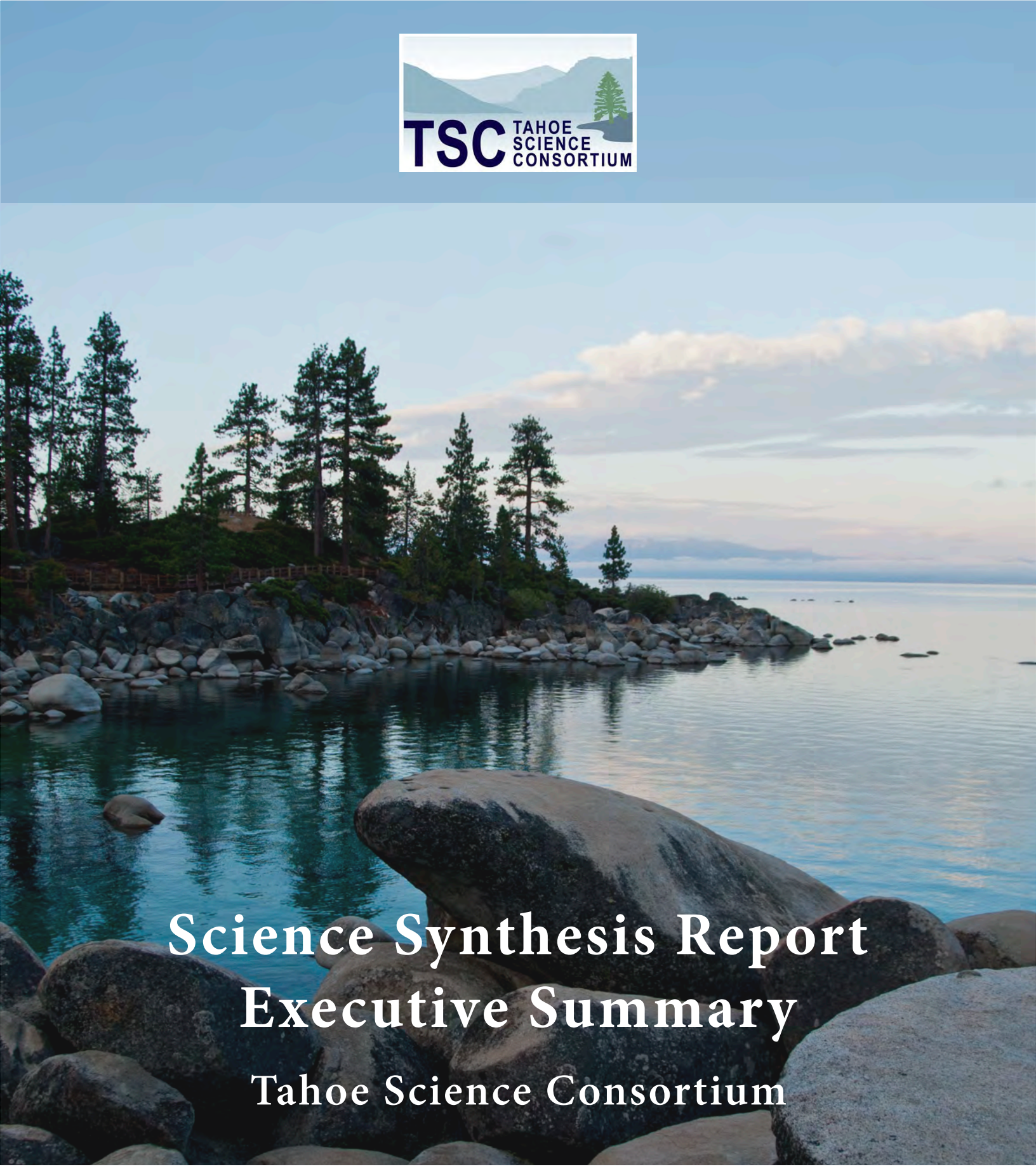

Science Synthesis Report Executive Summary

Tahoe Science Consortium

TSC TAHOE SCIENCE CONSORTIUM

DRI Desert Research Institute

University of Nevada, Reno

USGS science for a changing world

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

UCDAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER

SCIENCE SYNTHESIS REPORT

DESERT RESEARCH INSTITUTE
TECHNICAL REPORT NUMBER: 8159

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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 (SNPMA), 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.

TSC TAHOE SCIENCE CONSORTIUM
ADDRESSING SCIENCE NEEDS IN THE LAKE TAHOE BASIN

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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.

