was to:

- Provide a synthesis of existing methods and data;
- Develop draft recommendations based on that information;
- Identify information gaps relevant to implementation of the recommendations;
- Work with agency representatives to prioritize issues that may need to be addressed through future investigations.

Findings:

- This study compiled available stormwater runoff and stream FSP data to evaluate statistical methods that would estimate FSP concentrations using cost-effective surrogate measurements. A series of multi-parameter linear regression models were

systematically tested to identify the most powerful and cost-effective metrics to predict and convert FSP concentrations, both by mass and number of particles.

- Based on analysis of available datasets, the optimal regression models were shown to include regional location and month of sample collection to convert both stream or stormwater FSP concentrations between mass and number of particles.
- Turbidity was identified as a reliable proxy to predict FSP concentrations at urban stormwater sites with small improvements in statistical power if region and month are included in the conversion. The use of turbidity as a proxy for FSP concentrations in stream runoff was also promising, but the available data was extremely limited and would require additional paired turbidity-FSP monitoring in streams to create a statistically reliable model.
- This project also demonstrated, however, that different turbidity instruments produce different results from the same runoff samples, even when properly calibrated. Recommendations are provided for normalizing turbidity data from diverse instruments, as needed, and for reporting original data with the corresponding transformation functions and instrument IDs.
- Since *in situ* deployment of turbidity sensors is particularly sensitive to site monitoring configurations, additional suggestions are provided on important installation factors and sampling techniques that improve the reliability of data produced from dynamic field monitoring of turbidity.

Management Implications:

- The findings and recommendations will guide field monitoring, focused data collection, sample analysis, and FSP unit translations to obtain reasonable predictions of FSP in stream and stormwater runoff for Tahoe water quality monitoring programs going forward.
- It is recommended that LTIMP monitoring incorporate regular turbidity measurements in the stream water quality monitoring program along with additional paired turbidity-FSP monitoring to create a statistically reliable model of FSP concentrations.
- Protocols were developed for analytic techniques with three different types of instruments: an in-situ sensor, a portable turbidimeter and a laboratory turbidimeter. Recommendations are provided for normalizing turbidity data from different instruments, and for reporting this information with corresponding metadata.
- Cost savings should be achieved along with improved temporal resolution of loading characteristics for FSP in stormwater runoff to Lake Tahoe by using the turbidity to FSP regression models.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Heyvaert, A.C., 2NDNATURE and J.E. Reuter. 2015. Analysis of Turbidity as a Surrogate Indicator for Fine Sediment Particle Concentrations in the Tahoe Basin. Draft final report. Prepared for the USDA Forest Service, Pacific Southwest Research Station. July 2015.

P084, ROUND: 12, LEAD INSTITUTION: USDA FOREST SERVICE-ROCKY MOUNTAIN RESEARCH STATION

Development of an Online Watershed Interface to predict the effects of forest and fire management on sediment and phosphorus loads in surface runoff in the Lake Tahoe Basin.

William Elliot, Randy Foltz, Erin Brooks, Jan Boll, Michael Hogan

Status: This project is ongoing. Findings are preliminary. Due August 2016.

Objectives:

We propose to meet with stakeholders in the basin to determine the current fuel management activities. We will then develop watershed tools to allow managers to evaluate the subwatershed effects of these activities in terms of fine sediment and phosphorus delivery from subwatersheds that were treated.

Findings:

We have developed a way to use the current predictions within the WEPP technology to estimate not only the surface runoff and sediment delivery, but also delivery of fine sediment below a user-specified threshold, and phosphorus through both surface and subsurface lateral flow pathways.

Management Implications:

Use of the WEPP tool will allow managers to dynamically fine tune their projects to maximize the efficiency of BMPs designed to protect water quality.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Brooks, E.S., M. Dobre, W.J. Elliot, J.Q. Wu and J. Boll. 2016. Watershed-scale evaluation of the Water Erosion Prediction Project (WEPP) model in the Lake Tahoe basin. *Journal of Hydrology*, 533(2016) 389-402.

P087, ROUND: 12, LEAD INSTITUTION: UC DAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER

Emerald Bay control and management: stressors and mechanisms controlling Asian clam populations in Emerald Bay. Allison Gamble, John Reuter, Geoff Schladow, and Sudeep Chandra.

Objectives:

The proposed research will;

- Assess whether the large-scale deployment of bottom barriers in Emerald Bay will depress or eliminate Asian clam populations;
- Describe how dissolved oxygen (DO) and food supply drive the survival, depression or elimination of the Emerald Bay clam population under the barrier treatments;
- Determine whether augmenting bottom barriers with organic carbon can further facilitate, depress, or eliminate the Emerald Bay clam population.

Taken together, these data will help answer the key question of how to optimize the effectiveness of bottom barriers to treat the invasive Asian clam in Emerald Bay.

Findings:

- The sill in Emerald Bay is a dynamic and variable physical environment. Two-way water motion across the sill and through the sill is driven by baroclinic (water temperature) and barotropic (wind) forces. Water motion and substrate permeability affected both the integrity of the benthic barriers, and the ability to establish and maintain hypoxic conditions underneath the barriers.
- Changes in nutrient concentrations underneath the benthic barriers were limited, and nutrient concentrations underneath the barriers rarely differed significantly from the ambient control. This is likely due to the low densities of benthic infauna (including Asian clams) occurring throughout the Emerald Bay sill.
- We think the deployment of Curlex™ below the benthic barriers as an augmentation of organic material had little effect on *in situ* nutrient concentrations.

Taken together, results from the monitoring of DO saturation and water temperature suggest:

- A subset of the benthic barriers deployed in Emerald Bay (i.e., undisturbed barriers covering substrate with reduced permeability) was able to achieve sustained hypoxia, as well as shorter periods of anoxia in the summer. Hypoxic conditions also occurred under undisturbed barriers covering substrate with enhanced permeability, and disturbed barriers; however, both the magnitude and duration of these conditions were reduced compared to the undisturbed barriers over substrate of reduced permeability. Anoxic conditions under undisturbed barriers covering substrate with enhanced permeability, and disturbed barriers also were reduced in frequency and duration.
- The June – October period when water temperatures are > 10°C is the most effective time to kill Asian clams in Emerald Bay using benthic barriers to induce hypoxic conditions.
- Substrate permeability and the resulting potential for hyporheic flows affected the ability of the benthic barriers to induce hypoxic conditions. Substrate permeability must be considered in developing expectations for the performance of benthic barriers, particularly in areas such as sills where variations in bottom slope are pronounced.
- The benthic barriers demonstrated the ability to perform well as a physical barrier over nearly two years of deployment. However, more work is needed to develop improved anchoring methods, particularly where dynamic physical conditions predominate, and rapid response to barrier movement is not always possible.
- Changes in DO saturation levels under the benthic barriers could not be attributed to the addition of Curlex™. However, it is unknown if this amendment of organic material either produced little to no measurable effect on biochemical oxygen demand, or if the effect was overwhelmed by the effects of barrier integrity (i.e., disturbed vs. undisturbed) and substrate permeability.
- Asian clam mortality during the summer period was significantly greater under the three barrier treatment categories, compared to clam mortality at the control site (Kruskal-Wallis nonparametric analysis of variance; $H = 12.158$, $p < 0.01$).

- Clam mortality during the winter period was not significantly different from the control.
- Clam mortality rates during the summer period were the highest and very similar under the two undisturbed barrier treatments (reduced and enhanced permeability), while lower levels of clam mortality occurred under the disturbed barriers.

Management Implications:

- The large scale deployment of gas impermeable benthic barriers in Emerald Bay, Lake Tahoe significantly reduced the density and caused significant mortality in the population of Asian clams. However, complete eradication from the area was not achieved and is highly improbable.
- The data suggest that the stress caused from the benthic barriers forced clams to put less energy into reproduction and more into survival and metabolism.
- The presence of benthic barriers did not affect the sediment carbon content.
- These results suggest that gas impermeable barriers can be used to control for Asian clams, however many variables, such as upwelling, wave action, and temperature contribute to the success of these barriers.
- It seems reasonable to expect that the future treatment of Asian clams in the sill area of Emerald Bay using benthic barriers would attain average clam mortality rates of between 45% and 70% during the summer period, with short-duration mortality rates exceeding 90%. Duration times of heightened mortality would likely increase with improved barrier integrity as discussed above.
- It may be appropriate to extend benthic barrier treatment into the winter period for logistical reasons, but the contributions to overall clam mortality during this period are insufficient to justify targeted treatment.
- The addition of an organic amendment is considered unnecessary to attain clam mortality in Emerald Bay.
- Excluding an amendment may help to both reduce costs and to optimize barrier performance by reducing the potential for water motion disturbance; thus reducing the variability in water quality.
- It may be possible to obtain higher levels of clam mortality overall by combining the use of benthic barriers with other physical treatment techniques.
- Pursuing an integrated treatment strategy incorporating multiple techniques represents a fruitful area for further testing.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Paul R. Stumpner, Controls on Exchange Flow between Emerald Bay and Lake Tahoe, CA-NV. Masters Thesis, (Indiana University, Bloomington) 2004.

Caldwell, T.J., Chandra, S., Beebe, B.A., Appendix A: Large scale deployment of gas impermeable benthic barriers to control invasive Asian clams in Emerald Bay, Lake Tahoe. Aquatic Ecosystems Analysis Laboratory, Department of Biology, University of Nevada – Reno, 2015.

Zachary P. Hymanson, Katie J. Webb, Tom Mathis, and Alex Forrest, Principal Investigators: Allison Gamble, John Reuter, and Geoffrey Schladow, Appendix B: An Assessment of Physiochemical Conditions Associated with the Treatment of Asian Clams, (*Corbicula fluminea*) in Emerald Bay, Lake Tahoe, California. University of California Davis, Tahoe Environmental Research Center, July 31, 2015.

6. STORMWATER MANAGEMENT

Projects: 5, 10, 11, 23, 25, 26, 37, 38, 39, 40, 52, 54, 55, 71, 72, 74, 77, 88, 97

P005, ROUND: 7, LEAD INSTITUTION: UNIVERSITY OF IDAHO

Assessing the sources and transport of fine sediment in response to management practices in the Tahoe Basin using the WEPP model. Dr. Erin S. Brooks, Dr. William Elliot, Dr. Jan Boll, Dr. Joan Wu.

Objective:

The goal of this round 7 SNPLMA project was to test and develop the Water Erosion Prediction Project (WEPP) as a watershed management tool for evaluating the impacts of specific management practices on the generation of fine (< 20 micron) sediment transport at the hillslope and watershed scales in the Lake Tahoe Basin.

Findings:

- Close agreement between simulated and observed snow water equivalent, streamflow, and both fine (<20 micron) and coarse (>20 micron) sediment load was achieved at each of the major watersheds located in the high precipitation regions of the basin with minimal calibration.
- Minimal sediment load was correctly simulated in the drier watersheds (i.e. Logan House and Glenbrook). However, annual streamflow was overpredicted. This overprediction was attributed to unique hydrogeology on the east side of the basin.

