Chapter 2: Conceptual Framework for an Integrated Science Program[1]

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Introduction

Uncertainties always accompany the best efforts of environmental and resource managers. They are inescapable. Accordingly, many managers seek guidance from science to enhance the likelihood that their management actions and restoration efforts will meet desired objectives. Science to support land and resource management applies principles and practices in an integrated fashion to acquire objective and verifiable information to fill knowledge gaps, thereby reducing uncertainties. Scientific principles and practices employed to generate new information include the formulation of explicit hypotheses, application of the scientific method (the approach for designing experiments to test hypotheses), selection of methods to avoid bias (applying techniques that ensure independence and randomness), utilization of statistical analyses to transform data into information, and development of tools to transform information into knowledge. To support the information needs of land and resource managers and regulatory agencies, scientific activities are best organized and implemented through an integrated science program.

Conceptually, the activities carried out under an integrated science program that can serve to inform the management, conservation, and restoration of natural resources include three basic components—monitoring, research, and data application. Monitoring is used to establish baseline conditions, track management activities, and record outcomes. Empirical research seeks to elucidate cause-effect relationships, and in so doing enhances the understanding of ecosystem interactions and the effects of management actions in the context of natural environmental variation and anthropogenic influences. Data application includes a broad array of activities associated with handling data, including analysis and interpretation; modeling; data management; information dissemination; and knowledge application for assessment, evaluation, and decision support. This chapter provides more detail—including near-term priorities—for each component of an integrated

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[1] Citation for this chapter: Manley, P.N.; Murphy, D.D.; Hymanson, Z.P. 2009. Conceptual framework for an integrated science program. In: Hymanson, Z.P.; Collopy, M.W., eds. An integrated science plan for the Lake Tahoe basin: conceptual framework and research strategies. Gen. Tech. Rep. PSW-GTR-226. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 19–35. Chapter 2.

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science program. These descriptions are followed by a discussion of adaptive management, which describes how an integrated science program can help to inform and guide the management of complex systems. The chapter concludes with a section that introduces the reader to conceptual models: a tool used throughout this science plan.

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 a form of research and, like research, is best implemented in an experimental framework that differentiates between alternative explanations of how managed resources respond to environmental change. Monitoring has been defined as the "measurement of environmental characteristics over an extended period of time to determine status or trends in some aspect of environmental quality" (Suter 1993). In the Lake Tahoe Watershed Assessment, Manley et al. (2000) provided an expanded definition of monitoring, describing three forms of monitoring:

- **Implementation monitoring**—The monitoring of management actions in relation to planned activities. This form of monitoring catalogues the completion of projects or activities. It also documents compliance with environmental regulations and mitigation obligations in project implementation.
- **Effectiveness monitoring**—The monitoring of the effectiveness of management practices and actions in achieving desired conditions. This type of monitoring is recommended as an integral part of capital improvement, regulatory, and incentive programs (fig. 2.1), such that the outcomes of individual or combined effects of actions taken under various programs are known. Effectiveness monitoring does not address the uncertainties that are associated with techniques or designs, nor does it attempt to compare the relative effectiveness of different techniques or designs—these questions reside in the realm of empirical research. Integration of effectiveness monitoring and research to address priority uncertainties is the efficient and desired approach.