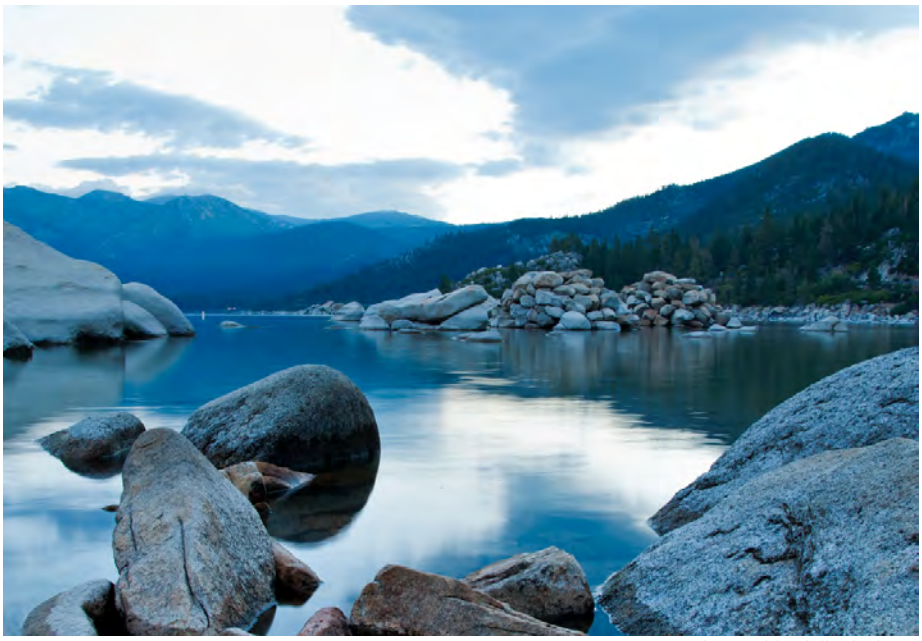
The researchers supported by the SNPLMA Science Program have collected and analyzed data, developed models, built tools, shared knowledge, and learned the challenges of managing complex ecological systems, thereby stimulating new scientific discoveries. This rich body of knowledge has been put to work 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

DRI Desert Research Institute
University of Nevada, Reno
USGS science for a changing world
UCDAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER



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. (Elliot-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).

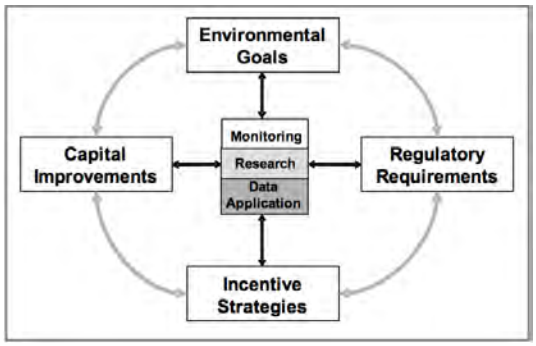
The Tahoe Science Consortium (TSC) was formed through a memorandum of understanding in August 2005 to foster a greater level of collaboration between research organizations and resource management agencies. In 2010 the TSC published the "Integrated science plan for the Lake Tahoe basin: conceptual framework 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