Management Implications:

- A simple web-interface tool was developed and populated with the Tahoe-specific input files to allow end users to easily predict the impact of disturbances on fine sediment loading from single hillslopes. The input files were also modified to allow access to the Tahoe-specific input files in the WEPP-windows program. This free program, operating in the windows environment, provides experienced users greater flexibility for simulating impacts of management practices from complex hillslopes.
- The project also provided Tahoe-specific soil and management input files for representing the impact of hillslope disturbances and subsequent restoration options on fine sediment loading. These input files were created using existing rainfall simulation data collected in the basin over the past 10 years. Major land cover treatments include:

mature forest, thin or young forest, shrubs, good grass, poor grass, low-severity fire, high-severity fire, bare, mulch only, mulch and till, low-traffic road, high-traffic road, and skid trail.

- A high priority was placed on developing user-friendly tools and providing training. A simple web-interface tool was developed and populated with the Tahoe-specific input files to allow end users to easily predict the impact of disturbances on fine sediment loading from single hillslopes. The input files were also modified to allow access to the Tahoe-specific input files in the WEPP-windows program. This free program, operating in the windows environment, provides experienced users greater flexibility for simulating impacts of management practices from complex hillslopes. For advanced users, algorithms were provided to simulate streamflow and fine sediment loading from large complex watersheds.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P010, ROUND: 7, LEAD INSTITUTION: USFS-ROCKY MOUNTAIN RESEARCH STATION

Improving road erosion modeling for the Lake Tahoe Basin and evaluating BMP strategies for fine sediment reduction at watershed scales. Randy B. Foltz, William J. Elliot, and Natalie S. Wagenbrenner.

Objectives:

The overall objective of this study was to reduce sediment entering Lake Tahoe by improving and validating the WEPP model applications for road management in the Lake Tahoe Basin. Specifically, we proposed to:

- Parameterize the WEPP model for the Lake Tahoe Basin;
- Improve WEPP: Road interface for the Lake Tahoe Basin;
- Validate the WEPP model for the Lake Tahoe Basin;
- Develop a GIS-based quantitative approach to (a) predict the sediment loading using WEPP;
- Road, (b) identify erosional “hot spots” from a watershed-scale road network and (c) determine the optimal road network design that minimizes sediment production through Best Management Practice (BMP) application.

Findings:

- Lake Tahoe Basin derived effective hydraulic conductivity was nearly 2.5 times larger than the generic WEPP values for the granitic soils (9.3 vs. 3.8 mm hr⁻¹) and nearly 30 times larger for the volcanics (7.5 vs. 0.27 mm hr⁻¹). Based on soil texture rather than parent material, the volcanics were nearly 2 times larger than the WEPP recommended value for a sandy loam soil (7.5 vs. 3.8 mm hr⁻¹). In any case, the Lake Tahoe Basin

derived effective hydraulic conductivities were larger than the generic WEPP recommended values by at least two times.

- The two volcanic soil locations (Spooners Summit and Ward Creek) exhibited initial peaks in sediment concentration followed by a decreasing trend to reach steady-state sediment concentrations between minutes five and ten. Previous studies have reported similar trends in sediment concentrations. In contrast, the two granitic soil locations (Mt. Rose and Secret Harbor) had relatively low initial sediment concentrations followed by increases to steady-state levels. Both parent materials reached a steady-state sediment concentration approaching 15 g L⁻¹ and did not decrease with time as described in other studies.
- The 24 rainfall simulations yielded interrill erodibility values ranging from 1.11×10^6 to 7.82×10^6 kg s m⁻⁴. Basin derived interrill erodibility coefficients for granitics were essentially unchanged (2.2 compared to 2.0) while basin derived volcanics were 1.6 times larger than the generic WEPP ones (3.1 compared to 2.0).
- An improved WEPP: Road-like interface was developed specifically for the Lake Tahoe Basin incorporating the erosion parameter values determined from rainfall simulation.
- In three years, two years more than the original proposal, there were insufficient rainfall events to validate the model. This suggests that winter snowmelt runoff validation attempts could be more successful.
- A methodology using WEPP: Road and simulated annealing was demonstrated for 7.6 miles of roads in or adjacent to the Glenbrook Creek watershed. Over a 30-year prediction time frame, 4.4 miles produced no sediment with only 0.8 miles in a “High Risk” category. An optimal BMP application strategy was found that minimized sediment from the existing network subject to a variety of road budget constraints. This optimum application of BMPs resulted in a 64% reduction in sediment over the 30-year planning horizon.

Management Implications:

- Erosion models are powerful tools for land managers in their efforts to protect and manage resources. This project parameterized the Watershed Erosion Prediction Project (WEPP) model, improved the WEPP: Road interface, and validated the WEPP model for the Lake Tahoe Basin. The project also developed a GIS-based quantitative approach to predict sediment loading using WEPP: Road, identified erosional “hot spots” from a watershed-scale road network, and determined the optimal road network design that minimizes sediment production through BMP application.
- To minimize erosion from roads, managers install and maintain physical BMPs. BMP installation on a watershed scale is a difficult task because of the need to account for multiple constraints, such as available budget, BMP maintenance, and equipment scheduling. A methodology for addressing this challenge is presented here that combines WEPP: Road erosion modeling and simulated annealing optimization. Of the 173 surveyed segments, 30 segments were available to have BMPs installed. The best possible solution yielded a reduction in sediment leaving the buffer over the course of the planning horizon by 64%.

- Road erosion modeling combined with simulated annealing optimization provides a viable approach to water quality issues associated with sedimentation from forest roads.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Final Report - Improving Road Erosion Modeling for the Lake Tahoe Basin and Evaluating BMP Strategies for Fine Sediment Reduction at Watershed Scales [pdf], Randy B. Foltz, William J. Elliot, and Natalie S. Wagenbrenner

Final Report— Improving Road Erosion Modeling for the Lake Tahoe Basin and Evaluating BMP Strategies for Fine Sediment Reduction at Watershed Scales [pdf], Woodam Chung and James (Andy) Efta

Foltz, R. B., Elliot, W. J., & Wagenbrenner, N. S. 2011. Soil erosion model predictions using parent material/soil texture-based parameters compared to using site-specific parameters. *Transactions of the ASABE*, 54(4), 1347-1356.

P011, ROUND: 7, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Tahoe Stormwater and BMP Performance Database Monitoring and Reporting Guidance Document. Heyvaert, A.C., M. Leisenring, N. Beck and B. Wolfe.

Objectives:

The goal of the Tahoe Stormwater and BMP Performance Database (Database) is to provide a consistent data entry and storage system that can assist in the planning and implementation of stormwater projects in the Lake Tahoe Basin. The following are objectives of the Database:

- Compile Tahoe stormwater and Treatment BMP data in a centralized, internet accessible location.
- Organize stormwater and Treatment BMP data in a consistent manner to allow for data integration and data analysis across multiple studies, locations, and Treatment BMP types.
- Provide a structure that enables evaluations of Treatment BMP performance relative to key design parameters, drainage area conditions, maintenance activities, and influent water quality over time.
- Streamline routines for data upload and retrieval.
- Build upon existing efforts by focusing on the current Lake Tahoe pollutants of concern and Treatment BMP types employed, but provide a flexible framework so additional pollutants and Treatment BMP types can be added in the future.

Findings:

Four key directives were identified and addressed in the execution of this project:

- A centralized system was created for accessing and analyzing existing data;

- Guidance has been provided (in this document and appendices) for reporting relevant Treatment BMP design information;
- Consistent formats have been developed for reporting stormwater runoff and Treatment BMP data; and,
- Requirements have been clarified for reporting drainage area characteristics and conditions.

Management Implications:

- The Database in its current version is available to support data collection, management and reporting for the Tahoe Regional Storm Water Monitoring Program (RSWMP).
- The purpose of the Tahoe Stormwater and BMP Database is to guide the collection of consistent and reliable information on stormwater runoff characteristics and treatment best management practice (BMP) performance around the Tahoe Basin. As existing information and new data are uploaded into the database, it will support the continued development, calibration and testing of load reduction models and other stormwater management tools, and it will provide a framework needed for tracking stormwater BMP implementation, monitoring results, and maintenance activities.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P023, ROUND: 8, LEAD INSTITUTION: UC DAVIS

Development of a water quality modeling toolbox to inform pollutant reduction planning, implementation planning and adaptive management. Goloka Behari Sahoo, John Riverson, Brent Wolfe, John E. Reuter, S. Geoffrey Schladow.

Objectives:

Using the modeling tools that have been developed, the goals of this project were to (1) work with the water quality regulatory agencies to formally develop the envisioned *Tahoe Water Quality Tool Box*, (2) package selected models to include user-friendly protocols, documentation and application formats, leading to a means for technology transfer to Tahoe Basin users, (3) create conceptual and operational linkages between individual models as appropriate, and (4) update the Watershed Model to better address the critical issue of wildfire and pollutant runoff.

The specific objectives were:

- Review the performance of both the LSPC Watershed Model and Lake Clarity Model with regard to meteorology, stream loading and lake clarity on the basis of new observational data collected since 2004 when the models were initially validated.
- Ready the Watershed Model and Lake Clarity Model for transfer to agencies by creating a user-friendly packaging format.
- Develop a computational linkage between the Lake Clarity Model and the UC Davis 3-D lake circulation model using regional meteorology output.

- Develop a computational linkage between the project-scale Pollutant Load Reduction Model (PLRM) and the basin-scale LSPC Watershed Model.
- Update Watershed Model to better evaluate impact of wildfire on hydrology and loading.
- Develop a data product to house meteorology inputs used in water quality modeling.

Findings:

- In terms of flow volume and runoff impact, forest fires result in higher runoff and total water yield to the streams.
- The model projects that the sediment yield will be most impacted by fire because of disturbance of the surface cover combined with the changes in evapotranspiration, runoff, and water yield.
- The fact that the Angora fire occurred during a relatively dry period of time resulted in a below average increase in sediment and nutrient loads.
- The percent increase in flow volume and runoff during the first year of the 2007 fire was higher than the hypothetical 1994 fire; however, the actual volume of flow and runoff increase was comparable.
- Had the Angora fire occurred in 1994, the model projects that there would have been about a 350 percent increase in sediment yield during the first year, compared to about 100 percent increase for 2007.
- The model projects that the increase in loading from fire impact will not be linearly related with precipitation volume. The model projects that sediment would be most impacted by fire (in terms of percent increase in total load), followed by phosphorus and nitrogen.

Management Implications:

- It is recognized by both researchers and environmental managers that the use of models for water quality planning at Lake Tahoe has just started with the current Lake Tahoe Total Maximum Daily Load (TMDL) effort. This project was intended to extend this process by using the *Tool Box* concept to help organize and integrate the current loose confederation of models.
- This study was intended to establish a framework for future model development, application and revision; it was not intended to physically create all possible model linkages nor address all management questions.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

The response of Lake Tahoe to climate change. G. B. Sahoo , S. G. Schladow, J. E. Reuter, R. Coats, M. Dettinger, J. Riverson, B. Wolfe and M. Costa-Cabral

P025, ROUND: 8, LEAD INSTITUTION: UC DAVIS

Two-dimensional Numerical Modeling of Suspended Sediment on the Trout Creek Floodplain. Stephen Andrews, S. Geoffrey Schladow, and Daniel Nover.

Objectives:

The objective of this study was to create and implement a two-dimensional hydrodynamic and suspended sediment model in order to assess the sediment retention capacity of South Lake Tahoe floodplains. This model was then used to explore what simple changes to a restored floodplain could be made (for example plantings of specific vegetation types, or small berm or weir placements) in order to maximize floodplain fine sediment retention. The model was used to separate the physical processes responsible for the sediment removal and elucidate why certain modifications result in higher sediment retention. The correctly calibrated and validated model was then applied to additional field sites in the South Lake Tahoe area to estimate or predict sediment removal associated with a variety of flood events.

