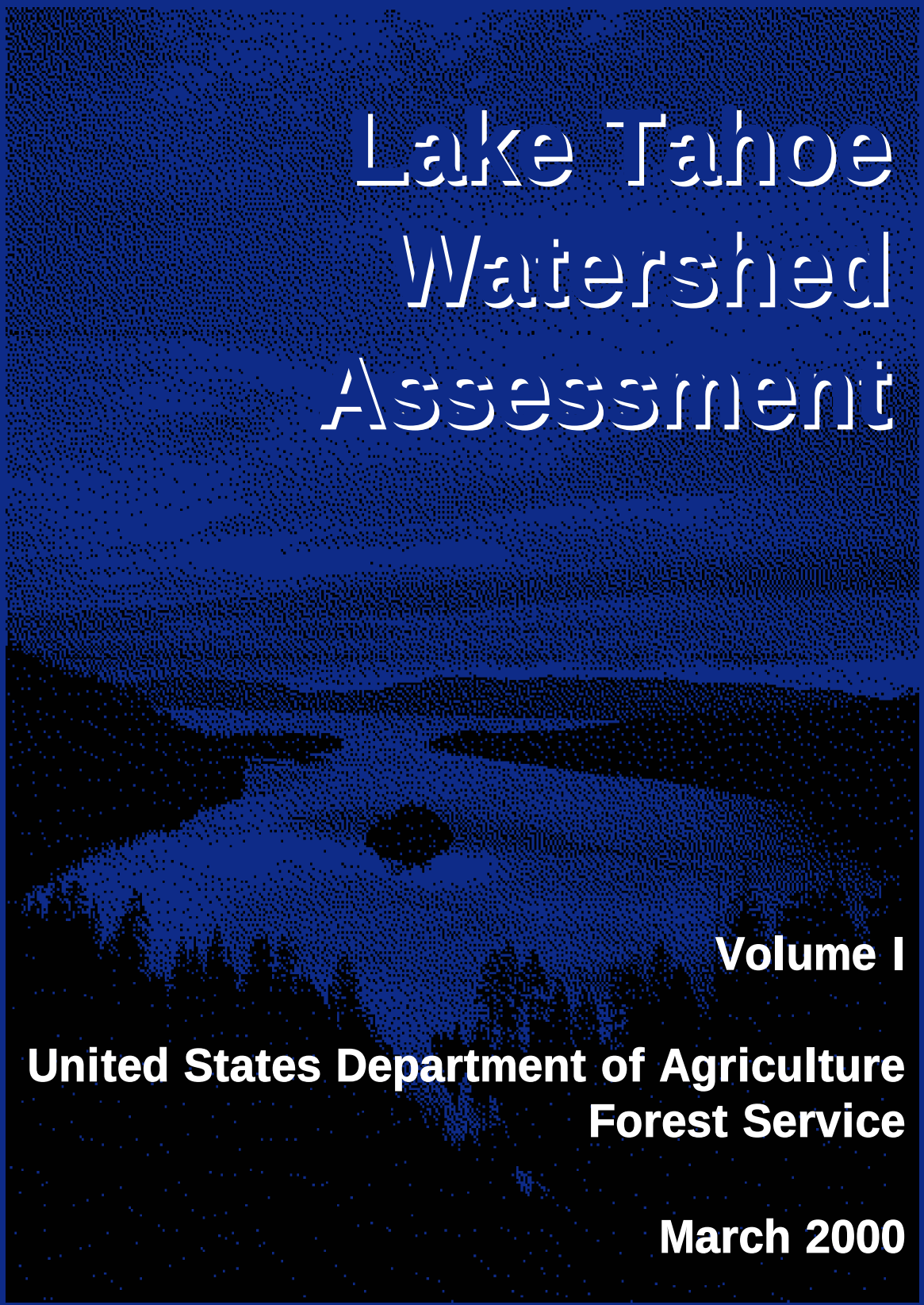
Lake Tahoe Watershed Assessment



Volume I

United States Department of Agriculture
Forest Service

March 2000



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Abstract:
Murphy, Dennis D.; Knopp, Christopher M., technical editors. 2000. **Lake Tahoe Watershed Assessment: Volume I.** Gen. Tech. Rep. PSW-GTR-175. Albany, CA: Pacific Southwest Research Station, Forest Service, US Department of Agriculture; 753 p.

This watershed assessment of the Lake Tahoe basin in northern California and Nevada is the first attempt to collate, synthesize, and interpret available scientific information with a comprehensive view toward management and policy outcomes. The seven-chapter report presents new and existing information in subject areas pertinent to policy development and land and resource management in the basin, including environmental history, air quality, watershed dynamics and water quality, biological integrity, and socioeconomic conditions. Key findings report the extent of recent climatic changes, historic accounts of past environmental disturbances, state of our understanding of why the Lake's clarity is declining, significant role that air quality plays in the decline, and an initial nutrient budget for nitrogen and phosphorous that are believed to fuel algae growth. In addition, important new work related to old-growth forests, the risk of wildfire and the conservation of biological diversity in the basin have helped to broaden our perspective of the interrelated nature of the environmental challenge facing the basin. A detailed analysis of institutional arrangements and capacities in the Lake Tahoe basin is presented in the context of environmental decision-making.

Retrieval Terms: environmental history, air quality, water quality, biotic integrity, socioeconomics, adaptive management, California, Nevada

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Publisher:
This report on the "Lake Tahoe Watershed Assessment," issued in two volumes (Volume II consists of appendices), was published by the Pacific Southwest Research Station, USDA Forest Service, in cooperation with the Pacific Southwest Region of the USDA Forest Service, Tahoe Regional Planning Agency, University of California at Davis, University of Nevada at Reno, and the Desert Research Institute, Reno, Nevada.

The Lake Tahoe Watershed Assessment Volume I

Edited by

Dennis D. Murphy
and
Christopher M. Knopp

March 2000

In collaboration with USDA-Pacific Southwest Region and Research Station, the Tahoe Regional Planning Agency, the University of California at Davis, the University of Nevada at Reno, and the Desert Research Institute, Reno, Nevada.

Lake Tahoe Watershed Assessment: Volume I

Technical Editors: Dennis D. Murphy, Christopher M. Knopp

Acknowledgments

In the summer of 1997, at the request of the local community and with the invaluable assistance of United States Senator Harry Reid, President Bill Clinton and Vice President Al Gore visited the Lake Tahoe basin to discuss issues surrounding its decline in environmental quality. As a result of that visit, funding was provided by the USDA Forest Service to complete this comprehensive report on a watershed assessment of Lake Tahoe and its subsequent publication.

Mike Dombeck, Chief, USDA Forest Service, G. Lynn Sprague, former Regional Forester, and Brad Powell, current Regional Forester, Pacific Southwest Region, USDA Forest Service, provided the institutional and financial support necessary to conduct this assessment.

The Lake Tahoe Watershed Assessment Team expresses its appreciation to the following individuals for their hard work in developing and refining portions of this report: Mark D. Palmer, Patricia Arneson, Patricia Bucknell, Mauri Janik, Robert Leonard, Earl R. Byron, George J. Malyj, Richard Axler, Robert N. Coats, M. Levant Kavvas, Geoffry Schladow, Neil Sugihara, John Battles, John Maher, Dana Supernowicz, Alan Wallace, Sarah Michehl, Todd Caldwell, Rick Susfalk, Tinker McSwain, Lisa Cullen, Peter Hartsough, Anya Butt, Alan Gertler, Jim Allison, Trent Procter, Chris Adair, Kevin Hill, Brant Allen, Lori Allessio, Robin Barron, Larry Benoit, Aaron Bilyeu, Stephanie Byers, Allen Cooperrider, Almo Cordone, Ann Dennis, Dennis Desjardin, Jason Dunham, George Elliott, Nancy Erman, Maurya Falkner, Gabe Garcia, Bob Hall, David Hatfield, Sherry Hazelhurst, Daniel Hintz, Mollie Hurt, Victor Insera, Richard Kattlemann, John Keane, Rod Kerr, Lynn Kimsey, Kevin Laves, Dennis Lee, Karen Leyse, Peter Maholland, Michelle McKenzie, Peter Moyle, Josh Murphy, Joanne Nevers, Larry Neel, Lisa O'Daly, Dorrie Panayotou, Mary Peacock, Sanjay Pyare, Matthew Rahn, Michael Reed, Jeff Reiner, Dave Roberts, Rick Robinson, Dirk Rodriguez, Colleen Shade, Jim Shevock, Steve Shoenig, Donald Storm, Paul Stover, Debra Tatman, Mike Taylor, Susan Urie, Kathy Van Zuuk, Garrett Villanueva, Mark Vinson, Gary Walter, Jeff Waters, German Whitley, Karen Willet, Brian Woodbridge, Mary Ward, Mitch Riddle, Brad Shaffer, Yiqi Luo, Shi kui Xue, Bernie Bahro , Mark Finney, and Bill Zelinski..

