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An Integrated Science Plan for the Lake Tahoe Basin: Conceptual Framework and Research Strategies

Editors

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Front cover: Lake Tahoe view from Mount Rose Highway scenic pullout, looking northwest toward Tahoe City, California. Back cover: Lake Tahoe view from Mount Rose Highway scenic pullout, looking south. Both photographs by Peter Goin.

An Integrated Science Plan for the Lake Tahoe Basin: Conceptual Framework and Research Strategies

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Abstract

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An integrated science plan was developed to identify and refine contemporary science information needs for the Lake Tahoe basin ecosystem. The main objectives were to describe a conceptual framework for an integrated science program, and to develop research strategies addressing key uncertainties and information gaps that challenge government agencies in the theme areas of (1) air quality, (2) water quality, (3) soil conservation, (4) ecology and biodiversity, and (5) integrating the social sciences in research planning. Each strategy concludes with a presentation of near-term research priorities. Several factors (e.g., changing agency priorities, funding levels, and the emergence of new issues, new information, or new technologies) can affect the applicability of near-term research priorities. Thus, this science plan is considered a living document. The research priorities are best reviewed and revised regularly to ensure they reflect the changing information needs and evolving priorities of agencies charged with the welfare of the Lake Tahoe basin.

Keywords: Lake Tahoe basin, air quality, water quality, soil conservation, ecology and biodiversity, social sciences.

Summary

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 two decades. Increased attention and funding over the past decade, in particular, have resulted in remarkable progress toward restoration goals, along with considerable information on the strengths and weaknesses of different approaches to addressing the substantial restoration challenges. Restoration has focused not only on Lake Tahoe, but also 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. 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.

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. Yet determining how to proceed with conservation and restoration efforts in the face of limited information remains a central challenge to these efforts. Science (e.g., monitoring, research, and modeling), particularly applied science 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. However, effort is required to organize and describe the science activities needed to inform adaptive management focusing on the conservation and restoration of a complex system. This document presents the results of science community efforts to organize and describe the initial elements of an integrated science plan for the Lake Tahoe basin: a conceptual framework for completing science to inform adaptive management, and focused research strategies covering topic areas of relevance to Tahoe basin management and conservation. Separate, agency-led efforts are underway to develop other essential elements of an integrated science plan including programs for status and trends and effectiveness monitoring, new data applications aimed at converting data into information and knowledge, and the integration of monitoring and applied research efforts.

This science plan was developed to identify and refine science information needs for the Lake Tahoe basin. The main purpose of this effort was to develop a set of research strategies addressing key uncertainties and information gaps that challenge resource management and regulatory agencies. The research needs

identified in these strategies are based on assessments of the issues and information needs that currently confront government agencies and stakeholders working in the basin. The resulting strategies are intended to guide future research efforts and to help maximize the information gained from future science investments. Three common needs drive the recommendations presented in each research strategy:

- Increasing our understanding of the factors and processes driving change.
- Developing the tools and knowledge to predict future conditions in the Lake Tahoe basin and permit comparisons among alternative futures.
- Providing information for future management decisions aimed at conserving and restoring the natural and human environments of the Lake Tahoe basin.

This science plan comprises seven chapters. Chapter 1 examines the need and approach for developing the science plan, and also provides important contextual information. A brief review of past science planning efforts presented in chapter 1 shows that merely producing a science plan is not enough to ensure the establishment of a sustained science program that can deliver useful information covering a diversity of issues. Clear policy direction to obtain and use scientific information is essential, but a deeper level of commitment among all relevant parties will guide progress from planning to implementation. An explicit assumption of this effort is that the agencies charged with responsibility for the welfare of the Lake Tahoe basin will collaborate to establish the funding, resources, and infrastructure necessary for sustained implementation of an applied science program. Brief summaries and recommended priority science needs for each of the six remaining chapters are presented below.

Conceptual Framework for an Integrated Science Plan

Conceptually, the efforts and activities of an integrated science program can be divided among three basic elements: (1) monitoring, (2) empirical research, and (3) data application. To be effective, however, it is recommended that efforts be integrated across all three elements and applied to land and resource management efforts through adaptive management. This is the basis for the conceptual framework presented in chapter 2. The overview conceptual model presented in this chapter will orient readers to the important issues covered in this science plan, the relationships among those issues, and the format of more specific conceptual models presented in each of the research strategies. Near-term priorities for each science activity are as follows:

Monitoring—

Effective monitoring schemes are essential elements in integrated science programs. Monitoring results are often the main source of scientific information in support of adaptive management systems. Monitoring is used to establish baseline conditions, track management activities, and record outcomes. Several monitoring needs were identified in discussions between scientists and managers during the course of developing this science plan. What emerged from those discussions is not a comprehensive list of the monitoring needs for the Lake Tahoe basin; rather, the list represents the recommended highest priority monitoring information needs to be addressed within the next five years.