Findings:

- The calibrated model indicated that, of the physical mechanisms leading to fine sediment removal considered, flocculation was the largest, with gravitational settling and sediment stranding by infiltration also being significant.
- Floodplains have great potential for removing fine sediment, as these sediments are the ones most prone to removal by flocculation.
- Floodplain modification simulations indicated that changes made to the floodplain vegetation and the addition of small backwater depression areas will have minimal impacts on overall sediment retention
- Small weirs placed in the channel during flooding will have large effects on fine sediment removal, with increases in sediment retention of 20%, if weir placement results in the flooding of previously dry areas.

Management Implications:

- If the results of this study are to guide future restoration efforts, small weirs are the recommendation of the authors to significantly increase floodplain sediment retention. It is clear that these weirs must be carefully placed so that the resulting flooding inundates previously dry areas and creates the greatest benefits.
- Weirs, through their low costs and low planning demands, may have value as an interim floodplain BMP while more extensive and more broadly beneficial stream/floodplain restoration projects are being developed.
- Changes in floodplain vegetation or the addition of backwater pond areas are not likely to produce significant effects on sediment retention although they may have other benefits related to habitat, scenic value etc.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Two-dimensional Numerical Modeling of Suspended Sediment on the Trout Creek Floodplain.
Stephen Andrews, S. Geoffrey Schladow and Daniel Nover.

P026, ROUND: 8, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Sources of Highway Runoff Fine Suspended Particulates in Stormwater and Streams of the Tahoe Basin. Alan C. Heyvaert, James M. Thomas, John E. Reuter, Tim Minor, Charles Morton.

Objectives:

The goal of this study was to determine whether chemical analyses of suspended fine sediments in road and highway runoff at Lake Tahoe could produce relative signatures of Fine Suspended Particulate (FSP) source type. An approach for fingerprinting highway sediment sources, *Sources of Highway Runoff Fine Sediment – September 2012*, was successfully applied in Japan, and similar approaches have been used in other studies. Therefore, this study examined the element composition of particles from various sources and locations in the Tahoe Basin to assess the potential for FSP source fingerprinting.

Findings:

- Distinct chemical differences were evident between source samples, so hierarchical cluster analysis was used to further separate the source samples into a few distinct self-similar groups. Based on this analysis two broad groups of abrasives could be distinguished, one representing the volcanic cinder origin of materials used by both Eldorado County and the City of South Lake Tahoe, while the other group was composed primarily of granitic sands common to the area.
- The rock samples were generally different from the other source materials, including regionally derived abrasives.
- Analysis of selected samples by scanning electron microscopy showed considerable numbers of very small (<8 µm) mineral particles generally dominating the runoff sample particle size distribution.
- The discriminant analysis between source materials performed well, using a mix of elements statistically selected as representing significantly different compositions across sources.

Management Implications:

- Despite a robust statistical separation by discriminant analysis, the source samples are quite similar and the discrimination is based upon very small differences in relative element composition. This fact, in conjunction with a broader range of element concentrations naturally represented in the highway runoff samples, means that there is too much overlap inherent to the test samples in their source sample attributions.
- Alternative normalization schemes are being evaluated for the purpose of reducing noise in the data set and to improve the results of mixing models applied for resolving relative source attributions. The authors are confident that progress in this area will

soon yield reliable data on relative contributions from the main sources evaluated in this study, despite very similar compositions resulting from a common geologic origin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Sources of Highway Runoff Fine Suspended Particulates in Stormwater and Streams of the Tahoe Basin, Alan C. Heyvaert, James M. Thomas, John E. Reuter, Tim Minor and Charles Morton

P037, ROUND: 9, LEAD INSTITUTION: EL DORADO COUNTY

Urban Stormwater Fine Sediment Filtration Using Granular Perlite. Russ Wigart.

Objectives:

The goal of this research was to advance understanding in the Lake Tahoe Basin relative to media filtration options available for the treatment of fine sediment in urban runoff by evaluating perlite filtration media. This research quantified the water quality benefits, fine sediment treatment, measured load reduction and operational concerns relative to treatment. The hypothesis of this research was that filtering urban stormwater with granular perlite would be:

- Effective in significantly reducing fine sediment from urban runoff;
- Practical for installation and operation in a drainage inlet within an extensive storm drain system;
- Economically efficient relative to other filtration alternatives for the treatment of fine sediment.

Findings:

- The filtration efficiency ranged from -19% to 86% effective for TSS and -14% to 75% effective for <16 micron TSS.
- The unit cost of sediment removal was calculated to be (at best case scenario) between \$29-\$57 / lb of TSS removed. The <16 micron portion of TSS was calculated between \$85-\$170 / lb.
- In the Lake Tahoe Basin, a TMDL credit equals 1.0×10^6 or 200 pounds fine sediment particles with a diameter smaller than 16 micron. The range in annual load reduction based on actual monitoring data and modeled flow data determined that the annual <16 micron load reduction can range from 12-24 pounds / filtration unit / year. This equates to .06 - .12 credits annually per filtration unit when operated optimally with intensive maintenance.

Management Implications:

- It was found that the filter system is susceptible to clogging at both the drop inlet (DI) and within the filter mechanism. This issue is exacerbated during freezing conditions.
- The preliminary results have indicated that the filter and DI plug fairly easily with debris and material transported from the road. This is discouraging in that it creates both flooding and liability issues.

- The results of this study indicate that this type of filtration system can be effective, but will be maintenance intensive and therefore, cost prohibitive.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P038, ROUND: 9, LEAD INSTITUTION: 2NDNATURE,LLC

Focused Stormwater Quality Monitoring to Inform Assumptions & Evaluate Predictive Capabilities of Existing Tools. 2NDNATURE and Northwest Hydraulic Consultants.

Objectives:

Expand and apply the urban road monitoring dataset to:

- Test and refine the Pollutant Load Reduction Model (PLRM) v1 Road Methodology assumptions regarding the role urban road factors may have on urban roadway water quality condition;
- Inform PLRM v1 estimates of the total suspended sediment (TSS) and fine sediment particles (FSP; TSS < 16 µm) Characteristic Runoff Concentrations (CRCs) from roads varying in condition, with inclusion of soluble reactive phosphorous (SRP) analyses as resources allow;
- Improve the breadth and quality of urban stormwater data on the generation, fate and transport of TSS and FSP, as well as SRP where resources allow;
- Collect focused and controlled data from urban roads to inform and improve the Road Rapid Assessment Methodology (RAM) tool;
- Apply cost-effective and comparable sampling techniques to increase our understanding of FSP generation from other urban land use types, including commercial and residential surfaces, and their variability of condition.

Expand and apply the on stormwater treatment BMP (SWT) monitoring dataset to:

- Improve the understanding of water quality treatment performance, specifically with respect to FSP, and SRP as resources allow, based SWT type and key design parameters;
- Inform and improve the PLRM v1 Characteristic Effluent Concentration (CEC) estimates based on SWT type and key design parameters; and
- Link average annual infiltration rates with measured CHP saturated hydraulic connectivity values to inform PLRM v1 infiltration input requirements.
- Apply the PLRM v1 to estimate and compare hydraulic capture among SWTs monitored.
- Collaborate with academic researchers in data and sample sharing for their development of appropriate numeric conversions from FSP concentrations and loads to number of particles.

- Develop data collection techniques to inform PLRMv1 modeling assumptions regarding the infiltration rate (i.e., Ksat) of compacted pervious road shoulders.
- Create a framework for refining user inputs and adapting PLRM technical algorithms to allow for better representation of road shoulder condition and its effect on infiltration and runoff calculations in PLRM.

Findings:

- Comparison of road specific sampling and mixed land use catchment water quality data support assumptions that the average FSP and TSS concentrations from roads per unit area are significantly higher than the average mixed land use signal. In contrast, the average SRP concentration is lower, suggesting that roads may not be a primary source of SRP to catchment pollutant loads.
- Roadway condition (as measured by the concentration of FSP obtained from the portable simulator and/or Road RAM) has a significant seasonal variability with the poorest road conditions consistently observed during winter months.
- Poor road condition in the late winter/early spring can result in a substantial downslope water quality risk when rains efficiently transport these pollutants into the stormwater system, requiring treatment and/or retention to prevent FSP from reaching the lake.
- Periodic evaluations of road condition from winter 2009 through summer 2011 and records of annual road abrasive application volumes by jurisdictions suggest a trend of decreasing abrasive application and improved winter road condition for water quality. This trend was found despite a sequential increase in winter snowfall totals each of the monitored years.
- The range, minimum and maximum road CRC values in PLRMv1 Road Methodology appear reasonable given the road specific dataset obtained. PLRMv1 bounds anticipated runoff quality and achievable runoff quality through improvements in road conditions based on the concept of road risk. Comparison of the volume weighted average FSP concentrations from this study indicates that the PLRMv1 guidelines for defining and categorizing road risk may be insufficient to reasonably capture differences in operational practices across jurisdictions and detailed recommendations for PLRMv1 user guidance improvements are recommended.
- Comparisons of observed and calculated FSP concentration ranges suggest that frequent street sweeping may provide greater FSP reductions than currently allowed in PLRM; however, more research would be necessary to determine potential adjustments to PLRM CRCs as a result of street sweeping actions.
- Observations support previous assumptions that increased sweeping frequency during the winter months removes coarse material delivered to road surface prior to pulverization. The lowest observed FSP concentrations were actually on high and moderate risk roads where high abrasive applications were coupled with frequent sweeping with high efficiency sweepers.
- A comparison of seasonal estimates generated from three water years of SWT hydrology data collection to PLRM predictions show a very strong correlation (significant above

99% confidence) between measured and modeled treated outflow volumes across a range of hydrologic conditions experienced by dry and wet basins. When the modeled to measured hydrologic comparisons are limited to seasons when baseflow is negligible, the alignment between measured and modeled hydrologic performance greatly improves. Future PLRM improvement should consider allowing a user to define a baseflow component for a modeled SWT facility.

- Results suggest that: 1) the PLRMv1 CEC FSP and TSS values are currently lower than achievable effluent quality from wet basins and dry basins for typical Tahoe Basin maintenance practices; and 2) the treatment capability to achieve effluent FSP concentrations < 100 mg/L are limited when inflow concentrations are relatively elevated (> 300 mg/L). These findings support the assumption that effective pollutant source control actions in the catchment will reduce the concentrations and loads of pollutants delivered to public stormwater treatment systems, thereby increasing their effectiveness and duration of adequate performance prior to maintenance needs.

Management Implications:

The primary focus of this research was to obtain a representative and reliable stormwater dataset to compare to applicable predictions from the Pollutant Load Reduction Model (PLRM) and provide road specific data to inform the development of Road Rapid Assessment Methodology. These currently are the only tools approved for use by the Lake Clarity Crediting Program (Crediting Program), a program intended to incentivize and measure progress toward the attainment of urban stormwater load reductions established in the Lake Tahoe TMDL.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P039, ROUND: 9, LEAD INSTITUTION: INTEGRATED ENVIRONMENTAL RESTORATION SERVICES

Road Cut and Fill Slope Sediment Loading Assessment Tool: Project Report. Kevin Drake, Rachel Arst McCullough and Dr. Mark Grismer.