We also thank the following organizations for their support, guidance and assistance: the Lake Tahoe Federal Advisory Committee, the Watershed Assessment Executive Oversight Committee, the Lake Tahoe Transportation and Water Quality Coalition, the California Tahoe Conservancy, the Nevada State Division of Lands, and the Washoe Tribe of Nevada and California.

Several consultants contributed to the development of this document: Tetra Tech, Inc., particularly Randy Varney and Cindy Schad, who provided the technical editing and layout; Joan Wright, who assisted the editorial process; Nick Dennis from Jones and Stokes, who contributed to the socioeconomic assessment; Kelly Berger and Steve Holl, also of Jones and Stokes, who performed some of the fire behavior modeling; and Johnathon Kussel, who assisted with early scoping meetings.

Several individuals made outstanding contributions: Sue Norman performed admirably in a variety of difficult roles, but perhaps none is appreciated more than her role in keeping our books and contracts up to date. Jim Baetge provided constructive criticism and guidance through an often difficult process; and Juan Palma gave valuable support.

The contents of this publication are in the public domain, except for the photographs on the cover and chapter divisions, which were provided by John T. Ravizé and Linda Ravizé, Institute of Mountain Photography, P. O. Box 444, Zephyr Cove, NV 89448.

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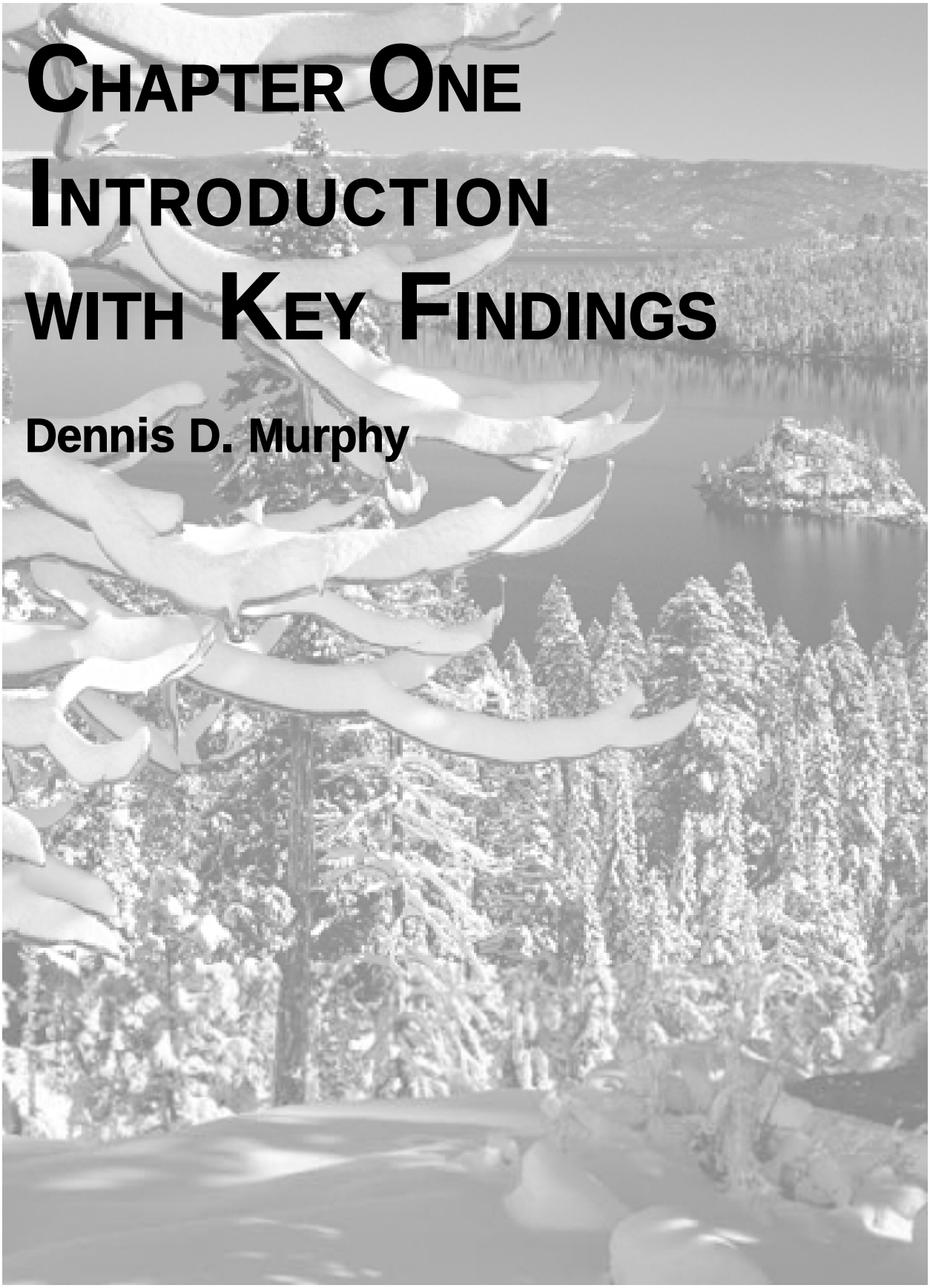
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Chapter One
Introduction with Key Findings

Dennis D. Murphy

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CHAPTER ONE

INTRODUCTION WITH KEY FINDINGS

Dennis D. Murphy

When Mark Twain first spied the immensity and grandeur of Lake Tahoe he could hardly contain himself, relating in his 1871 travelogue *Roughing It:*

"At last the lake burst upon us—a noble sheet of blue water lifted six thousand three hundred feet above the level of the sea, and walled in by a rim of snow-clad mountain peaks that towered aloft full three thousand feet higher still! It was a vast oval, and one would have to use up eighty or a hundred good miles traveling around it. As it lay there with the shadows of the mountains brilliantly photographed upon its still surface I thought it must surely be the fairest picture the whole earth affords.

"So singularly clear was the water, that where it was only twenty or thirty feet deep the bottom was so perfectly distinct that the boat seemed to be floating in the air! Yes, where it was even eighty feet deep. Every pebble was distinct, every speckled trout, every hand's-breadth of sand . . . The water was not merely transparent, but dazzlingly, brilliantly so."

Twain's romance with Lake Tahoe took an unexpected turn when just hours after he penned that description a campfire bounded from his control, engulfing the surrounding forest and charring miles around.

In so many ways Twain's initial Tahoe adventure epitomizes the last century and a half of human experience at the lake. The great montane body of water was discovered by excited explorers, rapidly exploited for its diverse natural resources, and then urbanized by waves of settlers. Only in the past several decades have the effects of our rapacious appetites for Lake Tahoe's resources become fully evident. And now, after loving and abusing the Sierra Nevada's grandest lake for so long, we embark on an era of restoration and renewal.

This written component of the Lake Tahoe Watershed Assessment is an initial step toward bringing better informed management to the lake and its surrounding basin—to make this era of restoration and renewal as successful as possible. The goal is to collect in a single document information that can be used by land and resource managers to develop a comprehensive conservation plan for the lake and its watershed. Although the lake has been the focus of conservation concern for decades, a sense of immediacy now prevails. Scientists warn that should lake clarity continue to decline at recent rates, Tahoe's famed aqua waters may be permanently compromised in less than a decade.