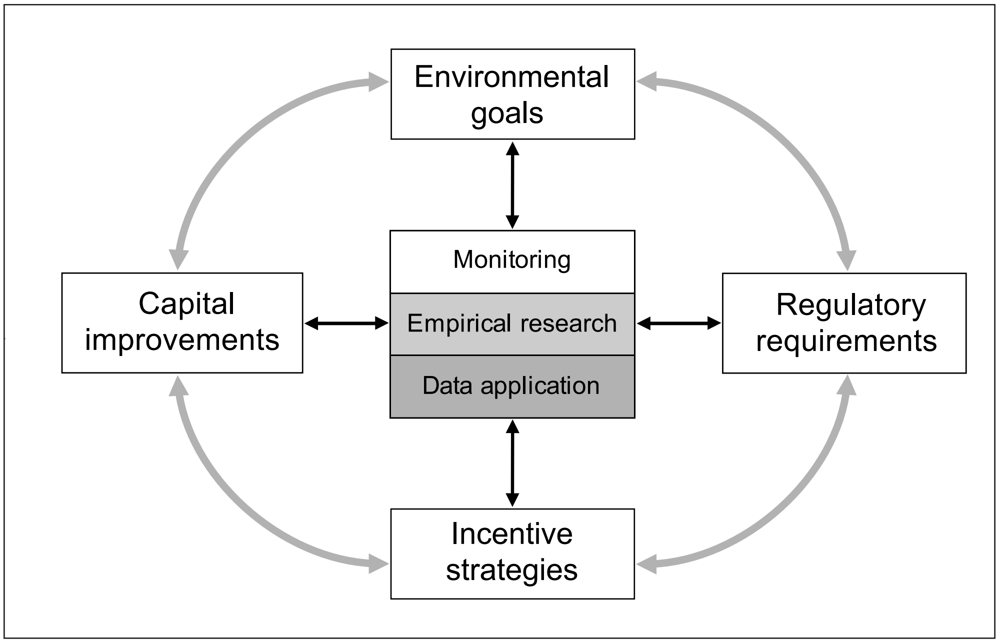

Figure 2.1—Illustration of the dynamic interface between an integrated science program (tri-shaded box) and the three types of implementation programs used to achieve and sustain the environmental thresholds or goals for the Lake Tahoe basin. The arrows indicate the pathways of information transfer and communication.

- **Status and trend monitoring**—The monitoring of the status and trends of resources, habitats, and their agents of change. This is the principal form of data gathering that informs management about overall environmental and resource conditions relative to established environmental objectives and thresholds. Typically, this type of monitoring serves to track the condition of indicators that have been selected to represent a set of conditions pertinent to environmental objectives.

Each of these types of monitoring is necessary to provide information of relevance to the management and conservation of habitats and resources in the Lake Tahoe basin (fig. 2.2). Integrated and coordinated monitoring programs are recommended to provide to agency managers and decisionmakers information about how implementation programs are affecting conditions in the Lake Tahoe basin. A multifaceted approach involves a dedicated and sustained effort to collect and analyze monitoring data on environmental and resource conditions at multiple spatial scales (project, watershed, and basin), in order to assess the effects of implementation programs, and progress toward achieving and sustaining environmental thresholds. Monitoring programs are best established in a coordinated and integrated framework so that information gains are maximized, while monitoring costs are minimized.

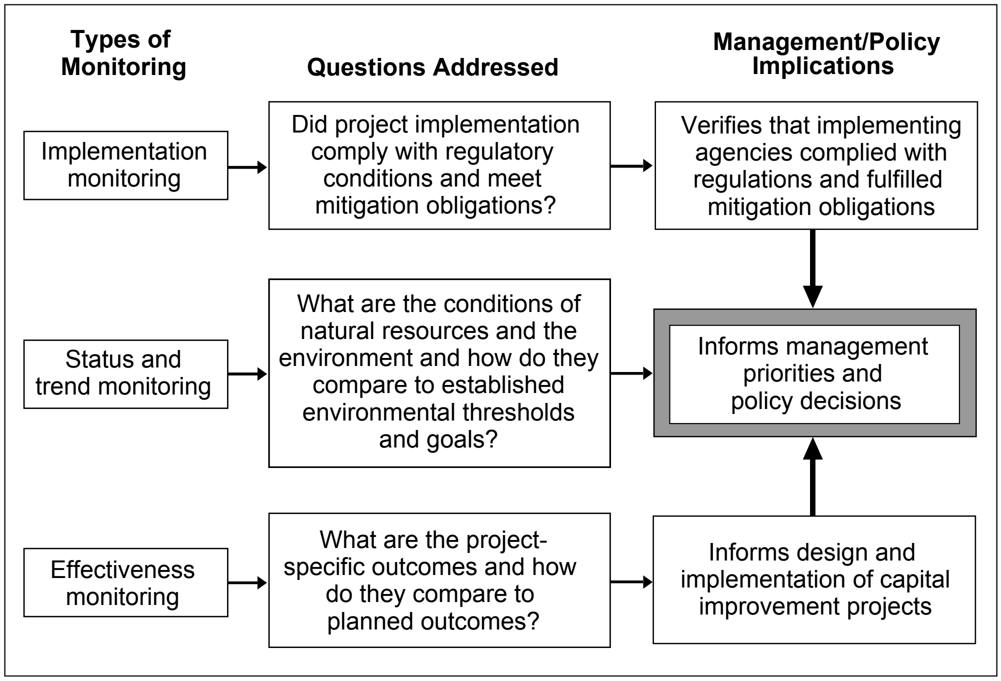

Figure 2.2—A conceptual diagram showing the relationships among various types of monitoring and the ways in which those types of monitoring can provide information to managers and policymakers. The questions also indicate how various types of monitoring provide information at the project, program, or, in the case of thresholds, basinwide scales.