- Meteorology and climate change:
  - Long-term acquisition of spatially relevant meteorological data on air temperature; wind-speed and direction; humidity; precipitation timing, amount, and type; streamflow; snowpack; and snowmelt are recommended to support environmental studies in all issue areas. The technology to capture these kinds of data has advanced, which allows them to be collected more efficiently at more locations than in the past. These data are fundamental to informing questions about air quality, water quality, soil conservation, ecology and biodiversity, and climate change.
- Air quality:
  - Improve air quality monitoring in the Tahoe basin. The first step is to develop a comprehensive monitoring plan for the basin that addresses the criteria air pollutants (covered under the National Ambient Air Quality Standards) and species affecting human and ecosystem health (including water clarity), along with the required spatial and temporal distribution of the measurements. Once this plan is prepared, sampling locations can be chosen and appropriate air quality sensors can be deployed. Air quality and meteorological monitoring are best integrated to maximize efficiencies and information gain.
- Water quality:
  - Initiate long-term status and trend monitoring of watershed hydrology and pollutant loads entering Lake Tahoe to (1) inform Lake Tahoe total maximum daily load (TMDL) land use and lake clarity models, and other water quality-related management models; (2) evaluate progress in meeting TMDL allocation requirements and other regulatory obligations; and (3) evaluate snowpack and snowmelt trends as they pertain to lake clarity. The Lake Tahoe Interagency Monitoring Program (LTIMP)

partially meets these monitoring needs, but this program has eroded over the last decade owing to funding restrictions. The LTIMP does not include some key pollutant sources (i.e., urban stormwater and road runoff), and it does not include some key water quality constituents that directly affect lake clarity (i.e., particle number and particle size distribution).

  - Develop a regional stormwater quality/best management practices retrofit monitoring program to assess the effects and effectiveness of capital investment projects at the project, watershed, and basinwide scales.

- Soil conservation:
  - Implement a consistent and effective monitoring protocol for key soil properties and conditions that is process-specific, uniform across agencies and contractors, and relies on current technology. Such a monitoring program is considered vital to informing the performance effectiveness of projects affecting soil properties and conditions throughout the Tahoe basin.

- Ecology and biodiversity:
  - Develop a forest fuel reduction monitoring program to assess quantitatively the effects and effectiveness of fuel reduction projects at the project, watershed, and basinwide scales.
  - Establish a long-term, basinwide status and trend monitoring program for terrestrial and aquatic biotic communities. It is recommended that biodiversity monitoring focus on the composition of biotic communities and the distribution, frequency of occurrence, and abundance of associated native and nonnative species using direct measures and indicators to inform environmental thresholds and desired conditions. Monitoring data also could provide a foundation for assessing the effects of climate change on terrestrial and aquatic biota of the Lake Tahoe basin.
  - Initiate status and trends monitoring for select focal species identified in regulations and basin management plans. Integration of focal species monitoring with biodiversity monitoring is recommended to the degree efficiencies can be gained, and to provide reliable estimates of the population parameters targeted in those regulations and plans.

- Social sciences:
  - Establish regular and systematic surveys to document the use of existing recreation resources and to help inform priorities for future facilities.

- Develop and implement infrastructure and common methods to collect basic social and economic data throughout the Lake Tahoe basin. Common sampling methods are recommended to ensure that data can be aggregated and analyzed to assess socioeconomic conditions within the various municipalities, within geographic regions, and throughout the entire basin.
- Develop infrastructure to support the centralized collection, inventory, and distribution of transportation data at regional and basinwide levels.
- Establish a spatially and temporally appropriate monitoring program to allow for the assessment of noise conditions relative to established threshold indicators.

Empirical research—

Research can be defined as a structured process of inquiry that aspires to discover, interpret, and revise our knowledge of facts. Research aims to produce an ever-greater knowledge of events, behaviors, processes, theories, and laws. Research may include laboratory or field experiments, or the development of models. Research is one of the fundamental ways in which science contributes to reducing uncertainties. Research and monitoring operate most effectively together. The single highest priority for research is to establish a stable funding stream to ensure that the level of scientific understanding of the Lake Tahoe basin continues to develop in order to support timely and effective science delivery and inform policy choices and management strategies. Specific, near-term research priorities are presented below for each research strategy included in this science plan.

Data application—

Data application includes analysis, reporting, management, and assessment to accomplish the following objectives (1) manage data and information in ways that ensure their quality and availability; (2) complete analyses that convert data into information that can directly guide management; and (3) share that information with others, such that information promotes knowledge. From a management standpoint, data application to real-world problems may be the most important element of an integrated science program, because it is this activity that provides research and monitoring results in forms that managers can apply directly to management actions, decisions, and policy choices. A dedicated source of funds and resources to support data management, analysis, and reporting together with the identification of responsible entities are recommended to ensure that this element of an integrated science program is accomplished and maintained, and that redundant efforts are eliminated. In the course of developing this science plan, a number of high-priority investments in data applications were identified for completion over the next 5 years.

- **Accomplishments report**: Completed annually, an accomplishments report from the science community would synthesize the results of research and other science projects completed during the previous year; this report can then be combined with updated running totals of administrative outcomes (e.g., dollars spent, number of projects completed) and program outcomes (e.g., acres restored, volume of storm water treated) from the management agencies. The accomplishments report would summarize scientific findings and relate the importance of those findings to ongoing and future management activities and policies. This report also could identify research needs that have emerged as a result of monitoring results, new environmental conditions, or changes in policy or regulation. Information in the accomplishments report will help agencies and scientists track projects completed or in progress, and develop or adjust near-term priorities for capital projects, research, monitoring, and analysis. Information in the report also could provide a snapshot of project outcomes.
- **Central monitoring database**: The value provided by a centralized information depository is manifold; however, a primary goal is to promote the management of both research and monitoring data in a manner that ensures their quality and accessibility. It is recommended that infrastructure be developed and maintained so that basic data and summary information are stored, integrated, and accessible to a diversity of users. The Tahoe Integrated Information Management System (TIIMS) has begun efforts to address the needs associated with this activity, but more work remains.
- **Environmental management knowledge base**: Create an environmental management knowledge base that documents our current understanding of conditions, interactions, threats, and desired outcomes. Use the outputs of this knowledge base to inform science and management priorities and activities. Integrated information systems can meet the array of information needs across institutions and disciplines in an efficient and transparent manner. Knowledge bases with their incumbent conceptual models provide valuable tools for integrated information storage and retrieval. A knowledge base system of environmental quality for Lake Tahoe that serves both management and research would:
    - Provide a transparent basis for evaluating desired conditions
    - Enhance the ability to communicate ideas and outcomes among stakeholders regarding management options at site and landscape scales
    - Facilitate rapid access by decisionmakers to needed information