Not only waters are at risk. The forests of the Tahoe basin were ravaged by indiscriminate timber harvests more than a century ago and by fire suppression since then. Today's landscape is haunted by a ghost of those disruptions to the natural cycle of forest disturbances, differing from its historical structure and composition, subject to devastating insect outbreaks, and at risk of wildfire ignitions as never before. So too, many of Tahoe's meadows and wetlands have been destroyed and others are in danger. Overgrazed at the turn of the century, overdeveloped since, their unique ecological role in filtering sediments from the turbulent stream waters of the Tahoe basin and supporting its diverse wildlife has been compromised by any measure. The resident species of the lake basin have hardly fared better. One of nature's most productive inland fisheries sustained generations of Native Americans. That fishery's vast uncountable numbers of cutthroat trout have not just declined, they have vanished.

Nevertheless, yesterday's environmental abuse has become today's environmental challenge, and that challenge is being met at this country's

highest levels of government. Recognizing the national importance of Lake Tahoe's diverse resources and their dramatic declines, United States Senator Harry Reid of Nevada brought President Clinton and Vice President Gore to Lake Tahoe in 1997 for a first-ever presidential forum. There Mr. Clinton affirmed "a shared responsibility to build on our commitments at all levels to be sure the lake and its environs are protected." On July 26 of that year the administration promised to fund a diversity of new and expanded efforts directed at water quality, forest management, transportation, and recreation and tourism, including the development of this watershed assessment.

The watershed assessment thus joins other ongoing scientific efforts designed to inform policy development and resource management at Lake Tahoe. Most closely linked to the watershed assessment are the water clarity modeling effort being carried out at the University of California at Davis, which is intended to advance our understanding of nutrient and sediment inputs to the lake and their impact on its clarity, and the Tahoe Regional Planning Agency's (TRPA) "real time" management program, which attempts to bring reliable information from research and monitoring to resource management in the basin.

The watershed assessment itself was proposed in the October 1997 document *Presidential Forum Deliverables* to provide for "the integration of ecological knowledge about the Lake Tahoe basin" and was "to clearly define the issues and priorities identified during the Presidential visit and to balance these priorities in resource management." The assessment was further intended to "describe and define existing conditions, reference variability, and desired future conditions for key ecosystem elements and environmental indicators." That job description was amended; in fact, a mature political process already has identified desired future conditions or "thresholds" for key environmental variables in the Lake Tahoe basin, which are evaluated and amended on a five-year cycle. Appropriately the watershed assessment does not prescribe specific management actions or land use policy. That job correctly resides with regional governments, agency staff, and the diverse coalitions of stakeholders at Lake Tahoe. This document, however, does offer explicit recommendations for research, monitoring, and an adaptive management strategy that will be necessary to inform future management. The task of compiling available information for future uses from widely dispersed sources has proven to be a fair challenge in its own right. The watershed assessment science team has largely restricted itself in this document to that narrowly defined task.

Science and the Watershed Assessment

A list of superlatives has served as the starting point for most environmental descriptions of Lake Tahoe. The lake is among the most dramatic manifestations of water and geology on earth (Figure 1-1). Its depth is more than a third of a mile. Its lake bottom is hundreds of feet below Carson City, Nevada, in the adjacent Great Basin. At nearly two hundred square miles, the surface area of the lake covers nearly two fifths of the Tahoe basin. No fewer than 63 small rivers and streams feed Lake Tahoe, and one large river, the Truckee, drains it (Figure 1-2). So much water resides in Tahoe that the travel of a snowbank droplet from nearby Mt. Tallac's alpine summit through the lake and out the Truckee River takes seven hundred years. This extraordinary residence time of waters in Lake Tahoe is the driving feature in plans for its restoration. Lake Tahoe's hugeness serves to ameliorate our lesser environmental excesses, but that same remarkable size creates a long-lasting memory of our worst insults. Disturbances to Lake Tahoe from past decades will challenge our best management efforts for decades to come. Nevertheless, fair hope exists for a solution to Tahoe's environmental crisis; more than four fifths of the lake's surrounding basin is in public ownership and can be managed to conserve and enhance ecosystem health and services (Figure 1-3).

The watershed assessment team presupposes that readers of this document are familiar with the dimensions of the lake, the physical characteristics of its surrounding landscape, its fate at the hands of settlers from the east, and recent attempts to reverse more than a century of environmental degeneration. Those less familiar with Lake Tahoe and its environment should take advantage of Douglas Strong's wonderful volume *Tahoe: from Timber Barons*

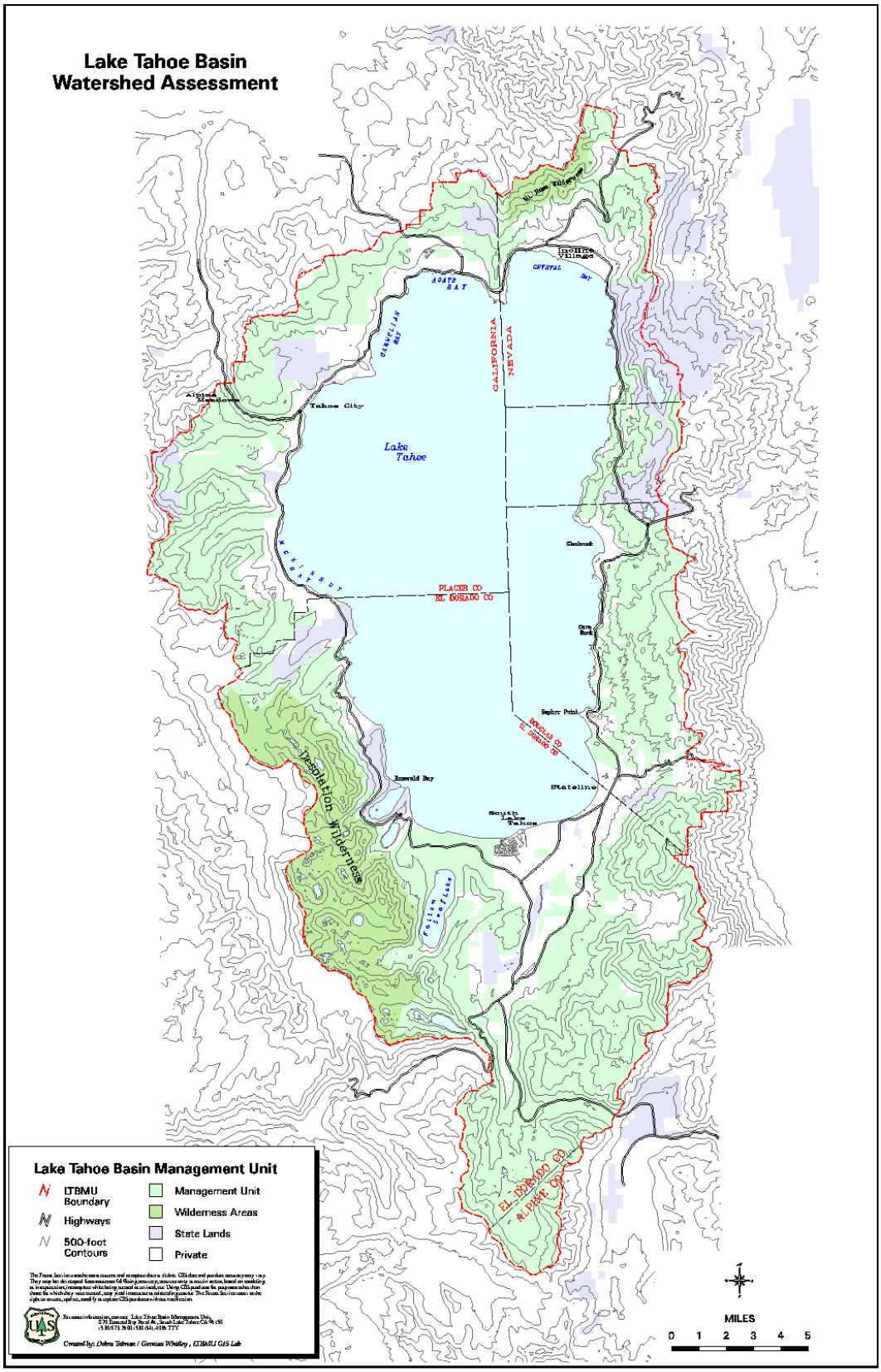


Figure 1-1—The Lake Tahoe basin and watershed boundary.