Objectives:

The project objectives were to: 1) develop a new land use category for road cut and fill slopes for the PLRM that leverages existing quantitative data and builds on the treatment tiers and functional condition classes already developed in earlier stages of the TMDL; and 2) develop well-defined classifications and field identification protocols for a range of disturbed and treated cut and fill slope conditions with associated loading potentials.

Findings:

- Over 900 rainfall simulations were analyzed to develop an Excel spreadsheet algorithm to predict erosion from road cut and fill slopes in the Lake Tahoe Basin. The prediction tool is called RCAT.
- Erosion estimates can be tailored by soil type, slope class, and cover type.
- Fine sediment yields from road cut and fill slopes of particles less than 16 µm can also be made using this tool.

- A users guide is available for use of RCAT.

Management Implications:

- The overall purpose of this project was to develop the data and tools necessary to improve estimates of pollutant loading and load reductions from road cut and fill slopes. The end product of this effort is the Road Cut and Fill Slope Sediment Loading Assessment Tool (RCAT), a simple and repeatable field assessment methodology and spreadsheet tool designed to assist the Lake Tahoe erosion control and stormwater community in characterizing the functional condition of road cut and fill slopes and estimating the associated sediment and fine sediment particle loading from these areas.
- After several discussions with the developers of the Pollutant Load Reduction Model (PLRM), it became clear that formal integration of the road cut and fill land use into PLRM would require a new module that was beyond the scope of this project. Therefore, a simple, stand-alone spreadsheet tool – the RCAT – was developed. Regulators and project implementers can use the tool to estimate the sediment loading potential of cut and fill slopes before and after project implementation. The data outputs from this tool (sediment loads and runoff volumes) can be used in conjunction with PLRM or separately.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Road Cut and Fill Slope Sediment Loading Assessment Tool: Project Report; Kevin Drake, Rachel Arst McCullough and Dr. Mark Grismer.

P040, ROUND: 9, LEAD INSTITUTION: UC DAVIS

Can a constructed stormwater facility remove fine particles from urban runoff? Adrienne Rochelle Aiona.

Objectives:

This study measured the ability of a stormwater detention basin and associated floodplain to remove sediment from stormwater runoff. Primary constituents measured were: flow, total suspended solids (TSS), the inorganic fraction of TSS, fine particle concentration (FSP) for particles 16 µm, and turbidity.

Findings:

- This study measured the ability of a stormwater detention basin (Cattleman's Basin on Trout Creek) and associated floodplain to remove sediment from stormwater runoff. Primary constituents measured were: flow, total suspended solids (TSS), the inorganic fraction of TSS, fine particle concentration (FSP) for particles 16 µm, and turbidity.
- Median inflow, basin outflow and floodplain event mean concentrations were: TSS (mg/L): 54.4, 9.27, 21.6; FSP (#/mL): 2.57×10^6 , 7.34×10^5 , 6.56×10^5 ; inorganics (mg/L): 39.22, 3.94, 12.46; and turbidity (NTU): 82.05, 15.22, 29.95, respectively.
- Cattleman's Detention Basin provided significant reductions of total loads of all constituents.

- Through the entire system, basin and floodplain, only fine particle concentrations showed a significant decrease.
- The basin removed fine particles at similar rates, by mass, as TSS and the floodplain coarsened the particle size distribution. The percent-by-mass of fine particles was 29 for the influent, 31 for the basin effluent and 21 for the floodplain.

Management Implications:

The basin is successfully removing fine particles from stormwater runoff. Extrapolating from the data collected, the basin is estimated to remove a total of 4.4×10^{16} particles annually; a little over 2% of the reductions El Dorado County is required to meet in the TMDL. Considering this facility is only treating an 11.2-acre drainage basin, this is a significant amount of removal.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Can a Constructed Stormwater Facility Remove Fine Particles from Urban Runoff? Adrienne Rochelle Aiona, Masters Thesis, 2013.

P052, ROUND: 10, LEAD INSTITUTION: USFS-ROCKY MOUNTAIN RESEARCH STATION

Development and validation of the Tahoe Project Sediment Model. Dr. William Elliot, Dr. Erin Brooks, Drea Traeumer.

Objectives:

The goal of this project was to develop the Tahoe Basin Sediment Model (TBSM) online decision support tool to be used by forest managers and planners in the Tahoe Basin to assess hillslope-scale fine sediment ($<20 \mu\text{m}$) loads for the most common forest upland management practices in the basin under current and future climate scenarios. The primary objectives of the project were to:

- Compile a database of existing upland rainfall, runoff, and erosion experiments in the Tahoe Basin.
- Develop WEPP input files from existing datasets in the basin for the most common forest upland management practices.
- Develop a climate generation tool that creates current and future climate files for any project location in the Tahoe basin.
- Develop the TBSM with user friendly protocols for evaluating the effects of alternative management practices on fine sediment loads.
- Validate TBSM loading estimates for fine sediment ($<20 \mu\text{m}$) from current and proposed monitoring projects within the basin).

Findings:

- SRP in surface runoff is likely less than 0.01 mg/L, whereas SRP concentrations in lateral flow and base flow are likely to be around 0.02 mg/l.
- Concentrations are the lowest during March and April when surface runoff is contributing to runoff and diluting lateral and base flow, but higher from June onwards when lateral flow and base flow are the main sources of water in the stream system.
- Total phosphorus delivered, however, is likely to be the highest during the peak flow times associated with snow melt in April and May

Management Implications:

- The TBSM User Guide was drafted, with worksheet exercises from the training workshops included as appendices to assist users.
- The interface clearly shows the link between sediment delivery and TP delivery. Past watershed research has shown that sediment budgets from forest watersheds are dominated by wildfire, with sediment delivery following wildfire as much as 100 times greater than associated with undisturbed forests. Such sediment pulses will likely dominate delivery of phosphorus in the same way as they dominate the sediment budget. Managers will need to consider the effects of management practices not only on immediate sediment delivery, but also on the effects that management may have on reducing the probability or severity of wildfires because of those activities (Elliot, 2013).
- Another interesting hydrologic feature of coarse forest soils is that unless the soils are highly disturbed, there is little surface runoff. Results indicate that when surface runoff does occur, SRP concentrations are low, but when lateral flow or subsurface flow dominate the runoff, SRP concentrations increase. The net effect of integrating the runoff and concentrations values suggests that total SRP delivery is the greatest when runoff is the greatest.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Dr. William Elliot, Dr. Erin Brooks, and Drea Traeumer, Development and Validation of the Tahoe Project Sediment Model. Final Report, December 2014.

P054, ROUND: 10, LEAD INSTITUTION: DESERT RESEARCH INSTITUTE

Tahoe stormwater particle assessment and management for urban and roadway runoff. Dr. Alan Heyvaert, Dr. John Reuter, Dr. Jim Thomas.

Objectives:

The goal of this project was to investigate urban stormwater characteristics and treatment for management of fine sediment particle (FSP <16 µm) concentrations, turbidity and nutrient concentrations in runoff. The urban watershed contributes about 70% of fine sediment delivered into Lake Tahoe, so the objectives for this project included:

- Assessing functional relationships between fine sediment particle concentrations, turbidity, fractional suspended solids and phosphorus in urban stormwater runoff;
- Providing information on the efficiency of fine particle removal in retention basins and vegetated treatment systems; and
- Evaluating how well pollutant removal processes for sediment particles and nutrients perform over the typical life cycle period of a constructed treatment wetland.

Initially, the approach for this project focused on evaluating performance characteristics in the Tahoe City Wetland Treatment System, a stormwater treatment method implemented in 1998. That system was taken off-line midway through the course of this project, so efforts were refocused on evaluating material accumulated within the basin over its lifespan as a treatment wetland, and using this information as an indication of performance and treatment capacity. Additional analyses and tests on urban and highway runoff samples from the Tahoe Basin were conducted to evaluate characteristics relevant to treatment processes and pollutant removal.

The overall approach taken in this project was to:

- Analyze stormwater runoff samples for distribution of fine sediment particle concentration, turbidity and size-fractionated nutrient content.
- Collect sediment cores from a stormwater wetland treatment basin at its end-of-life cycle and analyze these to establish nutrient and fine sediment retention characteristics.
- Develop recommendations for restoration and management of stormwater treatment wetlands in the Tahoe Basin.

Findings:

- Size fractionated stormwater runoff samples showed that on average over 85% of turbidity measured in unfiltered samples was associated with the <20 µm size fraction, and approximately 55% was associated with the <10 µm size fraction.
- On average, FSP in runoff samples represented over 50% of the total suspended particle mass while the <10 µm fraction contained about 37% and the <5 µm fraction contained about 23% of particle mass. Note, however, that particle number concentrations decrease exponentially with increasing particle size such that 99% of total particle numbers are contained in the <5 µm size fraction.
- Particulates in runoff samples averaged 28% organic material, with almost all of it in the <20 µm fraction. Phosphorus concentrations in runoff samples were predominately associated with the <20 µm size fraction (85%), with substantial amounts in the <10 µm fraction (57%) and in the <5 µm size fraction (38%). Results from nitrogen analyses were less consistent and much more variable than for phosphorus.
- Sediment accumulation in the constructed treatment wetland averaged 3.7 centimeters per year. Over the 16 year period of active use this accretion raised the sediment surface approximately 60 centimeters, sufficient to interfere with hydrologic function so that ultimately excavation was required to restore capacity and reestablish flow paths.
- Approximately 2300 cubic yards of accumulated material was removed during excavation. The bulk of this material consisted of senescent surface vegetation over an

organic-rich litter layer (52% organic), which overlaid a predominately inorganic mineralized layer (7% organic) that represented about 95% of total accumulated mass by dry weight (excluding surface vegetation).

- Composition of major nutrients was higher in the organic horizon than in the mineral horizon of the accumulated sediments. Mean concentrations by dry mass in the organic and mineral horizons, respectively, were 0.153% and 0.045% for phosphorus, 1.4% and 0.18% for nitrogen, 27.6% and 2.6% for carbon.
- The majority of mass accumulated in the mineral horizon, so accretion rates of nutrients were higher in this layer than in the organic litter layer. Total soil accretion rates by dry mass were $3.7 \text{ g m}^{-2} \text{ y}^{-1}$ for phosphorus, $17.7 \text{ g m}^{-2} \text{ y}^{-1}$ for nitrogen and $280 \text{ g m}^{-2} \text{ y}^{-1}$ for carbon.
- Total inorganic matter accumulation in the cores averaged $7.0 \text{ kg m}^{-2} \text{ y}^{-1}$, of which approximately 54% consisted of fine sediment particles less than $16 \text{ }\mu\text{m}$ (FSP), indicating an FSP accretion rate of $3.8 \text{ kg m}^{-2} \text{ y}^{-1}$. About 45% of total particle mass retained by the wetland system was in the $<10 \text{ }\mu\text{m}$ size fraction and 30% was in the $<5 \text{ }\mu\text{m}$ size fraction.