Monitoring Priorities

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 priority monitoring information needs within the next 5 years. A full array of important monitoring questions still awaits articulation by managers, ideally in collaboration with scientists. The allocation of resources to address monitoring information needs is outside the scope of the science plan, but will be essential to program success.

- **Meteorology and climate change.** Long-term, spatially relevant meteorological data on air temperature; wind speed and direction; humidity; timing; amount, and type of precipitation; annual hydrograph; 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, soil conservation, water quality, ecology, biodiversity, and climate change.

- **Air quality.** Improving Tahoe basin air quality monitoring is recommended by developing a comprehensive monitoring plan that addresses the criteria pollutants covered under the National Ambient Air Quality Standards (NAAQS) and those that impact human and ecosystem health (including water clarity) in an appropriate spatial and temporal framework. It is recommended that data collection use new technologies, including remote sensing and biomarkers. Once a plan is prepared, sampling locations can be chosen and appropriate air quality sensors can be deployed. Air quality and meteorological sensors would benefit from co-location 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). A regional stormwater quality/ best management practice (BMP) retrofit monitoring program is needed to assess the effects and effectiveness of capital investment projects at the project, watershed, and basin scales.
- **Soil conservation.** Develop and implement consistent and effective monitoring protocols for key soil properties and conditions. Monitoring protocols that are current, process-specific, and uniform across agencies and contractors would maximize effectiveness. Such a monitoring program is vital to informing the performance effectiveness of projects affecting soil properties and conditions throughout the Tahoe basin.
- **Ecology and biodiversity.** Develop a forest fuels reduction monitoring program to assess quantitatively the effects and effectiveness of fuels reduction projects at project, watershed, and basin scales. Establish a long-term, basin-wide 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 native and nonnative species using direct measures and indicators to inform environmental thresholds and desired conditions. Monitoring data can provide a foundation for assessing the effects of climate change on terrestrial and aquatic biota of the Lake Tahoe basin. Status and trends monitoring are recommended for select focal species identified in regulations and basin management plans. Integration of focal species monitoring is recommended with biodiversity monitoring to the degree efficiencies can be gained, to provide reliable estimates of the population parameters targeted in those regulations and plans.

- **Social sciences.** Regular and systematic surveys are recommended to document the use of existing recreation resources and to help inform priorities for future facilities. It is recommended that those surveys be based on common methods so that data can be aggregated among sites to obtain regional and basinwide estimates of use.
    - Develop and implement the infrastructure to collect basic social and economic data throughout the Lake Tahoe basin. Common sampling methods are necessary to ensure that data can be aggregated and analyzed to assess socioeconomic conditions within the various municipalities, within geographic regions, and throughout the basin.
    - Infrastructure is recommended to support the centralized collection, inventory, and distribution of transportation data at regional and basinwide levels.
    - Establishment of a spatially and temporally appropriate monitoring program is recommended to allow for assessing noise conditions relative to established threshold indicators.

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. Monitoring, particularly status and trends monitoring, generates the knowledge necessary to pose new hypotheses about key cause-and-effect relationships, and the role of underlying processes in shaping ecosystems and their processes. Research is the means by which new hypotheses are tested in order to elucidate and confirm the relationships and interactions that determine the environmental conditions we observe and experience.

Research to support adaptive management often plays a relatively limited role in informing management decisions and policy choices, because obtaining new information is generally considered subordinate to demonstrating that policy choices and management actions have generated immediate results—such as on-the-ground projects, land preservation, or new regulations restricting a former activity—and that those results fulfill management objectives.