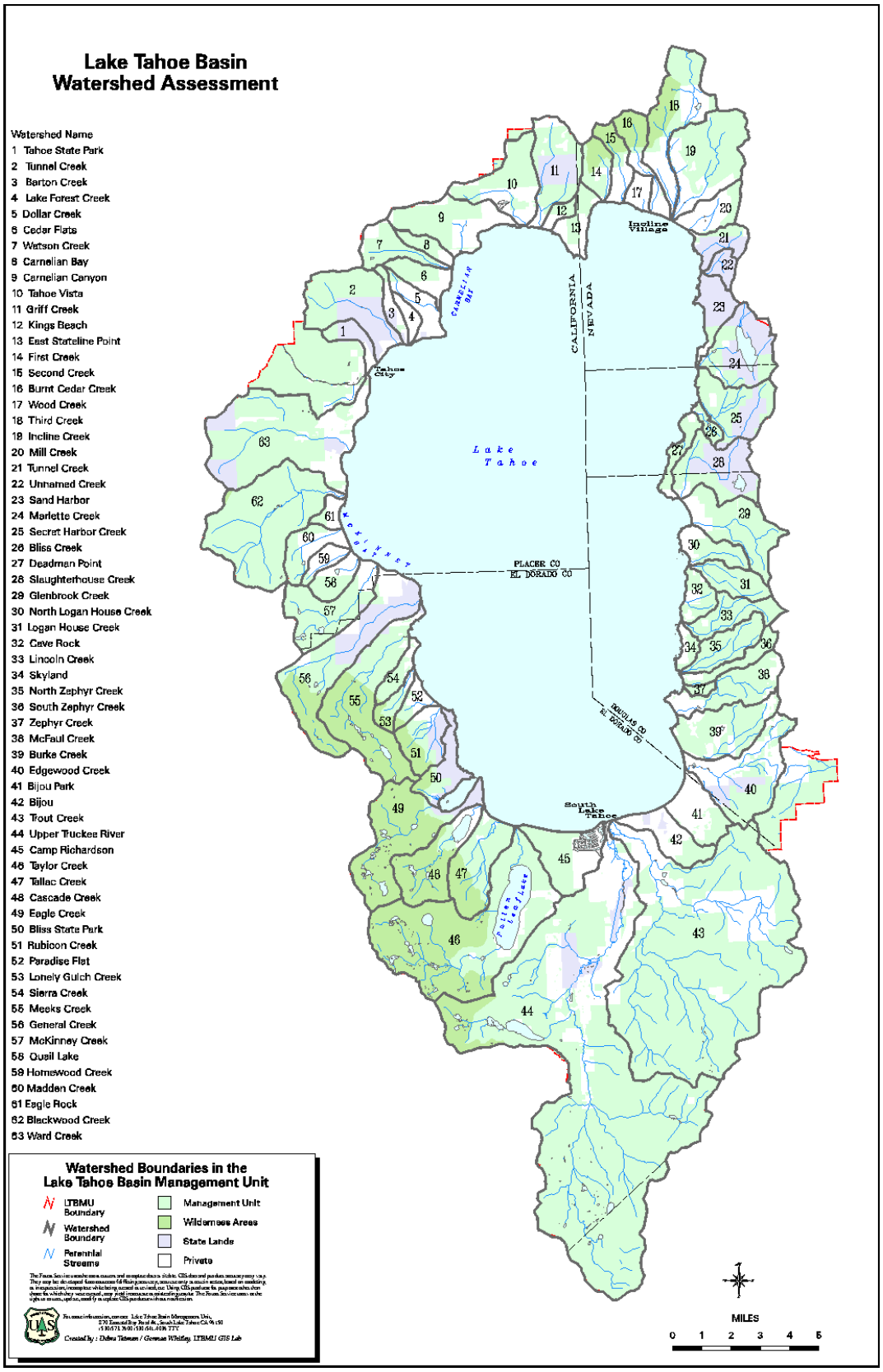


Figure 1-2—Lake Tahoe tributaries.

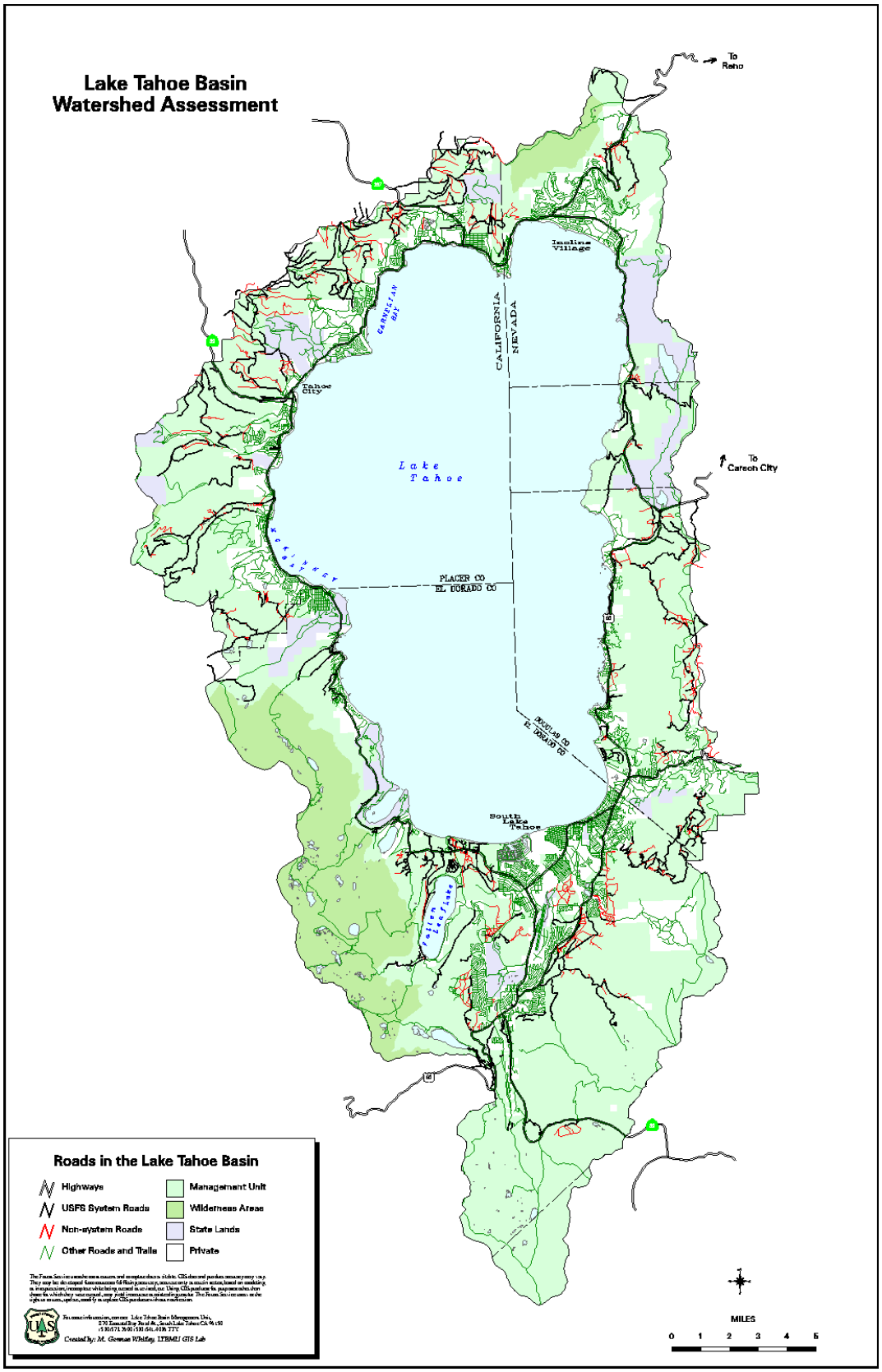


Figure 1-3—Lake Tahoe land ownerships and transportation network.

to Ecologists(1999). The multivolume Sierra Nevada Ecosystem Report, *Status of the Sierra Nevada*, includes a factually dense treatment of Lake Tahoe as a case study by Elliott-Fisk et al. (1997) that pairs an overview of the biophysical challenges faced by basin managers with a description of current institutional responses to those challenges. These two works and the many reports by TRPA that describe its efforts during the past thirty years to meet basinwide environmental objectives provide requisite reading for those desiring to take full value from this assessment.