    - Help prioritize information gaps to be filled, and illustrate the basis of priorities
    - Compare outcomes associated with various management options to help determine priority objectives for specific locations and how to balance objectives across landscapes
    - Serve as a tool to interpret changes in desired conditions over time, based on monitoring data.

- **State of the Lake Tahoe basin report**: Completed every fifth year, a state-of-the-basin report would include a comprehensive synthesis of the research and monitoring that has been completed over the previous 5 years. Results could be framed in terms of an environmental report card for the Lake Tahoe basin, which would evaluate conditions relative to environmental goals and thresholds. This information would be available for use in evaluating and (if necessary) modifying management strategies and implementation programs (i.e., informing the adaptive management process). This report also could alert high-level officials to emerging issues that may require new or alternative policies. The state of the Lake Tahoe Basin report would include the following subject areas:
    - Lake Tahoe
    - Basin watershed condition
    - Basin airshed condition
    - Living resources condition
    - Human environment.

Air Quality

Chapter 3 addresses the fact that air quality in the Lake Tahoe basin is known to affect lake water quality, forest health, and human health. To address these issues and develop a sound scientific approach for mitigating the impacts of atmospheric pollutants, this research strategy provides an update and builds on recent work to understand how changes in air quality affect various aspects of the natural and human environment in the Lake Tahoe basin. This chapter also delineates current knowledge gaps and defines the research needs and strategies to close those gaps. Near-term air quality research priorities are as follows:

- Many of the key chemical species and physical parameters leading to secondary pollutant formation and/or deposition to the lake are not currently measured. Air quality measurements of key species under a range of meteorological conditions and averaging times are recommended following the development of a monitoring plan (see air quality monitoring description above). Parameters to measure include nitrous oxides, ammonia, nitric acid; size-segregated aerosol mass; particle number and size distribution, and aerosol chemical composition. Once these data are obtained, it will be possible to assess atmospheric impacts and air pollutant trends. This information also will provide the necessary input for developing an understanding of the processes controlling air quality and atmospheric deposition in the basin.

- The only model adapted for use in the Tahoe basin is the Lake Tahoe Atmospheric Model, a heuristic model that is based on statistical input. It is recommended that an appropriate air quality model incorporating physical processes be developed that can utilize the full suite of meteorological, chemical, and particulate data. This will enable managers and scientists to better assess air pollutant trends, estimate impacts, and support the development of effective regulations that will assist in meeting air quality and other environmental goals.
- Atmospheric deposition to the lake is the major source of nitrogen and a substantial source of phosphorous and particulate matter. There is, however, significant uncertainty in deposition flux estimates. To reduce this uncertainty, it is recommended that focused studies (i.e., gradient or eddy-correlation studies, along with measurements of key species) be conducted of the sources and pathways of particle deposition to better inform models and restoration efforts.
- Mobile source emissions are a major source of pollutants in the basin. To improve the emissions inventory, it is recommended that Tahoe-specific vehicle model year distributions, emission factors, and activity data be conducted for use in mobile source emission factor models. These results will reduce the uncertainty in the emissions inventory and enable regulators to develop more effective strategies to reduce pollution in the basin.

Water Quality

Lake Tahoe is the most-studied feature of the Tahoe basin ecosystem with regard to water quality. Although a substantial amount of research and monitoring has been accomplished, knowledge gaps and uncertainties still exist, particularly in understanding how watershed restoration efforts influence the long-term water quality of Lake Tahoe. Because water quality restoration efforts in the Tahoe basin are expected to exceed $1 billion, it is critical that we continue to collect and deliver information in an organized fashion. The water quality research strategy in chapter

4 is intended to serve as a road map for discussions with resource managers. The chapter identifies those science projects necessary to help guide water quality restoration efforts and understand related ecosystem processes. Near-term water quality research priorities include:

- Pollutant loading and treatment within the urban landscape:
  - Develop a process-based understanding of sources, transport and loading of fine sediment particles (<20 µm) from different urbanized land uses in the Tahoe basin. Although this includes all features of the urban landscape, roadways appear to be particularly important and deserve focused attention.
  - Quantify the effectiveness of best management practices (BMPs) and other watershed restoration activities on the control of fine sediment particle and nutrient loading to Lake Tahoe. Major load reduction approaches include hydrologic source control (HSC), pollutant source control (PSC) and stormwater treatment (SWT). Although some data have been collected on BMP and restoration effectiveness in removing nutrients and fine sediment, these efforts have been for specific projects and have not provided basinwide process-based evaluations. A comprehensive basinwide watershed-scale evaluation of BMP and erosion control project effectiveness is needed, especially for the Lake Tahoe TMDL program.
  - Conduct focused studies to understand the influence altered urban hydrology has on pollutant pathways and determine how alternative hydrologic designs can enhance load reduction.
  - Investigate longer-term impacts from infiltration of stormwater runoff around the Tahoe basin, particularly as it relates to different soils, land uses, and groundwater quality.
  - Continue efforts to establish a Regional Storm Water Monitoring Program. Key elements of this program include (1) pollutant source monitoring; (2) pollutant reduction monitoring; (3) BMP design, operation, and maintenance monitoring; and (4) data management, analysis, and dissemination. Although this is not research per se, data collected under this program will be used to support research on BMPs and pollutant load reduction.
  - Validate pollutant reduction crediting tools that are currently being developed to track progress in implementing the Lake Tahoe TMDL. At the same time, develop a science-based adaptive management program to guide pollutant load reduction activities.

- Near-shore water quality and aquatic ecology:
    - Additional research is recommended to determine near-shore processes at various temporal and spatial scales. This research will contribute to an integrated database that can be used to determine trends and patterns for integrated, process-driven models. From this information, construct a predictive model to help guide ongoing and future management strategies. Ideally, this model would include features such as nutrient loading, turbidity, localized and lakewide circulation patterns, wave resuspension, periphyton and macrophyte populations, introduced and native species, and recreational uses and activities within the near shore.
    - Develop an aquatic invasive species research program with direct ties to water quality (e.g., threat of invasive species impacts on: [1] native species composition and aquatic food webs, [2] in-lake sources of drinking water, or [3] water quality and stimulation of benthic algal growth in the near shore).
    - Develop analytical approaches for establishing quantitative and realistic water quality standards and environmental thresholds for the near-shore region.

- Erosion and pollutant transport/reduction within the vegetated landscape:
    - Collaboration between researchers and agency representatives is recommended to evaluate fine sediment and nutrient loads resulting from forest fuels reduction activities. A major effort would include quantifying BMP effectiveness for controlling fine sediment and nutrient releases from wildfire, as well as from forest biomass management practices, such as prescribed fire and mechanical treatment.
    - Fully evaluate the benefits and risks from using large areas of the natural landscape (e.g., forests, meadows, flood plains, wetlands) for treatment of urban runoff.

- Water quality modeling:
    - Water quality management in the Tahoe basin has embarked on a pathway that will use science-based models to help guide management into the future. Continued support for the development, calibration, and validation of these models is recommended.
    - Develop appropriate linkages between the landscape, climate, and atmospheric and water quality models to provide more comprehensive assessment of primary and secondary drivers whose effects propagate through the ecosystem.

    - Build decision-support modules for the linked ecosystem models that will support evaluation of effects from larger spatial scales.
- Climate change:
    - Continue to document the effects of climate change on existing and future water quality conditions.
    - Apply predictive scenario testing for evaluating potential effects from climate change within the new and developing management models used for water quality in the Tahoe basin. In particular, models could be used to evaluate basinwide BMP effectiveness and load reduction strategies based on the expected changes to temperature, precipitation, and hydrology.
    - Limnological processes in Lake Tahoe such as stratification, depth of mixing, particle distribution and aggregation, species succession, aquatic habitat based on water temperature, and meteorology are all recommended for reevaluation in light of climate change and possible management response to the impacts of climate change.

Soil Conservation

Today soil conservation conveys a concept much broader than preventing soil erosion and reclaiming eroded lands. Soil conservation strategies go well beyond simply protecting soil from processes of physical erosion to now encompassing the protection and enhancement of overall soil quality and ecology. The intent of chapter 5 is to identify the most pressing management questions, uncertainties, and pertinent research needed to address a wide spectrum of plant-, soil-, and water-related issues in the Lake Tahoe basin. Near-term soil conservation research priorities include:

- Key soil properties and conditions:
    - Further quantify the distribution of various watershed properties such as soil water repellency, biologic and inorganic nutrient pools, infiltrability, and water balance parameters on a larger spatial scale. The impact of natural and anthropogenic activities such as development (impervious vs. pervious), forest management (fire suppression vs. mechanical or prescribed fire biomass reduction), vegetation (native vs. nonnative species), restoration (physical and chemical amendments vs. reduced fertilization), and features that have disrupted natural littoral and eolian processes on soil health at the watershed scale (including the intervening zones) remains poorly understood.

- Quantitatively assess which restoration methods are most effective in controlling event-based runoff and the transport and equilibrium chemistry of fine particles most associated with nutrient and sediment loading. Project success and longevity would be evaluated relative to the sustainability of hydrologic function, productivity, and erosion control over time.
- Characterize to the extent feasible and quantify where possible historical vs. current and natural vs. anthropogenic induced declines in soil status and resulting soil loss at the watershed scale. Research on soils in natural as well as disturbed settings is recommended whenever possible, with sites established to measure soil conservation parameters including inputs such as plant-soil nutrient fluxes through litter-fall, crown-wash, and root turnover as well as losses from erosion, leaching, runoff, wind, or fire. Research would focus on sites where a suitable control portion is available, especially if event (e.g., prewildfire or pretreatment) data are available.