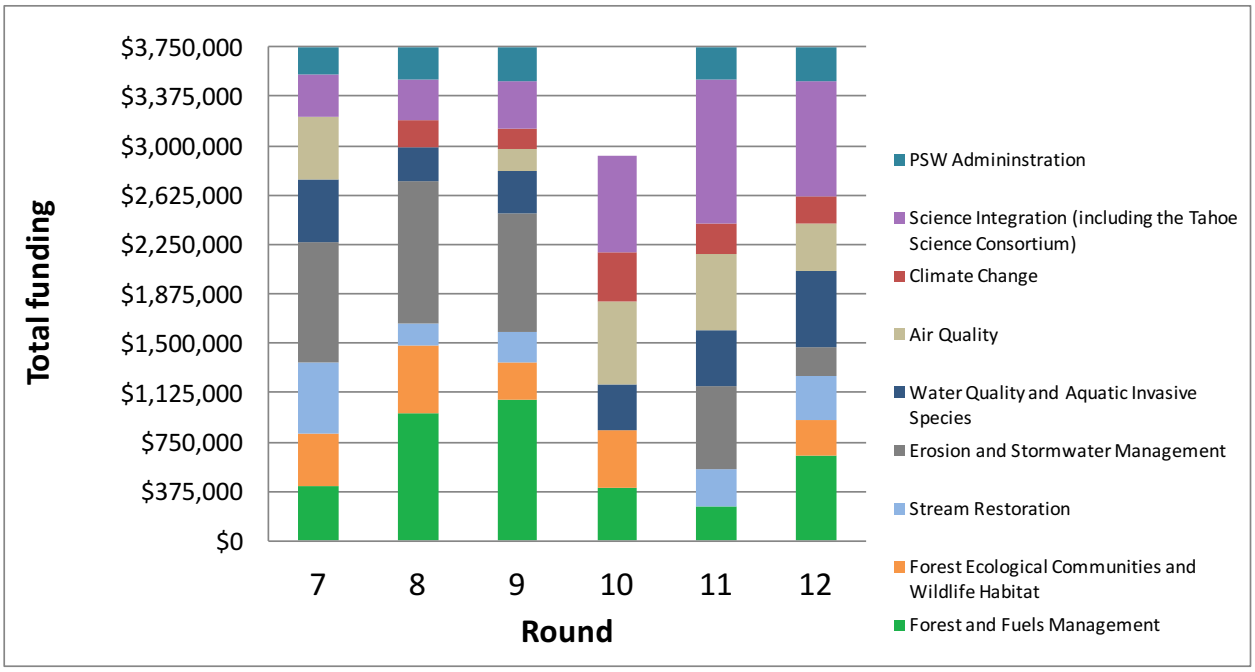
the Tahoe Science Consortium (TSC), conducted a scientific and management agency peer review of submitted proposals. The PSW Program Coordinator and the Tahoe Science Consortium, worked each year with the resource management agencies in the Tahoe Basin to identify research priority theme areas within 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.