The single highest priority for research is to establish a stable funding stream to (1) ensure that the level of scientific understanding of the Lake Tahoe basin continues to develop, (2) create the research tools and techniques necessary to best inform policy choices and management strategies, and (3) support timely and effective science delivery in terms of research findings and management implications.

Over the past several decades, much of the available research funding has been allocated to address the factors and processes that specifically affect Lake Tahoe water quality, particularly lake clarity. Although great strides have been made in knowledge related to lake water quality, a similar level of progress in understanding other ecosystem elements, such as forest health, biodiversity, air quality, or socio-economic dynamics has not occurred. Although it is known that terrestrial, aquatic, and atmospheric habitats are interconnected, and that all are influenced by human activities, the direction and intensities of interactions and effects are in many cases uncertain. We recommend balancing the distribution of new research funds across multiple theme areas so that we simultaneously increase our knowledge base across a diversity of issue areas. Research needs specific to each of the five theme areas are presented in chapters 3 through 7.

Data Application

Data application includes the activities of analysis, reporting, management, and assessment in order 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 the 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. To meet the growing data and information needs of resource management agencies and the public, it is important that data are translated into information and information is converted to knowledge as efficiently as possible to maximize its potential benefits. Ideally, a data management system works within existing institutional arrangements and policy requirements to meet agency communication and coordination needs, and allows for an integration of data and information sharing among a wide variety of entities inside and outside the Lake Tahoe basin.

Data Application Priorities

A dedicated source of funds and resources is recommended for data management, analysis, and reporting to ensure that this element of an integrated science program is accomplished and maintained. The identification of responsible entities and allocation of sufficient resources to fulfill this function is essential to achieving success and minimizing costs by eliminating redundant efforts among institutions. 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 would 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 stormwater 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 would 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 should be developed and maintained so that basic data and summary information is 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.

- **Environmental management knowledge base.** An environmental management knowledge base that documents our current understanding of conditions, interactions, threats, and desired outcomes can 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 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.** It is recommended that a state-of-the-basin report be completed every fifth year. This report could 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, and would evaluate conditions relative to environmental goals and thresholds. This information could be used to evaluate and (if necessary) modify management strategies and implementation programs (i.e., inform 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-basin report would include at least the following subject areas:
    - Lake Tahoe
    - Basin watershed condition
    - Basin airshed condition
    - Living resources condition
    - Human environment

Adaptive Management

An integrated science program is best applied to land and resource management efforts using structured adaptive approaches, which are referred to as adaptive management. Adaptive management has been dubbed, "learning by doing," but that label understates the technical and institutional challenges in implementing the process and sustaining it over time. The essential elements of adaptive management include the clear articulation of management goals and objectives; the development of conceptual models that describe how managers believe the ecosystem works; the identification of alternative management responses; and an implementation strategy that describes management actions, tools, and expected outcomes. Successful application of adaptive management relies on various information inputs (e.g., scientific, legal, or economic) into each element along with processes that allow adjustments and adaptation. The aim is to develop policies and management strategies that are responsive to the best available knowledge and increase the chances of management success.

A variety of processes and techniques have been advanced to guide those who wish to transfer available scientific information to policymakers and resource managers under adaptive management. In the Lake Tahoe basin, agency leaders have agreed to work together to develop and operate an adaptive management framework as a means to (1) integrate management actions across targeted resources, including air quality, water quality, lake clarity, soils and vegetation, and wildlife and fisheries; (2) coordinate monitoring, research, and ecological and hydrological modeling efforts; (3) define responsibilities among those contributing to adaptive management for data analysis, interpretation of study results, and the reporting of new information; and (4) identify protocols to facilitate collaborative decisionmaking in resource management and environmental restoration and in the updating of management strategies (TRPA et al. 2007).

An operational science program for the Lake Tahoe basin should contribute pertinent and timely information to help guide management actions by informing data collection in monitoring and assessment efforts, and by building a foundation of reliable scientific information from directed research about the basin's ecosystems (fig. 2.1). Interactions among science, management, and policy are typically complex and iterative. For example, agency-defined environmental thresholds that at least in part have been informed by scientific information guide many of the actions of the Tahoe basin's capital improvement program, while at the same time regulations informed by the same and different information are intended to prevent further degradation of conditions relative to those thresholds (fig. 2.1). Management strategies and policy choices rely on iterative interactions among environmental goals and implementation programs. An integrated science program is most effective if it operates to provide information at the intersections among these programs and the goals that guide them. An integrated science program can provide information that is useful in verifying cause-and-effect relationships, assessing program effects and environmental conditions, and influencing the selection of management strategies and policies that can ultimately translate into funding decisions and courses of action for program implementation.