There is a misperception that Lake Tahoe has been a unique focus of intensive applied research, where the answers to our most pressing environmental questions stand ready. In fact, decades of study of the hydrology of the lake's shallows and depths only now are being integrated into a coherent model and water budget. Significant gaps in our understanding of Tahoe's hydrological dynamics remain, with profound uncertainties about the contribution of ground water to the hydrological system. And, as this assessment reminds us, much less is known about crucial processes that introduce pollutants to and cleanse them from the basin's atmosphere, that shape the structure, composition, and function of its plant and animal communities, and that create and direct the complex human economy of Lake Tahoe. Prior to this assessment, a comprehensive and systematic review of scientific information pertinent to management had been lacking; however, two earlier efforts to present available scientific knowledge on Lake Tahoe merit note.

The first effort, published informally in 1974 under the title *Research Needs for the Tahoe Basin*, was funded by the National Science Foundation as part of a project attempting to "encourage research needed to achieve the planning and management objectives of public and private entities" and to "provide scientific expertise and data to support effective planning and management programs." The report was authorized in response to a perceived need that still resonates a quarter of a century later—"a general feeling that research efforts and their end product were not specifically directed nor given proper priority to deal with development pressures in the Lake Tahoe basin." Identifying more than 700 research reports, articles, and books on the lake and its surrounding watershed dating back to 1878, the report described information shortfalls that compromised management of the basin's air, water, vegetation, fish and wildlife, and resource systems (the latter referring to the cumulative effects of human activities on integrated ecosystem services). More than eighty separate research agenda items were proposed and given "five years as a workable time span to emphasize current problems over anticipated ones." Despite expenditures of more than a million dollars per year in water quality monitoring alone, few of the broad-ranging research priorities called for in the 1974 report have been addressed.

In 1979 a second compilation of information was presented in support of a *Lake Tahoe Environmental Assessment*, an interagency product of a "federal partnership" among the US Environmental Protection Agency, the USDA Forest Service, the Department of Housing and Urban Development, and the Department of Transportation and Department of Energy, as well as numerous state and regional agencies. It summarized data on air quality, water resources, vegetation, fish and wildlife, land use, visual quality, transportation, noise, energy use, and social, economic, and demographic features of the lake basin. The assessment aggregated data into a model, which then was used to evaluate "effects accumulated through webs of interactions," concluding that during the 1970s "the basin's environmental quality had depreciated in a measurable, cumulative way." It introduced the formal concepts of carrying capacities (that is, intrinsic limits to land development and certain other activities in the Tahoe basin) and thresholds (quantitative standards to set these limits). The 1979 report greatly influenced the establishment of the nine environmental threshold categories now guiding conservation efforts under the Tahoe Regional Planning Compact. Subsequently, TRPA threshold reports have provided additional broad reviews of scientific information pertinent to those environmental thresholds.

The ensuing twenty years has seen a proliferation of research publications scattered across professional journals, reports, and filed documents. The majority of that work is related to water quality, some on the Tahoe basin's air quality and sources of

pollution, a disappointing few on the health of the basin's forests, shrublands, grasslands, and wetlands and on the status of the myriad plant and animal species they support. This assessment pulls together this scientific record and makes it accessible to those who might use it for guidance.

At the center of this document are five core chapters that provide a comprehensive foundation of baseline information to assist resource planning at Lake Tahoe. The first of those core chapters, Chapter 2, reviews the environmental history of Lake Tahoe. Selective treatments of Tahoe's discovery and dynamic early years of development and exploitation have been presented before, but not with the empirical detail in this chapter. Chapter 2 recognizes and elevates the knowledge accrued by the Washoe tribe during its long stewardship of the lake basin and its resources. The chapter's review of historical knowledge is reinforced with detailed timelines.

Chapter 3, on Lake Tahoe's atmosphere and air quality, is built around the quantitative Lake Tahoe Airshed Model (LTAM), which was developed specifically to describe current atmospheric circumstances in the basin and to predict outcomes associated with diverse management options. Several results are provocative. For example, prescribed burn treatments in autumn are more likely to lead to air quality violations than are prescribed burn treatments in summer. That finding will interest managers who have hoped to employ more intensive forest management techniques during shoulder seasons, when both fire danger and basin visitation are low.

Chapter 4 consolidates the best available scientific information on the basin's dominant issue—the clarity of Lake Tahoe itself. Anticipating a comprehensive lake clarity model, this chapter reviews the substantial standing literature on the status of the lake and the sources of the sediments and nutrients that are compromising its fabled transparency. Despite the depth of this treatment and the solid evidence linking upland sources with inputs to the lake, the chapter shows that much has yet to be learned before restoration efforts can be efficiently prioritized to maximize benefits and minimize costs.

Chapter 5 of the assessment takes on three key interconnected issues in managing Lake Tahoe's biotic environment. The chapter provides information that can assist in managing the basin's forested lands to conserve and expand current remnant old growth forest patches, thus facilitating movement toward historic forest composition and structure. It presents an analysis of fire risk in the basin, which can assist fuel reduction prioritization schemes and, ultimately, the return to a more natural fire regime. Additionally, the chapter documents the biological diversity of the basin and highlights conservation needs and priorities that will be useful in planning conservation measures for biotic resources in the face of intensive management actions.

Chapter 6 distills sources of information for an array of socioeconomic variables that link key environmental issues to human activities in the Lake Tahoe basin. The chapter presents an institutional assessment that describes the basin's unique structures of governance and interrelationships among governmental authorities, as well as routes and capacities for public input. This selective treatment of a widely dispersed body of information provides a foundation for expanded analysis of the human dimension in ecosystem planning for the Tahoe basin.

Key Findings

The Watershed Assessment Team has chosen to present that wealth of information on Lake Tahoe, its surrounding landscape, and its people in a format that organizes data, analysis, and narrative as answers to explicit questions about the basin's management and policies. What follows are some of the more significant observations and findings in the core issue areas.

Environmental History

The Lake Tahoe basin embodies the consequences of a long legacy of human interactions with the environment. Interactions during the past 120 years have involved substantially greater changes in the vegetation and biota of the watershed than in previous periods, and are largely responsible for the current decline in the clarity of the lake.

1. The climate at Lake Tahoe is subject to cyclic dramatic changes affecting the level of the lake and the biota in the basin. The current climate is wetter than the climate that existed at the turn of the 20th century, therefore even if human impacts to

basin resources could be reversed, restoration still could not achieve ecosystem conditions that existed at that earlier time.

2. Attempts to restore the Lake Tahoe ecosystem will benefit from an understanding of the ecological role of aboriginal people, and how their management and subsequent management by Euro Americans have affected the structure, composition, and function of the ecosystem. Understanding how terrestrial and aquatic systems have responded in the past will help us to understand how they will respond to future management.

Air Quality

Although visibility at Lake Tahoe has been a concern for more than three decades, a basin-wide atmospheric sampling scheme addressing nutrients that affect lake clarity has not been established. As a result, sources of air pollutants in the Tahoe basin, as well as the contribution of those pollutants to lake nutrification, have not been conclusively ascertained. A Lake Tahoe airshed model (LTAM), developed specifically for this watershed assessment, has provided valuable predictions about the basin's atmospheric quality, descriptions of likely roles of pollutant sources and cleansing processes, and hypotheses that can be tested in future empirical studies.

Key findings of the air quality assessment are as follows:

1. Atmospheric deposition is the source of about a fourth of the phosphorous and nearly half of the nitrogen contributing to the nutrification of Lake Tahoe. Air quality studies have yet to ascertain the specific sources of these pollutants, but in-basin wood smoke and road dust are hypothesized to be significant sources of atmospheric phosphorous. Although a greater accounting of nitrogenous atmospheric compounds has been established, the relative atmospheric contribution from in-basin and out-of-basin sources has not been established. Further study of the links among sources, transport, chemical transformation, and deposition to the surface of Lake Tahoe will be necessary to complete integrated management models.