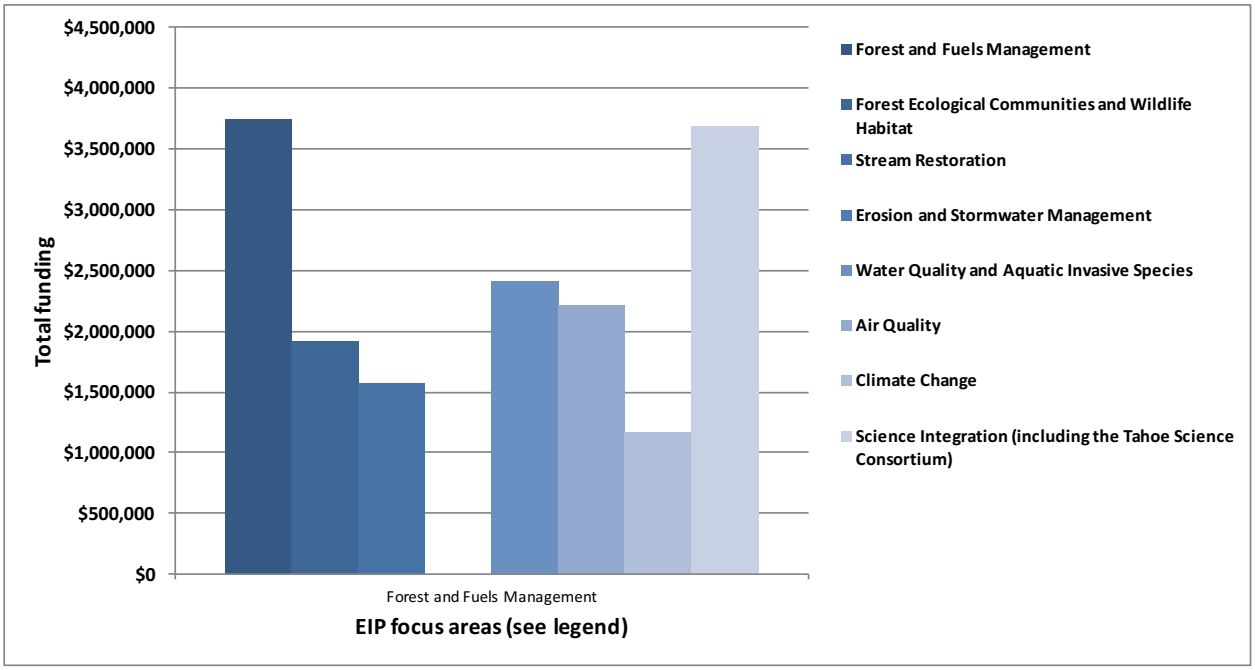
SNPLMA SCIENCE RESEARCH THEMES

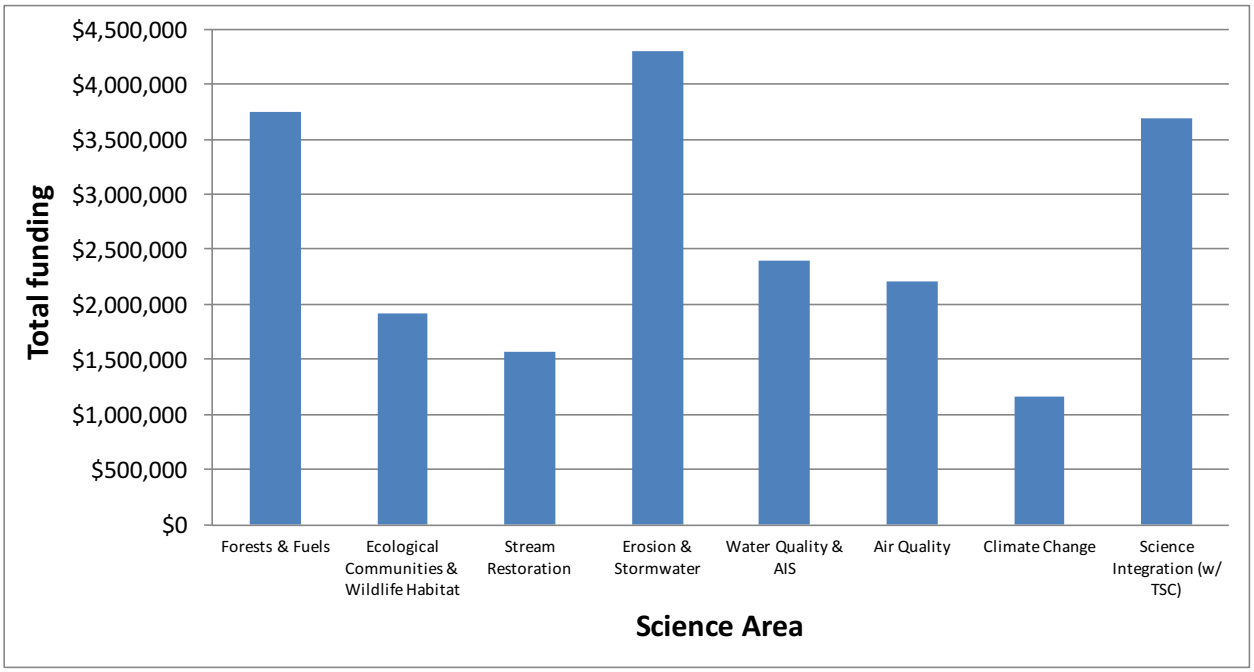
- **Air Quality:** Air pollutants pose threats to health of humans and forests at Lake Tahoe, as well as to the clarity of the lake itself. Research evaluated these impacts and developed appropriate treatments.
- **Climate Change:** Research focused on developing new and expanding tools to inform policymakers 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.