***Knowledge advancement potential*—**The fate of Sierran ecosystems in a changing environment will have a direct impact on soil health, fire hazard, biomass mitigation strategies, erosion, and water quality. Manipulative research projects that include random assignment of treatments and replication are challenging to perform in the Tahoe basin. And yet a crucial research need is to identify and quantify key indicator parameters in a variety of historical and current ecological settings, under various manipulations, and over time. In such cases where robust experiments are possible, restoration methods that are most effective in controlling runoff and transport of fine particles, as well as those most effective in the reduction of nutrient discharge loading and its direct effect on water clarity can be better assessed. This would allow a more complete understanding of the environmental factors (i.e., temperature, moisture, vegetation, and litter) that determine the formation, persistence, and dissipation of seasonal and long-term effects on runoff water quality and erosion. In this context, similar slope stabilization, infiltration, revegetation, or sedimentation techniques could be tested against each other in similar and divergent environments as a means of ascertaining why some work better than others in one locale vs. another. Research focused on the identification, monitoring, evaluation, tracking and adaptive management of individual and collective BMP systems, and linking them to geographic information system layers at the watershed and basin scale would go a long way toward addressing the concerns of stakeholders and agencies alike. Being able to track and revisit BMP strategies would further facilitate true adaptive management.

- Development and application of predictive models as related to soil conservation:
    - Successful model application dictates the need for site-specific parameterization and model calibration. Model use and application can then become more consistent, and interpretive assessment more uniform among agencies basinwide. Research and monitoring protocols are recommended to provide relevant information for predictive model development, improvement, calibration, and field validation specific to the Lake Tahoe basin. Prioritization is recommended to determine which soil, vegetation, and hydrologic parameters are important; what should be measured; and what information is needed to parameterize and calibrate the models.
    - Develop a spatially explicit water balance, nutrient cycling, and erosion potential model to better understand current sediment and nutrient transport at the watershed scale and under conditions of potential changes in hydrologic and soil parameters. Further studies of the role of hydrophobic soils are recommended to determine the spatial distribution of recharge areas vs. those that are overland flow generating, and their influence on soil erosion model output estimates. A prioritization of which parameters are important, what should be measured, and what information is needed to parameterize and calibrate the models is recommended.
    - Develop a better understanding of how various factors or stressors change soil status in Tahoe basin watersheds to assist forest managers in preparing management plans and make predictions about ecosystem response to natural (e.g., fire, insect attack, drought, or erosion) and anthropogenic (e.g., air pollution, harvesting, development, or climate change) perturbations. For example, a comprehensive assessment of the effects of both wildfire and prescribed fire and postfire vegetation on long-term response in biological and physicochemical soil parameters is needed to better understand fire and its role in restoration ecology.

***Knowledge advancement potential*—**Because regulatory policy is often based on the subjective judgment of "risk potential" rather than on a sound quantitative decision support system, the application of predictive models can provide important tools to understanding and estimating the potential outcome of management strategies and programs. Successful model application, however, is accomplished through site-specific parameterization and model calibration. Establishing the means for prioritization of which ecosystem parameters are important, what should be measured, and what information is needed to parameterize and calibrate the models is recommended. In the event that the current models are not adequate predictors, appropriate modifications or adjustments are needed to make the existing models more functional. If this is not an option, starting from scratch and developing a new model that is simple, accurate, and appropriate for the Tahoe basin may be necessary. Model use and predictive application is recommended to enable consistency among agencies basinwide wherein the acquisition of a more robust quantitative database could provide the foundation for policies of future management strategies.

- Effects of climate change as related to soil conservation:
  - There is concern that anthropogenic activities over the last century have resulted in nontypical ecosystem structure throughout the basin of which the distribution, character, variability, and potential response to climate change have not been evaluated. Consequently, strategic efforts directed toward long-term site restoration in response to a quasi-natural state will be the more likely scenario. Quantitative assessment of what we can and cannot hope to accomplish on a long-term basis is recommended.
  - More comprehensive localized point source precipitation, surface runoff, erosion, and nutrient transport data is recommended to quantify potential discharge loads as a function of amount, type (snow vs. rainfall), frequency, and precipitation intensity. It is recommended that research and monitoring projects be designed to address potential changes in hydrologic parameters as a result of climate change.
  - Investigate the implications of climate change on slope stability parameters. It is recommended that surface soil stability, compaction, soil structure and aggregate stability, infiltrability and runoff, and potential for mass wasting all be tested under scenarios of different temperature and moisture regimes to estimate the potential effects of climate change on soil erosion in the Lake Tahoe basin.

Knowledge advancement potential—The implications associated with climate change cannot be ignored. Predictions for changes in precipitation quantity and intensity are quite variable for the Sierra Nevada. One scenario is that precipitation will increase in intensity leading to large-scale flooding. Another is that the Lake Tahoe area will be subject to overall warmer temperatures and more evapotranspiration, while increased precipitation will be more common farther to the north. There is general agreement, however, that with warmer temperatures snow elevation levels will be higher and accumulation likely lower, which will lead to longer fire seasons. Examination of management strategies involving biomass reduction, drainage control, and practices to diminish sediment and nutrient transport to Lake Tahoe is recommended in the context of shifting the quality and amount of hydrologic input. Such an examination will likely necessitate new approaches. It is recommended that future planning for the production of resilient, spatially heterogeneous and diverse forest structure be designed to account for potential changes in hydrologic function in response to different moisture regimes to determine what the ultimate effects of climate change could be on management protocols for sensitive areas at the watershed and local scales.