An adaptive management framework can provide links between management needs, scientific activities, and management actions, thus ensuring that the best available knowledge systematically informs planning and management activities (Manley et al. 2000). Incorporating a science program into an adaptive management framework explicitly acknowledges that critical uncertainties confront those who develop policies and implement management strategies. A functional adaptive management system will integrate the commitments to reducing uncertainty through research, monitoring, and data applications with the commitments to implement restoration actions.

An adaptive management framework typically makes explicit the linkages between information acquisition, management decisions, and management action (fig. 2.3). In the purest form of adaptive management, uncertainties associated with management policies and strategies are treated as working hypotheses and

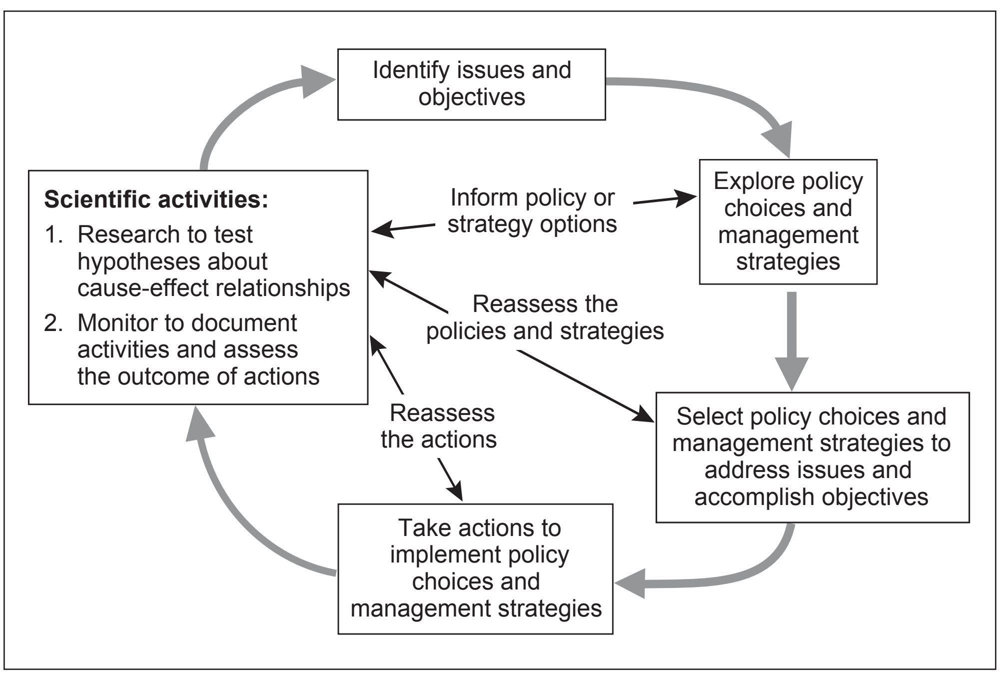

Figure 2.3—An adaptive management framework illustrating the major steps in a decisionmaking process, and the various linkages by which scientific information can inform each step in the process.

are not permanent features (Lee 1993). Working hypotheses are tested through research and monitoring, with the outcomes of these data-gathering efforts (i.e., experiments) providing opportunities to acquire new knowledge that can inform subsequent policy and management decisions (Hollings 1978; Lee 1993, 1999). Both research and monitoring are essential elements in this form of adaptive management, framing policy choices as working hypotheses, and testing those hypotheses.

In an appraisal of adaptive management, Lee (1999) found that "adaptive management has been more influential, so far, as an idea than as a practical means of gaining insight into the behavior of ecosystems utilized and inhabited by humans." As a result, adaptive management is frequently applied as a partial overlay to existing, frequently imbalanced infrastructure for problem identification, policy choices, and management actions. In such situations, opportunities to obtain new information are opportunistic endeavors that do not detract from the central objective of achieving management results. Accordingly, monitoring is viewed as the "science" needed to document the effects and effectiveness of management strategies. In either application of adaptive management, the role of science is to provide objective information that can tell us about the outcomes and consequences of actions or choices and that can help to improve future decisions.