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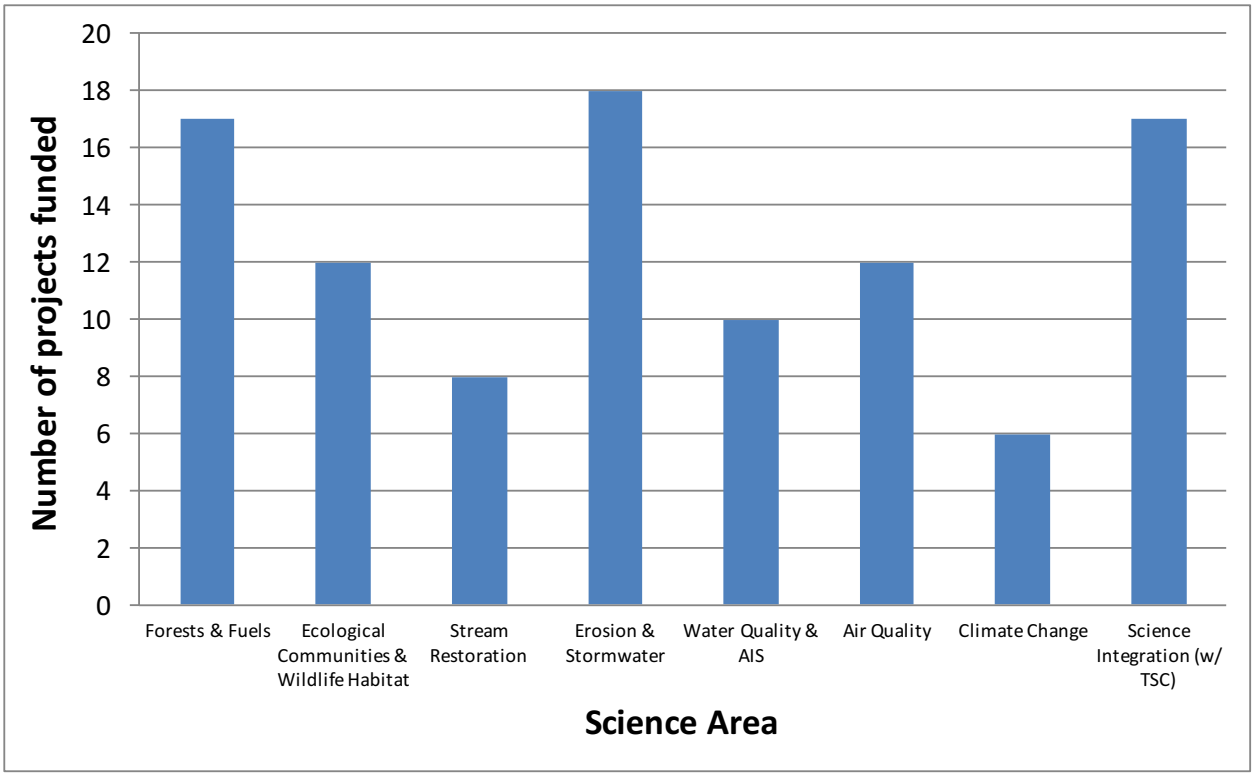
Total funding
Forests & Fuels
Ecological Communities & Wildlife Habitat
Stream Restoration
Erosion & Stormwater
Water Quality & AIS
Air Quality
Climate Change
Science Integration (w/ TSC)
Science Area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Number of projects funded
Forests & Fuels
Ecological Communities & Wildlife Habitat
Stream Restoration
Erosion & Stormwater
Water Quality & AIS
Air Quality
Climate Change
Science Integration (w/ TSC)
Science Area

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 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. 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 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.

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CHAPTER 2: INTERVIEWS WITH BASIN EXECUTIVES

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CHAPTER 3: SYNTHESIS

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Project List

1. Air Quality
P001, Round: 7, Lead Institution: Desert Research Institute
P013, Round: 7, Lead Institution: Desert Research Institute
P041, Round: 9, Lead Institution: Desert Research Institute
P060, Round: 10, Lead Institution: Desert Research Institute
P061, Round: 10, Lead Institution: Desert Research Institute
P062, Round: 10, Lead Institution: Desert Research Institute
P063, Round: 10, Lead Institution: USFS-Pacific Southwest Research Station
P064, Round: 10, Lead Institution: Desert Research Institute
P065, Round: 10, Lead Institution: Desert Research Institute
P075, Round 10, Lead institution, Desert Research Institute
P076, Round 11, Lead Institution, Desert Research Institute
P094, Round 12, Lead Institution, Desert Research Institute
P095, Round: 12, Lead Institution: Desert Research Institute.

2. Climate Change
P028, Round 8, Lead Institution: UC Davis
P029, Round: 8, Lead Institution: Northern Arizona University
P030, Round: 8, Lead Institution: UC Davis
P044, Round: 9, Lead Institution: USFS-Pacific Southwest Research Station
P045, Round: 9, Lead Institution: UC Davis
P049, Round: 10, Lead Institution: Portland State University
P058, Round: 10, Lead Institution: USFS-Pacific Southwest Research Station
P068, Round: 11, Lead Institution: USFS-Pacific Southwest Research Station
P085, Round 12, Lead Institution, Pacific Southwest Research Station
P086, Round 12, Lead Institution, Portland State University