- Policy implications and adaptive management strategies as related to soil conservation:
    - Monitor and study established environmental thresholds for attainment and performance effectiveness. It is recommended that regulatory agencies and land managers develop a protocol for periodic review, verification, and update of processes, quantitative thresholds, and policy relevance. More research and monitoring of existing regulatory programs is recommended, such that their overall effectiveness and applicability can be more quantitatively assessed relative to their actual reduction of nutrient and sediment loading to the lake, and the subsequent enhancement of water clarity. Develop a basinwide protocol for "standard methods of ecological measurement and monitoring in the Tahoe basin."
    - Continued research that addresses critical natural resource issues and critical management questions relevant to soil conservation in the Tahoe Basin is essential. This exercise can begin by identifying a list of agency-specific management questions pertinent to soil conservation relative to key soil properties and conditions of interest. For example, what are the appropriate management strategies that maximize defensible space (measures taken to protect homes from wildfire, e.g., removing vegetation), but at the same time function to minimize erosion and the degradation of runoff water quality? It is then important to take advantage of unique opportunities and small-scale experimental field trials to quantitatively evaluate potential impacts. To ensure credibility and applicability, such research would make every effort to be scientifically defensible, applicable to the Tahoe basin or similar ecological settings, and publishable in peer-reviewed journals.
    - Restoration and BMP strategies are generally implemented to mitigate known adverse impacts from either natural events or anthropogenic

activities. Choosing the most effective strategy therefore necessitates a thorough knowledge of the mitigation objective, process mechanics, both short- and long-term functionality, and whether or not these components will differ depending on location within a given watershed or the Tahoe basin in general. Performance evaluation is commonly assessed on a collective (e.g., projectwide) rather than individual (e.g., specific management activity) process basis. Complete evaluation of which strategies are truly the most effective in meeting specific restoration objectives would require testing each management activity against one another as well as assessing their cumulative effects. Management strategies implemented for one purpose (e.g., defensible space) may or may not have an effect on other issues of concern and ascertaining why some work better than others in one locale vs. another (or not at all) is a critical issue.

Knowledge advancement potential—If greater confidence in performance effectiveness can be developed, consistency will likely follow. With new technology comes the opportunity for innovative soil conservation strategies that could alter or refine historical threshold values. In the past, technological advancement and expansion of the knowledge base was much slower. Today, it is not unusual for substantial new advancements to take place on a 5-year rather than a 25-year cycle. Key to the success of any such approach, however, is the development of a consistent and effective monitoring protocol for key soil properties and conditions that is current, process-specific, and uniform across agencies and contractors. Hence, research is recommended to develop a standard protocol for ecological measurement and monitoring in the Lake Tahoe basin, which includes variable levels of intensity that can be applied to different types and scale of projects. In its absence, implementers and agencies frequently employ different techniques in attempting to evaluate the performance effectiveness of similar soil conservation activities. Comparative interpretive assessment is then difficult to impossible. Furthermore, evaluating which conservation and/or restoration methods are most effective is recommended in the context of a more comprehensive framework wherein each on-the-ground management strategy could be tested against one another in similar and divergent environments. Therein lay key opportunities where new and unique soil conservation strategies could be explored. Finally, agency representatives can clearly identify agency-specific areas of concern, and then work with scientists and implementers to articulate the respective critical soil conservation issues. This would greatly assist in the development and design of successful monitoring, opportunistic, and/or experimental research programs that generate data and information directly applicable to agency needs.

Ecology and Biodiversity

The integrity of animal and plant communities serves as a critical measure of the effectiveness of implementation policies designed to protect and restore ecosystem processes in the Lake Tahoe basin. The conservation of plants and animals in the Tahoe basin is wholly dependent on the conservation of its terrestrial and aquatic ecosystems. Thus, the research agenda for biological diversity and ecological function is based on investigations that integrate data collection efforts across scientific disciplines to maximize the recovery and persistence of biological diversity. The Ecology and Biodiversity research strategy in chapter 6 highlights the interactions between native species and communities, and natural and human-caused stressors that present the greatest ecological and social risk, and for which research can reduce uncertainties presenting barriers to more effective management. Near-term ecology and biodiversity research priorities include:

- **Old-growth and landscape resilience**: The ultimate objective of forest management is to restore and maintain forest health and resilience such that forests and their associated biota are able to maintain the full range of functions, their native biological diversity, and continues to perform the ecosystem services upon which human communities in the basin depend. The primary uncertainty limiting management's ability to meet this objective is a clear understanding of what environmental conditions to create, and when and where to create them. Specific questions pertain to the historical amount and distribution of forest structural conditions, associated plant and animal species composition, and how to translate historical conditions into target conditions for the future that will enable forested ecosystems to adapt to future environmental stressors without the loss of function or biological diversity. Old forests are of particular concern and interest, since despite the maturity of existing forests, it is apparent that extant forests have lost ecological complexity associated with old forests, and therefore species and functions restricted to old forests are rare and most at risk from uninformed management. Finally, robust measures of forest biological diversity and resilience are recommended to enable simple and effective tracking of management progress and success.