Science Plan Conceptual Models

Conceptual models are an essential centerpiece of adaptive management and its integration of monitoring, research, and data applications into more effective, efficient, and accountable management actions. Their function is to communicate a shared understanding about the key elements, linkages, and stressors associated with ecosystems among those who are responsible for and contribute to their management. In essence, they document our hypotheses about how ecosystems function and thereby inform management planning, the development of assessment and monitoring programs, and the design of research efforts. Conceptual models that have been vetted through scientists, managers, and stakeholders can serve as the basis for numerical models that attempt to describe the consequences of alternative management actions. Without conceptual models, there can be no reliable adaptive management.

Conceptual models describe in graphical or narrative form the ecological system subject to management, allowing inference about how that system "works." A model of riparian forest function in the Lake Tahoe basin, for example, would describe the relationships between the vegetation and the animals that depend on it, the hydrological and other physical processes that affect those relationships, and the roles of human activities in disturbing and sustaining the system. Such models help to clarify the verbal descriptions of what we have observed in nature, and force us to think about ecosystem elements and interactions that we might otherwise ignore. In the formulation of a conceptual model, the combinations of parameters that drive ecological systems often become apparent, which in turn provides planners a more complete context to understand how various management strategies or regulations might affect system function and the condition of natural resources. Attributes of particular importance to ecosystem function and sustainability are strong candidates for management attention and assessment using monitoring. Conceptual models help us to assure that our current and future management actions target the correct ecosystem features and attributes, and increase the likelihood that our actions will produce the desired management outcomes. Acceptance of a common suite of conceptual models by agency and stakeholder representatives signals agreement regarding critical aspects of ecosystem well-being for which they share management responsibility.

A conceptual model should clearly identify key system elements and key physical and biological processes. The model should articulate how the system is impacted by stressors (i.e., disturbances and perturbations) from both natural and human-generated sources and how management can intervene to reverse undesirable conditions or trends. That description can take one or more forms, including box and arrow diagrams, cartoons accompanied by narrative descriptions, simple linear pathway illustrations, or even straightforward text descriptions.

Conceptual models will always fall short of a full and accurate portrayal of ecosystem elements and processes—highly detailed renditions would be counter to the primary objective of serving as a communication device among stakeholders. Their very imperfection is part of their utility, in that they make our understanding of how natural systems work available for review and discussion; thus, they help to identify areas of uncertainty and direct efforts to the information necessary to make better management decisions. Once agreement is reached among stakeholders on workable conceptual models, they can begin to serve as a framework for decision-support systems that can help managers evaluate the relative risks and opportunities associated with various management options. If adaptive management is effective, conceptual models will improve in their accuracy and effectiveness as we learn more over time.

We developed conceptual models for the Lake Tahoe basin Science Plan that had multiple objectives. They are intended to provide a roadmap to the key research needs identified in the theme areas considered in this science plan, orient the reader to the focal elements within each theme, and identify the interactions and linkages among these elements and the subthemes. Perhaps more importantly, they serve as a starting point for discussion and further development in collaboration with managers and other stakeholders in the Lake Tahoe basin. Here we provide an overview model of the primary elements of the research strategies and their linkages (fig. 2.4). The primary biophysical and sociocultural elements of each theme—the subthemes—are shown in association with their respective themes. The themes and subthemes are arrayed around a circle to indicate that they are all part of a single-basin ecosystem and thus affect one another to various degrees. Primary interactions between subthemes and across themes are indicated by arrows that span the circle. Interactions between subthemes within a theme are not shown—they are numerous and are addressed in the theme-specific models within each chapter.