3. Forest Fuels and Vegetation Management
P006, Round: 7, Lead Institution: Desert Research Institute
P008, Round: 7, Lead Institution: Northern Arizona University
P009 A, Round: 7, Lead Institution: USFS-Pacific Southwest Research Station
P009 B, Round: 7, Lead Institution: USFS-Pacific Southwest Research Station
P009 C, Round: 7, Lead Institution: USFS-Pacific Southwest Research Station
P012, Round: 7, Lead Institution: BMP Ecosciences
P017, Round: 8, Lead Institution: USFS-Pacific Southwest Research Station
P018, Round: 8, Lead Institution: USFS-Pacific Northwest Research Station
P019, Round: 8, Lead Institution: Humboldt State University
P020, Round: 8, Lead Institution: Pennsylvania State University
P032, Round: 9, Lead Institution: USFS-Pacific Northwest Research Station
P033, Round: 9, Lead Institution: USFS-Pacific Southwest Research Station
P034, Round: 9, Lead Institution: USFS-Rocky Mountain Research Station
P036, Round: 9, Lead Institution: USFS-Pacific Southwest Research Station
P051, Round: 10, Lead Institution: Humboldt State University
P067, Round: 11, Lead Institution: Integrated Environmental Restoration Services, Inc.
P078, Round: 11, Lead Institution: Spatial Informatics Group, LLC
P083, Round: 12, Lead Institution: USFS-Rocky Mountain Research Station
P091, Round: 12, Lead Institution: Humboldt State University

4. Habitat Improvement
P007-A, Round: 7, Lead Institution: USFS-Pacific Southwest Research Station
P007-B, Round: 7, Lead Institution: USFS-Pacific Southwest Research Station
P022, Round: 8, Lead Institution: Pacific Southwest Research Station
P047, Round: 10, Lead Institution: USFS-Pacific Southwest Research Station
P050, Round: 10, Lead Institution: USFS-Pacific Southwest Research Station
P053-A, Round: 10, Lead Institution: USFS-Pacific Southwest Research Station
P053-B, Round: 10, Lead Institution: USFS-Pacific Southwest Research Station
P059, Round: 10, Lead Institution: California Native Plant Society
P090, Round 12, Lead Institution: University of Nevada-Reno
P092, Round 12, Lead Institution: University of California, Santa Barbara
P099, Round 12, Lead Institution: Consultant

5. Lake Quality
P002, Round 7, Lead Institution: UC Davis
P014, Round: 7, Lead Institution: Desert Research Institute
P015, Round: 7, Lead Institution: UC Davis
P024, Round: 8, Lead Institution: Em Consulting
P027, Round: 8, Lead Institution: UN Reno
P035, Round: 9, Lead Institution: USFS-Pacific Southwest Research Station
P048, Round: 10, Lead Institution: Desert Research Institute
P056, Round: 10, Lead Institution: UC Davis
P069, Round: 11, Lead Institution: UC Davis
P070, Round: 11, Lead Institution: UN Reno
P080, Round: 12, Lead Institution: University of California Davis
P081, Round: 12, Lead Institution: Desert Research Institute
P084, Round: 12, Lead Institution: USDA Forest Service-Rocky Mountain Research Station
P087, Round: 12, Lead Institution: UC Davis Tahoe Environmental Research Center

6. Stormwater Management
P005, Round: 7, Lead Institution: University of Idaho
P010, Round: 7, Lead Institution: USFS-Rocky Mountain Research Station
P011, Round: 7, Lead Institution: Desert Research Institute
P023, Round: 8, Lead Institution: UC Davis
P025, Round: 8, Lead Institution: UC Davis
P026, Round: 8, Lead Institution: Desert Research Institute
P037, Round: 9, Lead Institution: El Dorado County
P038, Round: 9, Lead Institution: 2NDNATURE,LLC
P039, Round: 9, Lead Institution: Integrated Environmental Restoration Services
P040, Round: 9, Lead Institution: UC Davis
P052, Round: 10, Lead Institution: USFS-Rocky Mountain Research Station
P054, Round: 10, Lead Institution: Desert Research Institute
P055, Round: 10, Lead Institution: Integrated Environmental Restoration Services, Inc.
P071, Round: 12, Lead Institution: 2NDNATURE, LLC
P072, Round: 12, Lead Institution: UC Davis
P074, Round: 11, Lead Institution: 2NDNATURE,LLC
P077, Round: 11, Lead Institution: Spatial Informatics Group, LLC
P088, Round: 12, Lead Institution: 2NDNATURE, LLC
P097, Round: 12, Lead Institution: University of California, Tahoe Environmental Research Center

7. Riparian and Stream Restoration
P003, Round: 7, Lead Institution: USDA Agricultural Research Service
P004, Round: 7, Lead Institution: 2NDNATURE, LLC
P021, Round: 8, Lead Institution: 2NDNATURE, LLC
P042, Round: 9, Lead Institution: 2NDNATURE, LLC
P073, Round: 11, Lead Institution: UC Davis
P079, Round: 11, Lead Institution: Humboldt State University
P089, Round: 12, Lead Institution: 2NDNATURE, LLC
P093, Round: 12, Lead Institution: Spatial Informatics Group, LLC

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