Management Implications:

- Most of the phosphorus in urban stormwater runoff is associated with the FSP ($<16 \text{ }\mu\text{m}$) fraction, and about half of that is contained and transported by the $<10 \text{ }\mu\text{m}$ size fraction. Similar results were found with turbidity and sediment loading. This suggests that best management practices (BMPs) should place increasing emphasis on the retention of $<10 \text{ }\mu\text{m}$ particle size fractions.
- Wetland retention basins efficiently combine the physical properties of a retention basin with the biological characteristics of wetlands. The Tahoe City system was designed to remove nutrients and fine sediments from urban runoff through retention basin physical processes and wetland basin biological properties. It was so successful in meeting these goals that it ultimately accumulated too much material and needed to be restored after 16 years of useful performance.
- Accretion of nutrients, metals and inorganic sediments in the Tahoe City constructed treatment system was much higher than found in natural wetlands. Retention of fine silt and clay-sized particles was much greater than would be expected from a stormwater retention basin without wetland function, which likely contributed to the relatively high rates of phosphorus and FSP removal, including the retention of sediment size fractions finer than $10 \text{ }\mu\text{m}$.
- Ultimately, accumulated soils in treatment systems must to be excavated to maintain their treatment performance and storage capacity. Experience with the Tahoe City treatment system suggests this would likely occur on a 15–25 year cycle, depending on input rates and management strategies.
- Bulk density of sediments in the Tahoe City treatment system were much lower than typical of most wetland soils. Subjecting wetland basins to periodic lowering of the water surface would create more consolidation and less elevation rise, which could increase life-cycle periods. Similarly, periodic draw-down followed by mechanical soil

compaction could be useful at extending the time period before restoration maintenance is required.

- More frequent soil removal strategies could be applied in a block-wise manner to allow recolonization from existing vegetation. This would reduce revegetation costs and maintain treatment performance on a continual basis without incurring the high cost associated with less frequent full-basin excavations.
- Soils removed from wetland treatment systems in the Tahoe Basin could be used for creating compost or for soil amendments in restoration projects. While concentrations of metals and other elements (Zn, Cu, Fe, Mn, B, Na) in the Tahoe City wetland soils were somewhat elevated, they did not present harmful concentrations for these applications.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Heyvaert, A.C., R.G. Qualls, J.E. Reuter. 2016. Assessment of Tahoe stormwater characteristics and treatment processes for management of urban and roadway runoff. Draft final report prepared for the USDA Forest Service, Pacific Southwest Research Station. January 2016.

P055, ROUND: 10, LEAD INSTITUTION: INTEGRATED ENVIRONMENTAL RESTORATION SERVICES, INC.

Defensible space-erosion protection tools development. Shelly Thomsen, Lindsay Downing, Kevin Drake, and Michael Hogan.

Objectives:

The following research identifies and quantifies defensible space practices around homes that are capable of reducing or eliminating fire risk (as per CA Public Resources Code 4291), while minimizing erosion, protecting water quality, infiltrating stormwater and snowmelt, reducing runoff and gaining acceptance from fire agencies and homeowners. This research is focused primarily on protecting water quality from poorly thought out defensible space strategies and perhaps improving water quality protection through implementation of defensible space practices.

Findings:

- Mulch cover is highly effective and important in preventing erosion. However, pine needles and landscape bark nuggets posed the highest fire risk of all the mulches tested.
- All mulches that were tilled into the soil (leaving limited mulch on the soil surface) were not able to be ignited with a drip torch. Further, tilled in wood chips had the highest infiltration rate and the lowest runoff rate.
- Pine needles had the fastest flame spread rate in this study.
- Duff mulch had the lowest erosion results of all mulches tested and failed to ignite.
- Distinct flammability differences were observed between fresh pine needles and duff (partially decomposed pine needles): Pine needles were easily ignited and readily carried

flame, whereas duff (partially decomposed pine needles) was not able to be ignited with a drip torch, and had the lowest sediment yield of all treatments.

- It is difficult to compare erosion resistance between tilled and mulch only plots in this study due to distinct differences in mulch cover/thickness and well vegetated baseline conditions.
- However, a large body of previous research at Homewood and throughout the Tahoe Basin indicates that loosening and incorporation of woody material into the soil can reduce sediment yield compared to compacted soil conditions when adequate mulch cover is in place to protect the soil from raindrop detachment.

Management Implications:

- Add or maintain mulch cover wherever possible – highly effective and important for erosion control.
- Manage duff: maintain 1-3” of native duff where it already exists in your yard by lightly raking only the top layer of dry pine needles without scraping down to bare soil. Fire districts recommend raking annually by May 1st and leaving pine needles that fall throughout the rest of the season.
- Roto-tilling amendments 4-12 inches into the soil (leaving only small amount on surface) substantially reduces fire risk and can help prevent runoff and erosion by increasing infiltration.
- Combination of tilling and mulching is the most effective defense against erosion.
- Tilling, mulching, managing native duff, and keeping a mosaic landscape in mind is the best combination for a fire-safe, erosion-resistant landscape.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P071, ROUND: 12, LEAD INSTITUTION: 2NDNATURE, LLC

Catchment-Scale Evaluation of Tahoe Stormwater Tools. 2NDNATURE and Northwest Hydraulic Consultants.

Objectives:

- Obtain and report reliable seasonal and annual urban catchment fine sediment particle (FSP) loads that can be compared across outfalls and allow detection of decreasing trends in urban pollutant loading as a result of effective management actions, should they exist.
- Identify the role and potential format of meteorological datasets when interpreting measured data.
- Standardize catchment outfall water quality monitoring and reporting.
- Document and test the influence that road practices and associated road conditions have on urban catchment FSP loading.

- Generate comparable Pollutant Load Reduction Model (PLRM) estimates for the site and time period monitored to improve PLRM model development guidance, inform potential future PLRM improvements, and refine the expectations and limitations of comparing measured and modeled stormwater pollutant loading datasets.

Findings:

- A series of data and information were used to document the runoff volumes and FSP pollutant loading from 3 urban catchments, evaluate the influence of changing road conditions on these pollutant loads, and build representative PLRM models to compare to the measured water quality datasets. Three urban catchment outfalls were selected, instrumented and monitored for one complete year (March 1, 2012 to February 28, 2013).
- This research developed a standardized and consistent annual summary format and template to synthesize the results of a year of catchment outfall water quality monitoring at a single site. The template provides a number of volume and pollutant load metrics normalized by catchment characteristics (catchment area, impervious area, etc.) to allow direct comparisons of measured data across sites.
- Available turbidity to FSP rating curves developed using thousands of paired samples obtained in the Tahoe Basin were used to consistently convert 10 min turbidity data to FSP concentrations.
- PLRM is a water quality planning tool designed to predict average annual runoff volumes and pollutant loads for use by Tahoe stormwater engineers and managers. The results of the model calibration exercise and comparison to measured pollutant loads suggest that PLRM models can perform reasonably well on the seasonal and annual time scales, as intended based on the objectives of the model design. However, the model's predicted runoff volumes and pollutant loads can have notable discrepancies with the measured data at the event time scale.

Management Implications:

- A variety of treatment Best Management Practice (BMP) types are constructed within Tahoe urban catchments to provide significant pollutant load reductions to Lake Tahoe. BMP Road Assessment Methodology (RAM) can be used to rapidly evaluate and track the relative condition of the larger scale treatment BMPs within the urban catchment over time.
- The tools developed in the course of this study have direct application for evaluating catchment effectiveness for fine sediment retention, road maintenance effectiveness, and FSP related BMP effectiveness.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

2NDNATURE and Northwest Hydraulic Consultants. 2014. Catchment-Scale Evaluation of Tahoe Stormwater Tools. Final Technical Report. Prepared for USFS Pacific Southwest Research Station. June 2014.

Evaluation of alternative abrasives and snow plowing practices and road sweeping/vacuuming as source control BMPs for load reduction of fine sediment particles and phosphorus in urban roadway stormwater. Hyun-Min Hwang, Russell Wigart, Raphael Townsend, Alan Heyvaert

Objectives:

This proposed study will evaluate the effectiveness of alternative abrasives, road sweeping and vacuuming, and the use of snow plows with rubber blades to serve as BMP strategies to reduce the generation and transport of fine sediment particles and associated phosphorus. This study will also address questions about how the two most commonly used sampling techniques (grab sampling and automated mechanical sampling) are different in collecting sediment particles and how these techniques affect measurements of some parameters such as particle numbers, mass, and turbidity. The specific objectives are:

- Evaluate the usefulness of alternative abrasive as a source control BMP to reduce the loadings of fine sediment particles and associated phosphorus;
- Evaluate the effectiveness of sweeping and vacuuming in removal of fine sediment particles from roads;
- Evaluate the effectiveness of snow plowing with rubber blades in diminishing the generation of fine sediment particles from road wear;
- Investigate time series changes of fine sediment particle concentrations within each runoff event to determine whether entire roadway runoff needs to be treated or only a certain portion of runoff can be treated;
- Identify source profiles of fine sediment particles and phosphorus and characterize their loadings in urban roadway runoff in terms of particle numbers, mass and turbidity.

Findings:

- Turbidity of wintertime highway stormwater runoff exceeded the stormwater effluent limit (200 NTU) for discharge to infiltration system in the first flush of all collected events.
- Turbidity of wintertime highway stormwater runoff exceeded the stormwater effluent limit (20 NTU) for direct discharge to surface waters throughout the entire storm period of all collected events.
- The peaks of turbidity were higher than 1000 NTU and declined exponentially from the peak.
- Road sweeping reduced turbidity of highway stormwater runoff significantly.
- Effects of vacuuming were not tested because a road dust vacuuming cleaner was not available.
- Wear of asphalt pavement materials accounted for up to 25-30% of fine sediment. However, it is not clear what fraction of it can be attributed to snow plow and snow chains.

- Contribution of abrasive sand was below 10% in all collected events.

Management Implications:

- Approximately 50% of highway stormwater doesn't need to be treated before being discharged to infiltration systems. Proprietary BMPs can target only the first 50% of stormwater runoff, and the second 50% can be detoured to reduce size of proprietary BMPs.
- Winter time pavement management practices need to be improved to reduce the wear of asphalt pavement materials.
- Snow plowing practices and/or snow chain utilization should be better managed to reduce wear of asphalt pavement materials.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P074, ROUND: 11, LEAD INSTITUTION: 2NDNATURE,LLC

Tools to quantify urban stormwater load reduction from SEZ restoration actions. Status: Report Submitted. 2NDNATURE,LLC.

Objectives:

This research builds on existing models, datasets and past and ongoing SNPLMA-funded efforts by the 2NDNATURE team, leverages existing datasets, methods and models in a manner consistent with the TMDL Pollutant Reduction Opportunity analysis, and is directly applicable to the Lake Clarity Crediting Program.

Findings:

See project 042 done concurrently with project 074.

Management Implications:

See project 042.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Comments:

Project 042 and 074 were combined at the request of the Committee of Scientists.

P077, ROUND: 11, LEAD INSTITUTION: SPATIAL INFORMATICS GROUP, LLC

Mapping hard and soft impervious cover in the Lake Tahoe Basin using LiDAR and multispectral images: a pilot study of the Lake Tahoe Land Cover and Disturbance

Monitoring Plan. Jarlath O'Neil-Dunne, Dr. David Saah, Tadashi Moody, Travis Freed, Dr. Qi Chen, and Jason Moghaddas.

Objectives:

- Map hard and soft impervious surfaces within the Lake Tahoe Basin (LTB) such that the user's and producer's accuracies for both types exceed 95% for the entire study area.
- Quantify the amount and extent of the various impervious cover types in the LTB by ownership, political, and environmental boundaries.
- Use this dataset to pilot implement the proposed Lake Tahoe Land Cover and Disturbance Monitoring Plan..