- **Fire regime**: One of the greatest ecological risks associated with fire is the uncertainty associated with the effects of fuel reduction treatments—both their effectiveness in changing fire behavior, and the consequences of treatment effects on other ecological conditions, such as biological diversity and forest ecosystem resilience. The near-term research priorities pertain to addressing risks and uncertainties posed by current management activities, which target fuel reduction treatments on thousands of acres without an indepth understanding of the ecological consequences. Therefore, near-term research priorities include improving the understanding of the effects of various types and intensities of treatments on the spectrum of ecosystem management objectives, including but not restricted to fire behavior. Of primary concern is the fate of terrestrial species and processes, as they are directly affected by forest conditions. It would be most efficient to develop and test silvicultural prescriptions in the course of addressing near-term research priorities, as opposed to after ecological risks are more clearly understood. Once the primary ecological objectives at risk as a function of reducing the threat of catastrophic wildfire are understood, it is important to develop simple and informative measures of their status for long-term monitoring.

- **Special communities**: The conservation and restoration of special communities in the basin all rely on similar information: (1) maps of current location and condition throughout the basin, (2) reference conditions based on historical data and other relevant data sources, (3) evaluation of the effectiveness of restoration approaches, and (4) the development of performance measures to assess status and restoration effects. A few unique information needs are associated with individual special communities. In aspen communities, techniques for converting conifer-encroached stands back to aspen-dominated habitats is a primary information need. Fens and meadows are under an unknown level of threat from various human activities. The current status of marshes is basic information that is lacking. Finally, detailed information on genetic and environmental sensitivities of Tahoe yellow cress are needed to aid population restoration efforts of this endemic species.
- **Aquatic ecosystems**: The emphasis of aquatic ecosystem research is on conservation and restoration of vertebrate biota in Lake Tahoe and the conservation of species in the rich array of other aquatic ecosystems around the basin. In Lake Tahoe, the uncertainties with the greatest potential impact on management are those associated with the interactions between nonnative and native plant and animal species. These interactions have potential consequences for biodiversity, lake clarity, and near-shore aesthetics. Research on measures to control established nonnative species is recommended. This research is best pursued through an adaptive management approach, where

information from scientific assessments of pilot projects is used to guide longer-term management strategies. Restoration of native fishes in Lake Tahoe presents a steep challenge, and information on the ecological interactions is key to making progress. The other aquatic ecosystems are in need of more basic information, namely the status of vertebrate populations and communities, and factors limiting the ability of sites to support native species. Once these things are better understood, the development of efficient measures that can be used to track conditions over time is recommended.

- **Urban ecosystems**: Research recently conducted in the Lake Tahoe basin identified substantial and unexpected effects of urban development and human activities on various elements of biological diversity. The patterns observed varied by taxonomic group (i.e., birds, small mammals, mammalian carnivores, ants, and plants), among species (some were sensitive while others were not), and by type of human disturbance (e.g., habitat loss, habitat alteration, habitat enrichment, or different types of human activities). The results of that work suggest the need to understand mechanisms of key responses such that development and management can be conducted in a manner that minimizes and/or mitigates negative effects on biological diversity. Questions of particular priority pertain to better understanding thresholds of change in habitat loss, habitat alteration, or habitat use indicated by past research, specifically changes observed at 30 to 40 percent development. Above this threshold, it is unclear what happens, but sites likely become sinks, traps, or abandoned by a wide array of species. In addition to site-scale mechanisms, landscape-wide modeling is recommended to understand the implications of existing results and facilitate the rapid evaluation of the implications of new information on landscape design and management priorities. Finally, as in other subthemes, as vulnerable species and target ecological objectives in more urban areas are clarified, development and testing of effective measures are recommended for use in monitoring and assessment.
- **Recreation**: Recreational uses have been identified to have substantial effects on the occupancy and abundance of many and diverse species based on multiple research projects. Alternatively, species thought to be impacted by certain recreational activities (e.g., effects of off-highway vehicle use on occurrence of American marten) did not exhibit negative responses. Specific uncertainties in the Tahoe basin pertain to the effects of dogs on retaining biological diversity in more urban environments, and the effects

of ski areas on montane obligates, namely American marten. Although population sizes of northern goshawk and bald eagle are limited, their sensitivity to the presence of people has important implications for the management of events and on-going recreational uses in the vicinity of known use sites. Effective measures of use and effects are lacking and their development will be important for monitoring.

- **Climate change**: Climate change is perhaps the ultimate source of uncertainty, and arguably poses a high environmental and economic risk. Under such circumstances, information needs start at the basics. In the case of ecological elements and processes, this translates to applying existing and new information to modeling potential responses—plant and animal ranges and associated effects on population sizes, species interactions, and ecological services—to predicted or potential climate change and associated broad-scale environmental responses. It is important for modeling to be conducted in the basin, as opposed to relying on modeling outside the basin or at larger scales because detailed information will be needed to inform how management can respond to potential threats. As with all other subtheme areas, as information is accrued, effective and reliable measures of key population and community metrics are recommended to be developed for monitoring.

Integrating the Social Sciences in Research Planning

The evaluation of social science research needs was included in this science plan to explicitly recognize that the processes underlying environmental degradation, as well as their conservation and recovery, are fundamentally based on human decisionmaking. Effective conservation and restoration policies rely on a well-grounded understanding of human behavior, the interaction of social and natural processes, and linking information from the social sciences to decisionmaking. The goals of the research strategy in chapter 7 are to (1) identify social science data and research needs for management objectives that are not directly environmental, (2) describe the research needs necessary to improve policy design and implementation for managing environmental conditions, and (3) develop a framework for prioritizing social science research needs in areas that focus on the interaction between the human and natural environments. Near-term recommended social sciences research priorities include:

- Recreation:
  - Develop a consistent, basinwide 3-year recreational survey cycle to track seasonal changes, crowding behavior, and long-term patterns of recreational activity change.