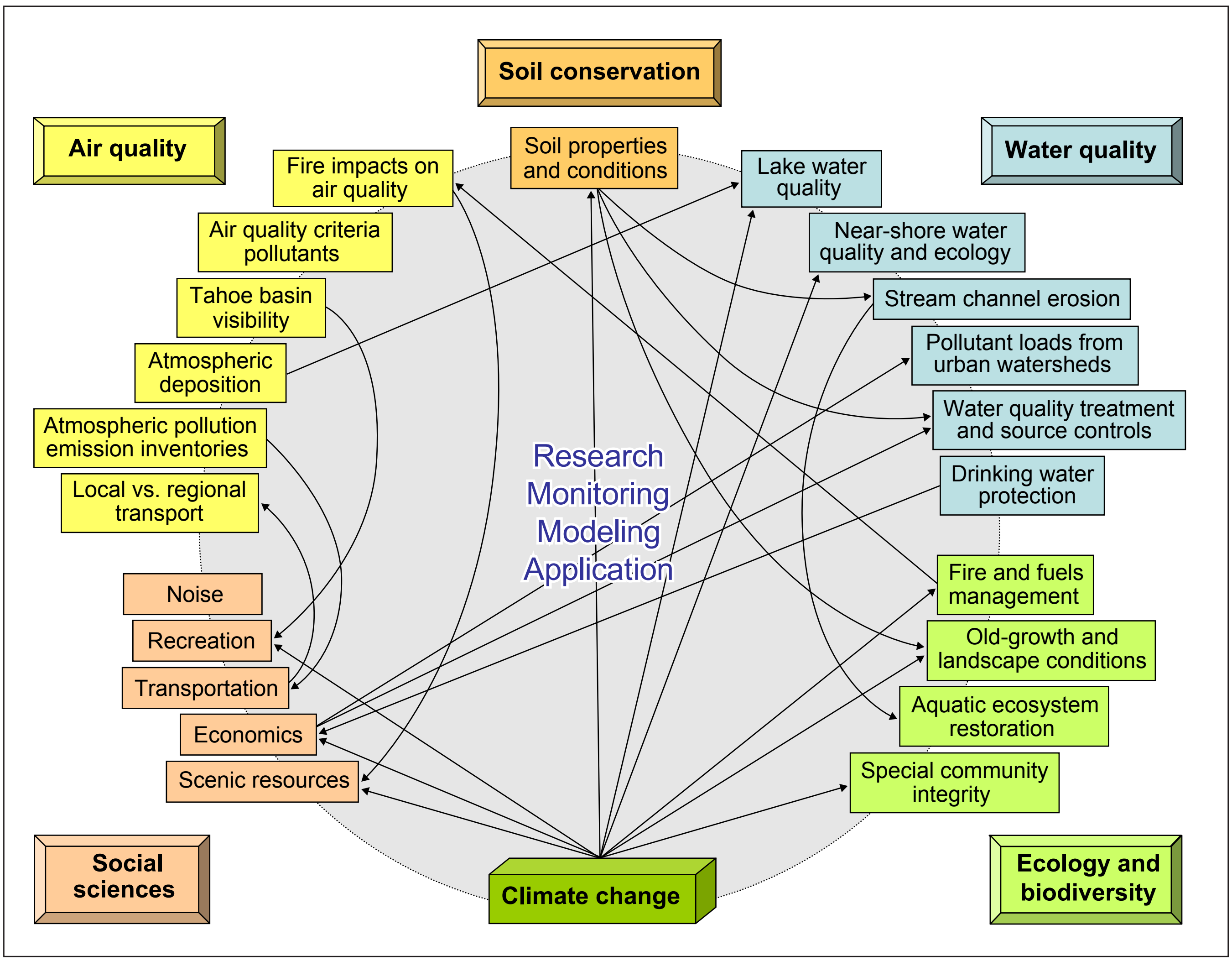

Figure 2.4—Overview conceptual model of the integrated science plan for the Lake Tahoe basin. The model includes the five theme areas covered in this science plan and the subthemes within them for which knowledge gaps and research needs are discussed as part of each research strategy. Climate change is included as an example of an environmental stressor, and its linkages to various ecosystem components are indicated.

Although the subthemes arrayed around the circle are unique to each theme, the themes share many features. Most environmental stressors affect multiple biophysical and sociocultural elements in various ways. Climate change, for example, has the potential of affecting every theme area and every aspect of well-being in the basin. Thus, climate change is shown as a stand-alone element and the subthemes that it is likely to affect first and most directly are indicated via arrows. Certainly, many other stressors, such as air pollution, urban development, and invasive species, affect multiple themes and subthemes. These stressors are discussed within each theme, but the development of stressor-based conceptual models would be a valuable future investment. Science-based activities in support of adaptive management are noted in the center of the circle—research, monitoring, modeling, and data application—indicating that they span subthemes and themes, and in fact are most effective when designed to do so.