Findings:

- Overall (including area associated with water bodies), 1.9% of the Tahoe Basin is covered by hard impervious surfaces, totaling 6,175 acres. 0.5% of the Tahoe Basin is covered by soft impervious surfaces, totaling 1,810 acres. All together, this equals approximately 7,942 acres.
- This estimated total impervious coverage acreage represents about 3.95% of the land area in the LTB (study area boundaries).
- In terms of impervious surface types the largest single type of impervious surface are roads, followed by other (driveway/parking lots), buildings, and trails.
- The majority of parcels (65%) have 20% or less of their land area covered by impervious surfaces.
- An analysis of parcel ownership categories shows that the majority of impervious surfaces are on private property. When the ownership patterns are broken down by surface types most of the hard impervious surfaces are on private land, but most of the soft impervious surfaces are on land owned by the Forest Service.
- The LiDAR derived soft and hard impervious cover map derived by Spatial Informatics Group (SIG) was utilized to estimate impervious land coverage by Land Capability Class..
- Only two Land Use Capability types, 1b and 2, exceeded previously determined coverage for combined totals of both soft and impervious coverage. Within Land Capability Type 1b, the coverage was exceeded by 668 acres or 5.9% above the total acreage recommended by previous studies. Within Land Capability Type 2, coverage was exceeded by 42.9 acres or 0.2%.

Management Implications:

By having impervious surface data summarized at multiple geographical units, managers have the information they need to identify and target specific areas from the watershed to the parcel, for the purposes of either removing impervious surfaces or disconnecting them from the hydrologic network. Furthermore, this dataset served to identify land capability classes that are not in compliance with development standards. The dataset produced as part of this study should serve as the foundation for future impervious surface mapping, lowering the cost of future mapping efforts and assisting managers in understanding how impervious surfaces are changing in the basin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P088, ROUND: 12, LEAD INSTITUTION: 2NDNATURE, LLC

Aligning stormwater quality datasets with priority management objectives. 2NDNATURE, LLC.

Objectives:

The purpose of this research is to provide relevant and useable technical guidance to the Tahoe stormwater community for management and reporting of multi-year stormwater datasets. This research developed specific recommendations to align urban stormwater monitoring datasets with priority TMDL, EIP and other water quality implementation and management questions in the Tahoe Basin.

Findings:

- Sections 5-10 of the final report provide the reporting, sample collection, and technical guidance for the two priority objectives. Specifically, sections 5-7 focus on Objective #1: Status and Trends, while Sections 8-10 address Objective #2: CECs.
- Reporting (Sections 5 & 8) defines the key concepts and terms relevant to each objective. In this section, the research team recommends methods for data analysis, noting important assumptions regarding data collection, specified tabular outputs, as well as site specific and basin wide graphical summaries.
- Monitoring and Management Considerations (Sections 6 & 9) provides recommendations for sampling and managing data in a consistent, basin wide format that emphasizes minimizing sample error and extraneous long term data collection and management costs.
- Technical Guidance (Sections 7 & 10) provides a more detailed description of the rationale of the calculations and metrics, an explanation of the specific statistical techniques used and a statistical resources guide for the software used in the status and trends analysis.

Management Implications:

- The value of this research is the definitions, guidance and processes provided, which translate the datasets to be generated for two high priority objectives into meaningful and easily interpretable results. In addition, the recommended data analysis and reporting techniques were identified such that they could be consistently and cost-effectively implemented by resource agency staff who are not necessarily statistical experts.
- To demonstrate the implementation of effective management actions in support of the TMDL, consistent monitoring at the same locations over many years is required and is therefore a key principle of RSWMP development.

- The reliance on automated field instrumentation is necessary to obtain high resolution datasets. Such instruments require continued calibration and maintenance, and data loss or calibration drift are a common challenge.
- The value of standardization and consistency in a continued stormwater monitoring program and its supporting data management structure cannot be understated. Insightful technical evaluations of the data results obtained and their implications to the TMDL, EIP, and BMP implementation and maintenance will be critical to continue to leverage the available dataset to inform programmatic decisions.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

2NDNATURE, LLC. 2014 Aligning Stormwater Quality Datasets with Priority Management Objectives. Final Guidance. Prepared for the USFS Pacific Southwest Research Station. December 2014.

P097, ROUND: 12, LEAD INSTITUTION: UNIVERSITY OF CALIFORNIA, TAHOE ENVIRONMENTAL RESEARCH CENTER

Quantifying the Potential for a Low-Cost Distributed Stormwater Detention System using LIDAR and Remotely Sensed Data. Geoff Schladow, Juanfran Reinoso and Carlos Leon.

Objectives:

This project seeks to utilize newly acquired LiDAR data and other remotely-sensed data to identify and quantify the potential to develop stormwater detention and infiltration areas based on small-scale patterns of land topography. The project:

- Quantified the volume of stormwater detention available through this means;
- Tested the methodology on an existing urban area in collaboration with a local agency;
- Ranked the individual MSIS by volume (largest to smallest) within each basin watershed;
- Worked with local jurisdictions assign a water quality weighting to each of the volume-ranked MSIS that indicate the highest influx of fine sediment particles;
- Developed a methodology whereby the accumulated sediment in an MSIS can be sampled, analyzed for particle size distribution and thereby provide firm data for the assignment of TMDL credits and validation of existing crediting tools (such as the Pollutant Load Reduction Model [PLRM]); and
- Made available a design tool utilizing the Tahoe Environmental Research Center's existing 3-D visualization laboratory where agencies can easily view and design these MSIS in an immersive three-dimensional environment using the LiDAR data and other spatial data.

Findings:

- The methodology has been developed and tested for two locations: Incline Village, NV, and South Lake Tahoe (CA and NV).
- For Incline Village, the analysis showed that a system of 1,300 distributed detention basins could detain (and potentially infiltrate) approximately 49,000 m³ of stormwater in the urban area. Such a system would be capturing water from 56% of the urban area.
- For South Lake Tahoe, the analysis showed that a system of 1,600 distributed detention basins could detain (and potentially infiltrate) approximately 1,200,000 m³ of stormwater in the urban area. Such a system would be capturing water from 42% of the urban area.
- The current system of 192 detention basins in South Lake Tahoe cover an area of 218,000 m². The addition of the full number of distributed detention basins would cover over 1,000,000 m².

Management Implications:

- Urban stormwater is the largest contributor to the decline of Lake Tahoe's clarity. The area of the urban watersheds that are being treated to remove or detain fine particles could be increased by many times. Moreover, because of the small size of the proposed basins, planning and permitting time is reduced by many years, thereby reducing costs. The scale of the proposed detention basins are such that could readily be constructed in a matter of days, thereby being a very efficient way of utilizing small amounts of residual funds.
- These estimates on the potential number of distributed detention basins are an upper bound. Ground truthing and comparison of existing infrastructure (e.g. hidden culverts), as well as eliminating sites with low permeability soils, would likely reduce this, as would finer scale assessment of private property and other considerations. Needless to say, even a 50% deployment of distributed detention basins would have a huge impact on stormwater capture rates. It would also do this in a way that had minimal visual impact, would require minimal planning and permitting delays, would utilize public lands fully to provide protections to the streams and the lake, and would provide seasonal wildlife habitat.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

7. RIPARIAN AND STREAM RESTORATION

Projects: 3, 4, 21, 42, 73, 79, 89, 93

P003, ROUND: 7, LEAD INSTITUTION: USDA AGRICULTURAL RESEARCH SERVICE

Experiments, model development and bank stability simulations to assess bank erosion rates and potential mitigation strategies. Natasha Bankhead, Andrew Simon and Robert E. Thomas.

Data collection and concepts model development and validation. Eddy J. Langendoen.

Objectives:

The primary objectives of the proposed study are to enhance and further validate the predictive, numerical models CONCEPTS and BSTEM to fully realize their potential as state-of-the-art tools for stream management, in the Lake Tahoe Basin and elsewhere. The project-scale data collection and resultant model enhancement will specifically inform adaptive management strategies for local restored streams, and the validated models will be available for use in evaluating design and expected performance of proposed restoration projects.

Specific study objectives include:

- Quantifying the effects of riparian vegetation and bio-engineered treatments on the resistance of bank materials to hydraulic erosion and bank undercutting for inclusion into both models;
- Developing a near-bank groundwater model to integrate with CONCEPTS and BSTEM for the purpose of simulating pore-water pressures dynamically;
- Developing algorithms for CONCEPTS to simulate lateral migration of meandering channels in a deterministic fashion by accounting for hydraulic and geotechnical controls;
- Validate the use of the CONCEPTS and BSTEM models at the project-scale for existing and restored reaches of selected Tahoe Basin streams using time-series historical data on flow, sediment transport and channel geometry.

The underlying hypothesis of this research effort is that with improved definition of the effects of vegetation and other bio-engineered treatments on boundary resistance coupled with enhanced algorithms to simulate channel response, resource managers in the Lake Tahoe Basin will have the ability to accurately evaluate restoration strategies to reduce fine-sediment loadings to the lake with state-of-the-art numerical tools.

Findings:

- Results of model simulations support the original hypothesis that failing to account for the erosion resistance of riparian roots resulted in over-estimation of bank erosion.
- The increased critical shear stress of bank-surface due to the below ground biomass is accounted for by increasing the value obtained for bare soil by an order of magnitude.
- BSTEM was improved by adding the Tahoe Basin riparian species to the database in the RipRoot submodel. Significant changes were also made to the original BSTEM-Static model to create BSTEM-Dynamic, capable of handling continuous hydrograph data, and incorporating a near-bank groundwater model.
- Overall erosion volumes for the 13 month period modeled were 0.75, 2.64 and 5.95 m³ per m of bank for the Upper Truckee River (UTR) Hole 6, UTR54 and UTR3 sites respectively. Total eroded volumes at the Trout Creek sites were lower than the Upper

Truckee sites at 0.45 and 0.24 m³ per m of bank erosion for Trout1 and Trout4 respectively. The differences between the two rivers were a result of both the general difference in bank heights (approximately 1.5 to 2m banks on the Upper Truckee, versus approximately 0.5 to 1m on Trout Creek), and the cohesion of the material at the sites.

- The height of riprap needed to reduce sediment loadings sufficiently depended on the load reduction required and the geometry and materials at each specific site. For example, placing 1m of rock at the base of the bank at UTR Hole 6 had no greater impact than just placing rock on the 0.7m high toe. In contrast, at Trout4, no reduction in hydraulic erosion was seen until a full meter of riprap was added in the BSTEM simulations.
- The effectiveness of an engineered log jam (ELJ) was similar to addition of riprap to a bank, in that its presence greatly reduced hydraulic erosion of the bank toe and face. The effectiveness of an ELJ does, however, depend on the height and width of the structure, and the way that the structure changes near-bank shear stresses in the bank zone.
- The results for runs involving addition of Geyer's willow trees to wet and dry meadow grass assemblages therefore showed that in general as the trees matured, the additional root- reinforcement reduced geotechnical erosion by increasing the resisting forces acting on the bank. The results also suggested that planting of additional vegetation may not provide a quick-fix for bank stability, as the root networks can take a few years to grow and develop to sufficient depths to cross potential shear surfaces within the banks.
- BSTEM results also indicated that if bank grading was used as a mitigation strategy in BSTEM without also replanting, adding riprap to the toe, or using other protection measures such as geotextiles, excessive erosion could still occur. Grading the banks back may therefore be a useful mitigation strategy for reducing eroded bank volumes and thus sediment loadings, but only if used in conjunction with other techniques that maintain channel roughness elements to absorb some of the excess shear stresses acting within the modified reach.