2. Historical wildfires with a 30-year return in the basin and an average of 30 acres per day during the summer burn season would not have reduced visibility below the current TRPA threshold for either regional or subregional visibility, according to preliminary predictions from the LTAM.

3. The LTAM predicts that 40-year return prescribed fires burning 125 acres per day in the autumn will result in significant subregional violations of both the human health-based air quality standards for particulate matter and TRPA visibility thresholds. Similarly, 20-year return prescribed fires burning 250 acres per day in the autumn will violate both health and visibility standards.

4. The LTAM predicts that maximum exposure of air pollutants to the lake surface occurs during the time of greatest atmospheric inversion, mostly during summer nights and early mornings, especially during winter. The situation is exacerbated by weak downslope winds that push human-generated pollutants over the lake each night, but the link between this exposure and deposition to the lake is uncertain.

5. Based on the predictions of the LTAM, fire prescribed for forest health is best conducted when ventilation is good, which typically occurs in the summer daytime.

6. An analysis of air quality data from all urbanized areas of California reveals that South Lake Tahoe is unique in exhibiting ozone concentration increases over the last 20 years. One hypothesis is that this increase is due to rapid development in the foothill communities east of Sacramento and Stockton, which is a source for ozone precursor pollutants.

7. Carbon monoxide in the basin has decreased by more than two thirds from 1970s levels. This has resulted from lower automobile emissions and has occurred despite increased traffic flow over the past two decades.

8. No significant upward or downward trend in atmospheric quality is concluded from particulate matter concentration data gathered by the TRPA at South Lake Tahoe.

9. Efforts to protect air quality are based on human health standards, rather than on standards that are designed to assure ecosystem health. More rigorous standards will be needed to limit atmospheric deposition to levels compatible with the recovery of Lake Tahoe.

10. An extensive search of air quality data at Lake Tahoe reveals the need for a comprehensive focused study of the impact of the atmosphere on the Lake Tahoe ecosystem.

Upland Water Quality and Lake Clarity

Lake Tahoe's water clarity has been measured since 1968. The long-term trend shows a significant ($p<0.001$) decline in clarity at a rate of -0.25 meters per year (m/yr). This decadal-scale change in clarity appears to be due to accumulations of algae and small mineral particles. Among the first visible evidence of eutrophication of Lake Tahoe was the increased amount of attached algae, or periphyton, growing along the shoreline. This increase in periphyton growth coincided with the period of rapid growth and development within the basin and can be attributed to an increase in nutrient loading (nitrogen and phosphorus) from the surrounding watershed via streams and ground water, supplemented by airborne nutrients. Spatial variation in periphyton growth around the lake reflects localized differences in nutrient sources that are linked to human activities. Since land development in the Tahoe basin began to escalate in the late 1950s, both phytoplankton productivity and human population density have risen. The first measurements of phytoplankton growth in Lake Tahoe were conducted in 1959. At that time, the loading rate was slightly less than 40 grams of carbon per square meter per year and was typical of an environment extremely deficient in plant nutrients. Values now commonly exceed 160 gC/m2/yr, with yearly increases of approximately five to six percent.

Existing data show a long-term shift from colimitation by both nitrogen (N) and phosphorus (P) to predominantly phosphorus limitation. These results confirm the value of current efforts to reduce P loading through erosion control and similar projects. Given the current close balance between N and P and the uncertainty about future nutrient limitation under changing loading conditions, it is not prudent to completely discount efforts that focus on N control. However, given the current conditions of P limitation in Lake Tahoe and the absence of unambiguous data on sources of atmospheric N, emphasis on projects that serve to control P inputs are warranted.

The following key findings begin with a discussion of nutrient and sediment sources and delivery and of nutrient cycling as they relate to control efforts. This is followed by a discussion of phosphorus and fine sediment control, which is believed to be central to the eventual success of reversing the declining trend in lake clarity. The water section concludes with discussions of lake water quality, nutrient dynamics, and lake biota.

Nutrient Budget

Nutrient loading to the lake is responsible for algae growth, which in turn has been a significant factor in the decline of clarity. Therefore, an essential element in reversing the decline in clarity is to control nutrient loading to the extent practicable. A quantitative nutrient budget identifies those sources that contribute most of the phosphorus and nitrogen to the lake. One of the key findings (and new information) from this assessment is the completion of the following preliminary nutrient budget.

1. Of the estimated 418 metric tons of nitrogen loaded to the lake during a representative year, more than half comes from atmospheric deposition. Direct runoff, stream loading, and ground water contribute *approximately* 10 percent, 20 percent, and 15 percent, respectively. Of the 45.7 metric tons of (total) phosphorus, about 27 percent comes from the atmosphere, while direct runoff, stream loading, and ground water account for about 34 percent, 29 percent, and nine percent, respectively. Shoreline erosion appears not to contribute significantly to nutrient loading. Independent measurements of nutrient loss from Lake Tahoe (in the form of sedimentation to the bottom and outflow) agree with source estimates.

Sources and quantities of biologically available phosphorus (BAP), which is believed to be primarily responsible for the algae growth, have not yet been completely assessed. Data on BAP are required for cost-effective phosphorus management programs, and such data would improve the accuracy of the water clarity model, which is being developed to assess the impact of P-reduction strategies. Nonethe-

less, the loading budget for dissolved-P, an initial estimate of BAP, was determined to be approximately 17 metric tons, or about a third of the total-P load. This level of contribution is not uncommon in the scientific literature and serves as a starting point for future refinements. (Note: this does not consider potential contributions of BAP from the particulate pool once that material enters Lake Tahoe.)

Sediment

2. Studies from the Tahoe basin show that movement of total phosphorus in the tributaries to Lake Tahoe correlates with sediment transport, supporting the contention that erosion and nutrient loading are related; however, this relationship is complex. The bulk of sediment is delivered during the spring snowmelt, although rainstorms can cause high runoff at any time. Sediment transport thus is variable, depending on erosion sources, streamflow, velocity, and volume. Much of the year-to-year variation in sediment loading in Lake Tahoe tributaries is directly related to the magnitude of rain and snow during the year.

3. A number of independent investigations identify streambank erosion as a very important source of suspended sediments in the tributaries to Lake Tahoe. The extensive road network around the lake, along with other forms of impervious land surface coverage and land disturbance, have caused changes to watershed hydrology. These changes in hydrology in turn affect stream morphology and result in the loss of streambank material through erosion.

Investigations suggest that effects of land development are evident primarily during years of high discharge, indicating that sediment and nutrient transport have a "threshold" relationship with flow. When total annual precipitation exceeds 100 to 150 centimeters, proportionately higher sediment and nutrient loads are delivered to the lake from west shore streams.

4. Surface erosion is also a significant contributor to suspended sediment. Erosion potential is linked with site condition, amount and type of runoff, and ground disturbance. Studies on Trout Creek and the Upper Truckee have reported that roadways were responsible for 48 percent of the suspended sediment found in the streamflow. Another study found that the greater the proportion of natural undisturbed conditions within 100 meters of a tributary, the lower the average amount of sediment discharge contained in the streamflow. The greatest adverse impact from recreational use was found to occur within 50 meters of the streams.

Phosphorus

The chemistry of phosphorus and its use by algae is only partially understood. In the absence of a conclusive understanding, P-control efforts should consider the elementary relationship between nutrient delivery and human activities. Effective control strategies must consider phosphorus transport and utilization by algae. Several key findings can be drawn from the current state of our knowledge regarding phosphorus transport in the basin's streams, which are being monitored as part of the Lake Tahoe Interagency Monitoring Program (LTIMP). Importantly, a detailed understanding of P transport from the atmosphere and direct runoff is still lacking, compromising our ability to set these findings in a complete source-control context.

5. Total phosphorus (TP) is found in two main forms—dissolved and particulate. Each form has an inorganic and organic component. Both forms are only partially available to lake phytoplankton (that is, readily taken up in growth and metabolism) or for storage. Of the dissolved forms, inorganic P (orthophosphate) is considered to be immediately bioavailable to phytoplankton, while only a portion of the dissolved organic P may be bioavailable. The bioavailability of particulate-P is quite variable among aquatic systems and depends on physical (desorption), chemical (dissolution), and biological processes (enzymatic degradation). The length of time that particulate matter stays suspended in water depends on a variety of factors, including material composition, particle size, and water turbulence. All of these factors considered simultaneously makes it difficult to quantify a nutrient budget for biologically available-P. It is not uncommon for 6 to 40 percent of the phosphorus bound by suspended sediments in tributaries to be ultimately available.