More detailed theme-specific conceptual models appear in each theme chapter. They display the subthemes (focal points of the research strategy), the components of each subtheme, and what factors (drivers) affect them (fig. 2.5). The theme-specific conceptual models identify the linkages between drivers and components. The conceptual models identify the linkages or elements that are priority areas for research, and for which specific research needs are specified in the strategy based on the combination of risk and uncertainty. The models also identify basic information needs where those needs can be a barrier to informing management, and they suggest useful monitoring indicators. Once a knowledge base is designed around the conceptual model, it can be used to assess conditions and derive information on relationships among its component parts. The relationships among any of the component parts of the knowledge base can be represented in the form of summary tables or figures akin to conceptual models. Using a knowledge base for this function alone can address a number of the commonly posed questions about ecosystem interactions from a management perspective. The real power of the knowledge base, however, is in evaluating ecosystem conditions, both across the entire planning area and by planning unit.

The "box and arrow" conceptual models developed for this science plan are a common format for portraying basic parts and interactions of a system of interest. In the Lake Tahoe basin, the large number and scope of issues of interest and the complexity of their interactions make conceptual models a valuable and necessary tool—a means by which essential information can be displayed and understood. With such a complex problem set, however, it is challenging, if not impossible, to render a conceptual model that is sufficiently detailed to be representative, yet simple enough to be informative. Managers and scientists alike benefit from

1. Theme areas Theme	Definition: Primary categories of biological, physical, and social conditions of interest to agencies and the public. Constituents: Interest areas are divided into their primary elements (i.e., air quality, water quality, soil conservation, ecology and biodiversity, and integrating the social sciences into research planning. Condition: Degree of consistency with desired condition statements on condition of elements.
2. Subthemes Subtheme	Definition: Categories within theme areas identifying the distinct subsets of interest. Constituents: Subthemes are substantive topics that are important to consider within each theme area. Condition: Degree of consistency with desired condition statements based on condition of individual constituents, or an aggregation of constituents, depending on the desired condition.
3. Components Component	Definition: Broad categories representing the substance of each subtheme. Constituents: Each component is represented by one or more indicators and affected by one or more drivers. Condition: Degree of consistency with desired conditions based on condition of indicators. Information on indicators—what they represent and how their values are derived—is contained within this tier.
4. Drivers 1° Driver 2° Driver	Definition: Drivers are agents of change, natural or human-caused, that affect the condition of improvements and indicator values. Primary drivers affect change directly, while secondary drivers affect primary drivers and often reflect the ultimate causal factors for environmental change. Constituents: Each component is directly affected by one or more primary drivers, which in turn are directly affected by one or more secondary drivers.

Figure 2.5—Elements and framework used to develop theme-specific conceptual models.

conceptual models, but models tend to fall short of the need to portray and analyze environmental interactions and complexities. It is likely that land and resource management agencies will be investing in knowledge base decision-support tools, and they will need conceptual models to serve as the roadmap for these knowledge bases. The theme-based conceptual models presented in this science plan are intended to contribute to this management need.

Ideally, conceptual models serve as the basis for working models that can be used in an interactive decision-support process. Hierarchical knowledge-base models can be an effective approach to dealing with decisionmaking in a complex biophysical, sociocultural, and regulatory environment. In such models, the detailed complex interactions, as they are understood and refined over time, can be accurately represented and their relative influence on outcomes tested and quantified. Knowledge bases are a logical extension of conceptual models, and their development and application to decisionmaking in the basin will become increasingly important as scientists and managers face the substantial uncertainties about how to maintain and restore ecosystem resilience and sustainability. They are a form of metadatabases that represent a formal logical representation of a network of relationships among elements of interest. The structure of a knowledge base for Lake Tahoe would need to be designed to meet a spectrum of information storage and retrieval needs. It would need to contain information on broad categories of environmental quality and basic measures of their condition to meet the communication needs of managers and decisionmakers across institutions. It would also house the more detailed information associated with how the values of the measures are derived, and the uncertainties and risks associated with those values to provide a definitive link between information acquisition and application.

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