Management Implications:

- The CONCEPTS and BSTEM models are ideal numerical tools for addressing the types of critical issues concerning stream-restoration design and performance aimed towards reducing fine-sediment loadings to Lake Tahoe.
- The project-scale data collection and resultant model enhancement will specifically inform adaptive management strategies for local restored streams and the validated models will be available for use in evaluating design and expected performance of proposed restoration projects.
- The most effective mitigation strategies were those that were able to reduce or prevent hydraulic erosion from the bank toe and bank face. By reducing the volume of erosion from these areas of the bank, the geotechnical stability of the banks tended to remain higher as the banks did not become oversteepened or undercut.

- Model runs involving the growth of riparian trees also indicated that root-reinforcement can be a significant factor for maintaining geotechnical stability, but only once they have matured enough for the roots to cross potential failures planes within the banks.
- Vegetation was also seen to be very important in terms of channel roughness as vegetation growing on the banks and in the toe region act to absorb some of the flow energy, thereby reducing the energy available to scour the substrate.
- Removal of vegetation would, therefore, decrease channel roughness and likely increase erosion rates throughout these channel systems.
- Further planting and growth of riparian species would, conversely, help to reduce rates of bank erosion.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

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P004, ROUND: 7, LEAD INSTITUTION: 2NDNATURE, LLC

Methodology to Predict Fine Sediment Load Reductions as a Result of Floodplain Inundation in Lake Tahoe Streams. 2NDNATURE, LLC, Catherine Riihimaki, Ph.D.

Objectives:

It is assumed that stream environment zone (SEZ) restoration actions that increase the frequency and duration of overbank flow events may result in substantial removal of the pollutants of concern, particularly fine sediment particles (FSP <16 µm), yet to date an accepted method for estimation and supporting data do not exist. The research herein provides a cost-effective data collection and analysis technique that quantifies the fine sediment particle load reductions as a result of floodplain inundation, and this analysis shows that stream restoration is a potentially significant FSP load reduction opportunity.

Findings:

- The estimated FSP load reduction as a result of restoration (Δ FSP) is estimated to be 0.8 MT and 36.5 MT for spring snowmelts 2009 and 2010, respectively.
- A precipitation frequency analysis suggests WY09 and WY10 were average total precipitation years, yielding an estimated average annual FSP load reduction due to increased floodplain retention of 18 MT/yr, or 2.1×10^{18} particles/yr, if the 4/5L restoration plans are implemented.
- This research provides evidence that FSP (fine sediment particles) retention by floodplains does occur and may provide a significant FSP load reduction during overbank flow events.

Management Implications:

- Resource managers need tools to quantify the water quality benefits of SEZ restoration efforts in a manner comparable to and consistent with the stormwater quality load reduction tools that have been developed to support the Lake Tahoe Total Maximum Daily Load (Lahontan Regional Water Quality Control Board [LRWQCB] and Nevada Division of Environmental Protection [NDEP] 2010) and Lake Clarity Crediting Program (LRWQCB and NDEP 2009).
- This research provides evidence that FSP retention by floodplains does occur and may provide a significant FSP load reduction during overbank flow events. However, the load reduction estimates provided are not yet directly comparable to an estimate of load reductions achievable by stream restoration for Tahoe streams. The data from one floodplain over three water years is limited in both its spatial and temporal resolution; however it is a site-specific and representative dataset, which is very challenging to obtain given the infrequency of overbank flow events.
- Upcoming research will explore methods to integrate both site-specific and readily available regional data with critical geomorphic and FSP fate and transport principles and to provide resource managers with a reasonable approach to consistently predict the FSP load reduction expected from stream restoration actions in the Tahoe Basin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P021, ROUND: 8, LEAD INSTITUTION: 2NDNATURE, LLC

Riparian Ecosystem Restoration Effectiveness Framework. 2NDNATURE,LLC, River Run Consulting, Environmental Incentives, LLC.

Objectives:

To focus and improve the quality of stream restoration effectiveness evaluations in the Lake Tahoe Basin.

Findings:

- A preliminary inventory of available documentation and effectiveness reports on riparian ecosystem restoration projects conducted to date (winter 2009) in the Lake Tahoe Basin led to the conclusion that the documentation of a clear process and format would greatly benefit the future development of riparian restoration effectiveness evaluations.
- The Riparian Ecosystem Restoration and Effectiveness Framework (Framework) was developed to focus the process and improve the communications when stream restoration practitioners are implementing specific restoration projects.
- The Framework process is expected to simplify the summary of existing (impaired conditions), the development of testable restoration project objectives, improve the quality of restoration project monitoring strategies and actualize the adaptive management process.

Management Implications:

- The final products of the Framework will increase consistency of the documentation of the restoration team intentions to interested parties many years following the completion of the restoration actions, thereby directly improving the availability and quality of the data and information available to make long-term adaptive management decisions.
- One primary goal of the Framework is to simplify the communication and documentation process for stream practitioners so that each effectiveness evaluation development team does not have to re-create the wheel. We believe the Framework process and the final products provide significant progress towards this goal.
- The Framework is intended to be this “tool.” Over the course of the two years since the 2007 research proposal, the Framework has evolved into a complete process that will help managers better identify measurable project objectives for an array of ecosystem attributes, measure progress toward these objectives, and track and report the physical, chemical and biological effectiveness of riparian ecosystem restoration projects.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P042, ROUND: 9, LEAD INSTITUTION: 2NDNATURE, LLC

Quantification and characterization of Trout Creek restoration effectiveness.
2NDNATURE,LLC.

Objectives:

This report and associated digital Stream Load Reduction Tool (SLRTv1) calculation templates are the final products for two complementary research efforts (Projects 042 and 074) funded by the USDA Forest Service Pacific Southwest Research Station using funds from South Nevada Public Lands Management Act (SNPLMA) research grants. The combined research goals were to obtain and leverage stream environment zone (SEZ) specific data to develop a methodology that estimates the average annual pollutant load reduction associated with SEZ restoration efforts.

The goals of this project were to:

- Apply the standardized approach of both simple and complex observations of Trout Creek to characterize pre and post-restoration stream reach condition by implementing the methodology and protocols of previously funded SNPLMA research (Round 7 and Round 8);
- Develop a simple methodology for the Stream Load Reduction Tool for local resource managers to predict the relative water quality benefits (total and fine sediment load reductions) as a result of stream morphologic modifications and floodplain restoration efforts using Trout Creek and Upper Truckee River as the tangible examples;
- Enable load reductions from stream restoration to be accounted for in the Lake Tahoe total maximum daily load (TMDL) and Lake Clarity Crediting Programs.

Findings:

- Reach scale water quality monitoring was conducted during two consecutive overbank snowmelt events (WY10 and WY11) to quantify the FSP load differences introduced to and exported from the restored Upper Reach of Trout Creek over the duration of the events. WY10 and WY11 reach scale monitoring identified significant FSP load reductions measured across the reach for each overbank event of 4.9 and 9.4 MT respectively.

Management Implications:

- A successful restoration of self-sustaining fluvial processes is expected to reduce pollutant inputs from chronic bank and bed erosion and increase pollutant retention on the floodplain as a result of increasing the frequency and duration of overbank flows. Significant temporal and financial requirements make the quantification of the actual long-term water quality benefit of a restored SEZ extremely challenging. The episodic nature of elevated flow conditions that cause erosion and/or inundate the floodplain means these events are unpredictable, infrequent and costly to monitor. In order to adequately capture and constrain the long term variability of the hydrology conditions that drive the water quality signal, consistent monitoring would need to be conducted for decades.
- The measured reach scale load reductions and the floodplain specific sampling conducted on both Trout Creek and the Upper Truckee River provide undeniable evidence that long term FSP load reductions can be achieved as a result of successful SEZ restoration efforts.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

2NDNATURE, Quantification and Characterization of Trout Creek Restoration Effectiveness and Stream Load Reduction Tool (SLRTv1) Technical document/user guidance, Final Report, July 2013.

P073, ROUND: 11, LEAD INSTITUTION: UC DAVIS

Fine Particle Capture by Synthetic Vegetation in a Laboratory Flume. Kristen Fauria.

Objectives:

This study focuses on the trapping of particles by vegetation, specifically using laboratory flume experiments to measure the rate of particle capture by emergent vegetation for a range of particle sizes and flow conditions. By reporting capture rates and discussing the effects of particle size, the existence of biofilm, flow velocity, stem density, and initial particle concentration on particulate trapping, the results demonstrate which variables are most important to particulate capture and help inform modelers and floodplain restoration efforts.

Findings:

- This study examines the process of particle removal from a continuous distribution of particle sizes in a laboratory flume using submerged, synthetic vegetation. The particle size distribution embraced the size range 1.25 – 109µm, and was provided from road dust removed from roadways in the Lake Tahoe Basin.
- Flow velocity, initial particle concentration, stem density, and presence of biofilm were found to have statistically significant effects on the rate of particle capture. The rate of particle trapping increased with stem density and the presence of biofilm and decline with increasing flow velocity.
- Our experimental results show that L50 (the distance on the floodplain over which half of the particles drop out of suspension) increases with flow velocity and decreases with particle size. This means that the effectiveness of trapping by plants increases as flow velocity decreases and particle size increases.
- L50(s,f) also decreased with increasing particle size and increased with flow velocity (i.e it required a longer distance for fifty percent of the particles to be removed from the water). This tendency for particles to be more effectively removed by settling as flow velocity decreases and particle size increases is well known. However, it is worth noting that L50(p) for 9.9µm particles is less than L50(s,f) .
- This demonstrates that trapping by plants may be more effective than settling and flocculation combined for 9.9µm particles. The combined effects of settling, flocculation and plant capture result in the smallest L50 distances.
- In summary, all the tested factors: biofilm, flow velocity, initial particle concentration, the presence of plants, and plant density are statistically significant to particle capture.

Management Implications:

No management implications were discussed.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

Kristen Fauria, Fine Particle Capture by Synthetic Vegetation in a Laboratory Flume, Masters Thesis, University of California – Davis, 2013.

Stream Condition Assessment of the Lake Tahoe Basin in 2009 and 2010 using the River Invertebrate Prediction and Classification System (RIVPACS). Alison O'Dowd and Andrew Stubblefield.

Objectives:

One element that was missing from the Stream Biological Integrity Monitoring Plan was clear guidance on how to evaluate and report bioassessment information. Consequently, the primary objectives of this project were to:

- Refine and develop data evaluation methods for benthic macroinvertebrate (BMI) data in the Lake Tahoe Basin to better guide manager's evaluation and reporting of stream condition information to decision makers and the public;
- Select methods that can be used in comparisons with other regions in the future (e.g., California statewide RIVPACS);
- Analyze BMI data collected from the Lake Tahoe Basin in 2009 and 2010 to examine the status of streams from those years;
- Compare 2009 and 2010 BMI results with earlier BMI data in the Tahoe Basin to look for possible trends;
- Develop and recommend methods for future trend analysis; and
- Explore potential relationships between habitat parameters, levels of urbanization, and observed vs. expected (O/E) scores at each site sampled in 2009 and 2010.
- This analysis is intended to determine if physical habitat variables gave satisfactory explanations for low O/E scores and determine if certain types of habitats or stream conditions were more likely to have lower O/E scores.
- The resulting analysis from this effort will aid in identifying the current and relative condition of streams (or stream segments) so managers can better target restoration efforts. In addition, this information will enable the characterization of trends in stream condition over time and may provide some evidence of the effectiveness of overall policy and management actions.