Observations suggest that all sediment is not the same with regard to its "P quality," and there

is a need to ascertain whether control measures for TP and bioavailable P are similar. To better assess lake phytoplankton growth, bioavailable P from all sources needs to be assessed, as well as information on P bioavailability and recycling in the lake's resident pool of particulate matter.

6. Analyses of LTIMP water quality data indicate that phosphorus loads are dominated by the particulate-P fraction. During water year 1995, between 56 percent and 94 percent of the total-P in the monitored streams was in this form. The contribution of phosphorus in the dissolved form is of particular significance because algal growth bioassay experiments show that Lake Tahoe phytoplankton particularly respond to this fraction. Annual average total-P concentrations for nine LTIMP streams from 1989 to 1996 ranged from 24 micrograms per liter (µg/L) in General Creek to 220 µg/L in Third Creek. Relationships between total suspended solids (TSS) and total-P were generally significant ($p < 0.05$); however, soluble and TSS typically were not related.

Predicted concentrations of total-P in Tahoe basin streams in the absence of disturbance have been estimated to be on the order of 12 to 15 µg/L, consistent with the current California water quality objective of 15 µg/L.

7. Phosphorus source-sink behavior is much more difficult to characterize than is that of nitrogen. Its mobility traditionally has been related to sediment transport and deposition of particulates. Recent research suggests that P also can form mobile complexes with mineral and organic colloids. At the watershed scale, geology, vegetation, and extent of erosion all affect the form and amount of phosphorus in tributary discharge. Soil core studies have identified a delayed peak release of inorganic P during leaching that could be significant during summer rains. The bioavailability of organic and mineral colloids of P are not well understood.

8. Numerous previous studies in the Tahoe basin suggest that on a localized scale, land use can have a large effect on the water quality of surface runoff. Factors, including total precipitation, drainage density, road miles, distance to tributary, land disturbance or coverage, slope, can affect the quality of runoff. Statistical analysis of the LTIMP data suggests that no single factor, whether natural geomorphic or anthropogenic, adequately explains all the variation between and within watersheds.

Nutrient Cycling

Understanding how nutrients are cycled in the watershed and then transported to ground and surface waters is essential to understanding how atmospheric deposition and management activities (such as prescribed fire) affect the delivery of nutrients to Lake Tahoe. The following findings are pertinent in this context.

9. Nutrient cycling through vegetation and soils of the Tahoe basin is not well understood. The relationship between nutrient cycling and the transport of nutrients and fine sediments in shallow subsurface flows is likely to be important and is undoubtedly affected by changes in vegetation, or surface disturbances, or even air quality.

10. Colloid nutrient transport can play a significant role in the migration of organic and inorganic nutrients to streams. Research at Lake Tahoe on this topic gives reason to expect that nutrient dynamics at this small scale are important, both in the upper watershed and in association with sedimentation and infiltration processes in best management practices (BMPs).

11. Several studies have indicated that elevated nutrient levels are present in some ground water and that ground water contributes nitrogen and phosphorus to Lake Tahoe. Discharge of nutrients to the lake via ground water flow can influence the growth of attached algae. Many soils of the Tahoe basin exhibit preferential infiltration and subsurface water flow, and these flowpaths can serve as shortcuts for ground water. As such, nutrients tend to bypass direct contact with the soil matrix, which would otherwise facilitate nutrient removal from the percolate. Research is needed to understand the dynamics of this subsurface transport process, which may be particularly important for the transport of biologically available phosphorus from fertilizers, for example.

12. Very little is known in the Tahoe basin about the influence of prescribed burns on water quality. The potential for site erosion following a fire depends on slope, initial erodibility of the soil, slope,

precipitation characteristics, severity and extent of fire, development of soil water repellency, and plant and organic cover remaining on the site following a burn. Nutrient availability following prescribed burns is affected by such factors as calcium, which forms a Ca-P complex that is biologically unavailable for algal uptake.

13. Studies suggest that climate change could profoundly change the magnitude, timing, and form of precipitation and hydraulic discharge in the Tahoe basin. Monthly estimates of runoff for the Upper Truckee River reveal a strong influence from the seasonal patterns of precipitation. Decreases in the proportion of winter precipitation that falls as snow, and an earlier and faster spring snowmelt associated with regional warming, could greatly affect nutrient cycling.

Effectiveness of BMPs

The current control strategy for phosphorous is to prevent erosion at its sources whenever possible. When this action cannot be realized with complete effectiveness, a secondary target is to treat surface runoff by containing sediment within retention structures and vegetated areas. Both these actions reduce the delivery of phosphorus and fine sediments to the lake. However, given our evolving understanding of the role of biologically available P in algae growth and the role of small particulates in lake clarity, the function and efficacy of our current strategy should be examined to maximize treatment within the framework of adaptive management. The following should have bearing on BMP success.

14. The Lake Tahoe basin is a large, topographically complicated ecosystem, with 63 individual watersheds and numerous intervening tributaries to the lake. Because of this complexity, it is highly unlikely that any single mitigation project will have a significant demonstrable impact on lake water quality. As a consequence we need a comprehensive watershed approach to management.

15. Quantitative research on BMP effectiveness is still needed. A large number of erosion control and other water quality improvement projects have been carried out in the Tahoe basin over the past fifteen years. Much has been learned from the experience of constructing these projects and from observing project performance in the field. While some of the information gleaned from the projects has been used to improve the designs of subsequent projects, most of the information has been qualitative and based largely on occasional site inspections and observations.

The lack of comprehensive and unambiguous data on BMP implementation presents a barrier to a clear understanding of their effectiveness. Not only do many BMPs take years to reach peak effectiveness, hydrologic variability during short monitoring periods adds significant complications to evaluation efforts. In addition many BMP evaluation studies at Lake Tahoe lack reference or control sites.

16. A priority or ranking system for selecting BMP and other restoration projects is lacking. The ranking system should include, but not be limited to, such considerations as distance from the lake, proximity to roadways, slope, soil erodibility, hydrologic connectedness to other disturbed areas, cost, ease of maintenance, expected reduction in loads, and logistical concerns.

17. Current levels of funding for research and monitoring in the areas of BMP effectiveness, source identification and control, and treatment of runoff in the Tahoe basin is inadequate to meet the demands of adaptive management.

18. While designing and monitoring BMPs is the responsibility of the implementing agency, what is learned from these projects is of significance to the overall effort of restoring Lake Tahoe and must be integrated into a multiagency, interdisciplinary conservation effort.

Lake Response to Nutrient and Sediment Loading

19. Year-to-year variability in primary productivity is directly related to the depth of mixing. However, the accumulation of nutrients and fine sediments in Lake Tahoe is considered to be responsible for long-term trends in algal growth rate.

An important lesson from the long-term data on clarity is that analysis of short time series may result in incorrect interpretations of water quality and lake clarity data. Individual Secchi measurements over the period of record have ranged from as great as 43 meters, during an upwelling event in February 1968, to as low as only 8.5 meters, in June 1983

during an El Niño year. The poorest clarity is associated with years of deep lake mixing and high surface runoff. Lake water appeared green when the lowest value was measured.

20. Monitoring the deep waters of Lake Tahoe (450 meters) shows a decline in dissolved oxygen between 1984 and 1998. While levels of oxygen are sufficiently high at this time to maintain beneficial lake processes and conditions, if the trend continues, levels could fall to below those recommended for salmonid fish in as few as 10 years. This decline in dissolved oxygen does not pose an immediate threat to the clarity of Lake Tahoe, but observed changes in this fundamental ecosystem parameter are cause for concern.

21. Nitrogen and phosphorus doubling times and settling rates occur on a time scale of a few decades. Loss of these nutrients from the Lake Tahoe water column is slow. The depth of the lake allows bacteria, fungi, and other aquatic microbes to effectively recycle these nutrients before they settle onto the bottom. The most efficient management strategy is source control, which could keep these materials out of the lake.