    - Statistical analysis of the factors associated with recreational quality in order to determine visitor preference and direct future infrastructure investment.
    - Analysis of recreational capacity in terms of ecological impact and infrastructure at both the specific site level and basinwide.

- Transportation:
    - Collection and analysis of current bicycle use data in order to determine road and trail use, and to determine adequacy of current bicycle routes and the potential for use as an alternative transportation mode.
    - Collection and analysis of public transit ridership data to and within the basin.
    - Centralized collection, inventory and distribution of transportation data at a basin level.
    - Develop a centralized Web-based information source about all basin-level public transportation systems.
    - Analysis of effective policy options for addressing parking in high-impact areas.
    - Predictive modeling on vehicle use, transit ridership, demographics, and linkages between economic health and emergency preparedness.

- Economics:
    - Increased data collection and analysis of housing trends at the community and basin level.
    - Increased data collection and analysis of employment trends at the community and basin level.
    - Increased data collection and analysis of tourism trends at the community and basin level.
    - Estimate affordable housing availability for year-round residents, public sector employees and workers in service and hospitality industry.
    - Evaluation, prioritization and coordination of Tahoe basin environmental improvement projects.
    - Development of community sustainability and well-being indicators.
    - Program evaluation of the effectiveness and cost-efficiency of existing policies.
    - Analysis of effective policy options for increasing affordable housing options.

- Scenic resources:
  - Examination of public perceptions of the scenic quality of natural and built environments.
  - Development of new TRPA Scenic Quality indicators.
  - Analysis of effective policy options for increasing building design diversity.
  - Analysis of effective policy options for improving overall scenic quality.
- Noise:
  - Increasing spatial and temporal monitoring to capture single-event noise levels.
  - Research on public acceptability and perception of current noise levels.
- Collaborative information management:
  - Information synthesis and knowledge-sharing about effective approaches for recreation infrastructure, and about mitigating environmental impacts in other alpine resort communities.
- Tahoe basin community management:
  - Consolidation of existing information, design of new collection instruments, and examination of methods for upscaling data to the Tahoe basin level and/or downscaling to the community level.
- Program design, policy evaluation, and policy process evaluation:
  - Develop policy conflict resolution mechanisms for programs working at cross purposes. Target research on policy evaluation and program design of costly programs.
- Fire and natural hazards:
  - Develop a basinwide emergency communications network, implement reforms to fuels management on private parcels, and begin extensive inter-agency review of basinwide coordination of fuels management.
- Climate change:
  - Develop predictive models of climate change impacts on the Tahoe environment. Focus on outputs that can communicate potential outcomes to local government, the general public, and agency personnel.

Those reading multiple chapters of this science plan will soon realize the research strategies differ in scope and breadth. These differences are due to the diversity of management issues that exist among the theme areas and to variations in the state of knowledge. Past efforts to obtain knowledge in each of the theme areas have not been equal. This means different levels of investment are needed to progress from this point forward. For example, we now have an operating Lake Tahoe clarity model that can be used to predict future conditions and analyze the effects of alternative management strategies aimed at improving Lake Tahoe water clarity. Thus, some research needs identified in the "Water Quality" research strategy will include recommendations to improve the validity and predictive capabilities of this model. In contrast, we are struggling to obtain and aggregate basic regional socioeconomic data for the Lake Tahoe basin that can inform us about trends in the human environment. These differences in knowledge base compromise our ability to understand and quantify interactions among resources, habitats, processes, and stressors. Continued commitment of future resources and funding across all five theme areas is recommended as the best strategy to even out the disparity in our knowledge base.

The near-term research priorities presented in the research strategies and above are based on the input of agency and stakeholder representatives received during subtheme identification, as well as the best professional judgment of the authors. Several factors (e.g., changing agency priorities, funding levels, the emergence of new issues or new information, and the availability of new technologies) can simultaneously affect the applicability of chosen research priorities. Thus, the selected priorities are best reviewed and revised regularly to ensure the current science needs and priorities reflect the changing information needs and evolving priorities of agencies charged with the welfare of the Lake Tahoe basin. For this reason, this science plan is considered a living document. The agency, stakeholder, and science community representatives active in the Lake Tahoe basin all share the continuing responsibility to revisit and update this document in the future.

Each research strategy is meant to serve as a stand-alone document. We think this organizational approach is most useful because government agency representatives and stakeholders often seek issue-specific information. This organizational approach also should aid those agencies dealing with multiple theme areas, because they are organized in distinct programs that generally coincide with the theme areas. However, this stand-alone approach affected the way cross-cutting issues are treated. In preparing this science plan, several issues that cut across multiple theme areas were identified:

- Quantification of key environmental indicators
- Model application and development
- Adaptive management functionality and effectiveness
- Research and policy implementation
- Effects of climate change
- Effects of fire

The stand-alone organization of the research strategies means information on cross-cutting issues is presented in multiple chapters. For example, those wanting to learn about the research recommended to improve our understanding of climate change effects will need to review the appropriate section in several research strategies. Although this organizational approach means the reader will have to do more work to synthesize information on cross-cutting issues, this approach does allow for better integration of cross-cutting issues within each research strategy.

The target audience for information presented in this document includes those individuals within government agencies and the stakeholder community that have a role in the protection and management of the Lake Tahoe basin ecosystem. We hope this document is of particular use to those individuals who find themselves responsible for deciding if and how new funding for science should be allocated.

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