Findings:

- RIVPACS O/E scores were assigned to 85 stream sites within the Lake Tahoe Basin. 48 sites (56%) scored in the Excellent category, 15 sites (18%) in the Good condition, and 24 (26%) Marginal. Thus 74% of the sites in the basin were in Good or Excellent condition.
- O/E scores in 2009- 2010 were compared with a pilot study performed in 2003. Eleven sites were found that had been sampled during both time periods. A paired t-test indicated no significant differences between the 12 sites sampled in 2003 and nearby sites sampled in 2009-2010 (p-value = 0.92).
- Impervious surface cover was calculated as a measure of urbanization and was calculated at the watershed scale and within a 1-km radius extracted from the watershed

upstream of each site. Impervious surface was not found to be correlated with O/E score. Although some urbanized parts of the basin such as South Lake Tahoe had degraded water quality in urban areas, there were also regions such as Incline Village on the north shore with Good conditions in urban areas, and regions such as the east shore, where poor conditions were observed in non-urban areas. This is different than the findings of many scientific studies linking degradation of water quality with increased impervious area. The overall impervious surface of Lake Tahoe Basin sites is extremely low, perhaps below the threshold at which impacts are observed. Also it was observed that many factors lead to stream degradation in the basin besides the level of urbanization.

- Seventy-seven habitat variables were collected for each site. Significant positive correlations between habitat variables and O/E score were observed for dissolved oxygen, riffle habitat, fish cover provided by boulders, barren ground cover (implying greater canopy cover), small and large boulders, and slope. Negative correlations were found for glide and pool habitat, nonwoody plant cover (grass and herbs), fines and temperature. Correlation coefficients were not high because of the high variability between sites and diversity of factors affecting stream condition. A multimetric habitat index or multiple linear regression approach would provide greater predictive ability.
- Habitat variables for sites scoring in the Marginal categories were examined closely to determine possible stressors leading to the impaired conditions. It was observed that a group of sites on the larger rivers in South Lake Tahoe were impacted by sedimentation and bank erosion. A group of sites on the east shore were affected by low flows and sedimentation. On the southwest shore, a group of sites were affected by high stream temperatures.
- Four regions were observed around the lake with characteristic conditions. O/E scores were high on the north shore of the lake despite urbanization at lake level. It was thought that steep stream gradients, riparian buffers and intact canopies created favorable conditions. On the east shore, O/E values were high at lake level and worse at upper elevations. Upper elevations were thought to be degraded from low flows and sedimentation from legacy land uses (pasture). On the south shore, the trend was reversed with Excellent conditions at upper elevations and Marginal conditions on larger rivers with lower gradients. The larger rivers were affected by sedimentation. This was attributed to intact forest riparian cover at upper elevations, and channel modification and historic grazing at lower elevations. Low gradient reaches are less able to flush out sand and fines to maintain good benthic habitat. The northwest had uniformly good conditions. The southwest had several streams affected by high temperatures, with one affected by low flow. It was proposed that low forest cover over glacial outcrops may have led to increased solar heating.
- The RIVPACS method for evaluating benthic invertebrate data, in conjunction with detailed habitat assessment according to SWAMP protocols, appears to be a powerful method for determining stream ecological condition in the Lake Tahoe Basin.

Management Implications:

- For future statistical analysis it is more important to resample the same sites multiple times instead of sampling randomly selected status sites each year. We recommend that all of the sites sampled become permanent sites.
- Once the CSCI scores are acquired for the Tahoe sites (data for 2009, 2010, and 2011 have been submitted) we recommend that TRPA use the analysis methods described in this report to analyze those scores.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

P089, ROUND: 12, LEAD INSTITUTION: 2NDNATURE, LLC

Estimated FSP load reduction of select stream restoration projects in the Upper Truckee River Watershed Lake Tahoe, California. 2NDNATURE,LLC.

Objectives:

The Lake Tahoe TMDL has focused water quality improvement actions to significantly reduce fine sediment particle (FSP) loading to the lake over the next several decades. Research and monitoring that supported the development of the stream load reduction tool (SLRT) suggests effective stream environment zone (SEZ) restoration can reduce sediment generation from bank erosion and significantly increase FSP removal in flood flows as a result of floodplain deposition. While standard methods to estimate the urban derived fraction of this FSP loading do not exist, it is likely some load reduction from catchment urban lands are being treated. There is a lot of political and social interest associated with the evaluation of restoration effectiveness within the Upper Truckee River (UTR) Watershed, making the results of this research relevant and important to many stakeholders within the Lake Tahoe Basin.

The three main objectives of this research were:

- Obtain and analyze the average annual FSP load reductions estimated for a series of restoration projects in the Upper Truckee Watershed both independently and collectively;
- Evaluate the cost effectiveness (\$/MT) of FSP reductions for completed restoration projects and compare to other pollutant load reduction strategies considered to meet the Lake Tahoe TMDL; and
- Identify and implement any improvements to the SLRT methodology and user guidance and produce SLRTv2.

Findings:

- Estimates of the average annual FSP load reduction (MT/yr) for seven stream restoration projects in the Upper Truckee River Watershed were completed using SLRT.
- A simple accounting method was developed to estimate the urban fraction of the average annual FSP load reduction provided by each restoration effort.

- Cumulatively, the estimated potential FSP load reduction is 105 MT/yr should all seven of these restoration efforts be implemented within the UTR watershed as planned, or nearly a 20% reduction in the annual FSP load of the UTR Watershed (assumed to be 521.8 MT/yr.). Over 69% of this cumulative FSP load reduction estimate on the UTR is achieved by floodplain retention, which likely includes a significant contribution of urban-derived FSP.

Management Implications:

- While the cost effectiveness of SEZ restoration actions to achieve pollutant load reductions varied across projects, this analysis does suggest that SEZ restoration is another valid and cost-effective tool in the pollutant load reduction opportunity toolbox for Tahoe Basin managers to reduce pollutant loads to Lake Tahoe.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

2NDNATURE, LLC. 2014. Estimated FSP load reduction of select stream restoration projects in the Upper Truckee River Watershed Lake Tahoe, California. Final Report. Prepared for USFS Pacific Southwest Research Station. March 2014.

P093, ROUND: 12, LEAD INSTITUTION: SPATIAL INFORMATICS GROUP, LLC

A Collaborative Definition, Classification Refinement, and Mapping of Stream Environment Zones in the Lake Tahoe Basin. Spatial Informatics Group, LLC.

Objectives:

This project responded to Lake Tahoe Basin stakeholders' identified needs to review and potentially update the current stream environment zone (SEZ) policy to ensure implementing ordinances and program elements are consistent with best available science and data, and support desired SEZ conditions, functions, processes and values.

This research builds directly upon previous and concurrent efforts to evaluate SEZ policies and programs in the Lake Tahoe Basin. This project will be integrated with the ongoing SEZ Roadmap effort to establish a classification system of different SEZ types based on soils, hydro-geomorphology and vegetation that is protective of identified SEZ desired functions. Specific objectives were:

- Review and documentation of SEZ desired conditions, functions, process and values;
- Review SEZ definitions;
- Review of SEZ field delineation criteria and indicators;
- Review of wetland and riparian area classification schemes with an eye towards identifying which system might be most applicable to SEZ;
- Map aquatic resources as a foundation to SEZ mapping. It was reasoned, based on the definition and field delineation indicators of SEZ, that aquatic resources were core to producing a basin-wide map of SEZ;

- Release the aquatic resource map to an impartial third party to judge the extent to which the aquatic resource map produced for this project was consistent with current California wetland and riparian mapping standards;
- Confirm the SEZ classification scheme recommended by the Field Delineation Workgroup;
- Produce a basin-wide SEZ map based on proposed SEZ classification scheme and proposed indicators provided by the Field Delineation Group.

Findings:

Perhaps the greatest value of this project was the contribution of the different individuals that participated in workgroups in combination with the project team. Each individual brought their respective technical expertise and years of institutional knowledge that combined, through many hours of discussion, have addressed several identified SEZ program update needs. Together, workgroups have forwarded a set of recommendations that very likely can be integrated into Tahoe SEZ program with some additional stakeholder, public and decision-maker review and discussion. The process followed in this project has resulted the following findings and recommendations:

- A review of existing SEZ definitions were found to be adequate and indicate no need for revisions.
- Desired SEZ conditions, functions, processes and values have been documented in this report and can help to focus management and regulatory actions.
- Although there are no recommendations for adjusting the overarching criteria (i.e., vegetation, hydrology, geomorphology, and soils) for SEZ delineation, several updates are proposed for SEZ indicators. The Field Delineation Workgroup found that updates to soil, vegetation, aquatic habitat, and floodplain indicators would bring the SEZ program up to date with current industry standards. Similarly, current methods for evaluating proposed indicators and thus determining SEZ boundaries are suggested to improve the consistency of SEZ delineation across SEZ practitioners.
- The Field Delineation Workgroup has proposed a pragmatic scheme for SEZ delineation and review that takes into account the different types and scales of project actions. Implementation of this system could lead to cost savings without a reduction in SEZ protection.
- A simple SEZ classification scheme is proposed based on California's Aquatic Resource Classification System and augmented to reflect Tahoe Basin ecology and existing SEZ policy. The proposed classification scheme includes and describes the different types of SEZ that exist in the Basin and should be valuable in supporting monitoring, restoration and regulatory efforts.
- The aquatic features mapping resulted in the most accurate and comprehensive datasets ever developed for the Lake Tahoe Basin. While no mapping effort is perfect, and the quality assurance review identified some deficiencies, the stream centerlines, open water polygons, and wetlands are far more accurately represented on the landscape and precise than any layers ever produced for the region. The success of the aquatic resource

mapping can be attributed to both the quality of the source input datasets, specifically the LiDAR and WorldView-2 imagery, along with the processing methods developed for this project. The foundation laid by this project will substantially reduce the cost of making future updates and improvements. However, additional attribution work is needed to bring the aquatic resource map into compliance with CARI and NHD standards.

- The aquatic resource map was core to developing the first ever basin-wide map of SEZ. It is important to note that the SEZ types and boundaries should be considered as *potential SEZ*; because some of the features were developed from soils and LiDAR-derived topographical and hydrological models, they do not necessarily reflect on the ground conditions. This reality is particularly evident in the “forested” type, which encompasses developed land uses (e.g., roads, buildings) south of Lake Tahoe and in other suburbanized parts of the basin. Thus it is recommended that field verification be conducted to validate the occurrence of SEZ as appropriate prior to on-the-ground actions.

Management Implications:

- The map of potential SEZ produced in this project indicates that there is considerably more SEZ (29,391 acres) than has been previously reported (approximately 17,700 acres). These differences probably do not indicate an increase in SEZ area since last mapped, but are more likely a function of higher resolution base data used for this project. Higher resolution data provided the ability to more accurately map stream tributary networks and better reveal wetland and riparian associated vegetation. In addition, previous SEZ mapping efforts may have been biased toward representing the extent of SEZ in the urban context where the greatest development pressures exist in the Tahoe Basin.

Publications:

www.fs.fed.us/PSW/partnerships/tahoescience

www.tahoescience.org

front and back cover photographs
by Shelbi Whitehead