22. Studies of deep lake sediment cores indicate that the baseline (predisturbance) sedimentation rate was 0.006 ($\pm$ 0.002) g cm^{-2} y^{-1}. This is slightly less than the sedimentation rate that was estimated for the intervening period between Comstock logging and urbanization (approximately 1900 to 1950). Because these rates are comparable, it would appear that landscape recovery was rapid after clear-cut logging ended. Restoration efforts can be expected to accelerate recovery rates.

Lake Biota

Species diversity in Lake Tahoe has been greatly affected by the intentional and unintentional introduction of exotic species, and many communities of both plant and animal life have undergone significant change since studies began. In the case of phytoplankton and zooplankton, these communities have a direct impact on lake clarity. For other species, changes have affected the lake's food web and consequently have altered its fishery.

23. Phytoplankton communities are central to many of the environmental issues at Lake Tahoe. They are responsive to physical and chemical changes in the aquatic environment. Long-term data for biomass and species composition show changes in community composition and biodiversity toward a more eutrophic environment. If nutrient loading continues, one or more of the following scenarios is likely to occur: primary productivity and phytoplankton standing stock will increase, species richness of phytoplankton will increase, phytoplankton community dominants will shift, or the deep chlorophyll maximum, arguably the most stable phytoplankton niche in Lake Tahoe, will exhibit changes in species assemblage and distribution.

24. The current assemblage of plants and animals in Lake Tahoe is largely the result of human influence in the Tahoe basin. Ever since Europeans began settling around the lakeshore, exotic species have been introduced both intentionally and accidentally.

The most visible and perhaps best known species in the benthic invertebrate community at Lake Tahoe is the signal crayfish. First introduced into the Lake Tahoe basin in 1895, the crayfish has become widespread throughout the shore region of the lake within mean density estimates of 10 individuals per square meter. One of the most important recent introductions was that of the omnivorous opossum, or mysid, shrimp in the early 1960s by California and Nevada fish and game officials. The previously "simple" zooplankton food web was dominated by four genera (two calanoid copepod, *Diaptomus* and *Epischura*, and two cladocerans, *Daphnia* and *Bosmina*) before the mysid introduction; but the food web was changed dramatically to a simpler community dominated only by the two calanoid copepods.

The history of the Lake Tahoe fishery has been marked by numerous species introductions. Lahontan cutthroat trout once dominated Lake Tahoe's waters and produced individual fish weighing more than twenty pounds. This species is no longer present in the lake due to human activities in the basin that included commercial fishing, water and land management practices, and exotic species introductions.

Biological Integrity

As noted above, three issue areas dominate discussions of current biotic conditions in Lake Tahoe. Managers have expressed a desire to return to a beneficial historical landscape condition by using the following techniques:

- Using management techniques to encourage the expansion of old-growth forest remnants and to return stands to a composition and structure more like that before the Comstock logging period;
- Reducing fire risk and hazard in the basin, while returning fire as a natural ecosystem disturbance feature; and
- Conserving and enhancing existing plant and animal diversity, potentially restoring species that have suffered population declines or extirpation events and eliminating or reducing threats from invasive organisms.

The following findings pertain to these goals.

Forest Composition and Structure

1. Five major forest types (or series) exist in the basin—Jeffrey pine, mixed conifer, white fir, red fir, and subalpine mixed-conifer forests. Each type may be subdivided into relatively moist phases (west side, more overstory cover) and dry phases (east side, less overstory cover). There are old-growth examples of each type and phase, which have been located and quantified on the ground and via interpretation of remotely sensed images.

2. In all cases except the red fir series, the abundance of overstory tree species (more than 180-years old), understory tree species (60- to 180-years old), and saplings (10- to 60-years old) were unrelated to each other; that is, the cohorts had germinated and grown up in different environments that were typical of the precontact period, the Comstock period, and the post-Comstock period.

3. During the last 150 years there has been a pronounced shift away from pine and toward fir in younger cohorts/canopy strata. White fir and incense cedar have doubled in relative abundance over the past 200 years, whereas Jeffrey pine has declined by half.

4. Reconstruction of precontact old-growth forests indicates that lower montane forests had a nearly equal ratio of white fir to Jeffrey pine on the drier east side but a 1.5:1 ratio throughout the basin. Tree density then was about 120 per hectare. Upper montane forests were more dominated by fir (2:1 ratio of red fir:pine) and had a higher tree density of more than 160 per hectare. The size distribution, measured by diameter at breast height (dbh) of upper and lower montane forest trees was flat, indicating that stands had a complex multiple-age structure.

5. Current lower montane forests have four times the density, an importance of white fir and incense cedar that is two- to three-fold higher, and an importance of Jeffrey pine that is 50 percent less than precontact forests. Upper montane forests have experienced a doubling of density but otherwise little change in the importance of individual species. Seral stands overall exhibit a 70 percent higher disease incidence, a five percent greater mortality, and 184 percent greater tree density than vegetationally comparable old-growth stands. Most of the increased density is in the smallest and youngest cohorts, less than 16 inches (40 cm) dbh.

6. Old-growth forests exhibit lower rates of infestation by dwarf mistletoe (on white fir and Jeffery pine) and rust (on incense cedar) than do second-growth forests, but there is no difference in the incidence of bark beetles nor of tree deaths over the past decade (although second-growth stands show higher mortality among younger trees than do old-growth stands).

7. Old-growth conifer forest in the basin today totals 2,138 hectares, which represents five percent of the entire forested area. In precontact time, old-growth may have occupied 55 percent of forest area, or 23,424 hectares. Although there is scientific consensus that current proportions are inappropriately low, there is no consensus as to an ideal proportion of old-growth and other seral stages.

8. Management of seral forest toward old-growth status would be best served with a focus on the few remnant old-growth stands where immediate neighborhoods are most suited to thinning and prescribed fire. As techniques become proven in their effectiveness and as monitoring becomes efficient

and accurately predictive, management can be extended to larger neighborhoods and other old-growth remnants.

Fire Management

9. Fires in the 20th century have been few, due to effective fire suppression and the high elevation environment, with its short fire season. Fire detection and suppression is excellent. Because of the large number of fire departments, response time to human-caused fires is among the shortest in the Sierra Nevada. Nonetheless, some of the highest fire ignition rates in the Sierra Nevada occur in the basin, concentrated around the urban interfaces.

10. Should a fire escape initial control attempts under extreme wildfire conditions, at least 50 percent of the area in the resulting burn would likely be crown fire, with overstory tree mortality greater than 50 percent. But even under the most extreme conditions, fires are unlikely to spread to more than one or two subwatersheds because of their orientation relative to wind patterns and the dissected topography along the lakeshore. Fire escape rates are low, at less than half a percent of recent historical ignitions.

11. Tree mortality (representing severity of fire effects on vegetation) likely would be high in most fires, given current surface and ladder fuel conditions. Locations of drought-, insect-, and pathogen-related tree mortality can result in decreased fire line construction rates and increased tree mortality in fires. These effects are most important where mortality is widespread and continuous. Drought-stressed trees often succumb to fires more readily than nondrought-stressed trees.

12. The greatest concern with large fires in the basin is the high property and natural resource values that they threaten (including lake clarity and limited old-growth forests). Even a small wildfire in the basin is potentially a significant event because of the juxtaposition of high ignition potential, high density and value of human developments, and high fuel hazard.

13. A significant proportion of the basin (53 percent) has little or no fuels due of the extent of water and rocky areas. Little or no fuels occur in 23 percent of the terrestrial portion. However, the narrow band of greatest fuel availability coincides with the band of greatest human development.

14. A combination of increased fire prevention, education, and strategic fuel hazard reduction will be most effective at reducing the likelihood of damaging fire in the basin. Fire prevention and education can reduce current high levels of human-caused ignitions that contribute greatly to fire risk.

15. Historically 2,100 to 8,000 acres burned on average annually in the basin, compared to fewer than 500 acres of underburning currently.

16. Because fire played a prominent role in shaping vegetation in the past, fully functioning upland ecosystems are not achievable without reintroducing fire into the landscape. While some effects of fire can be at least partially mimicked by mechanical treatment, other effects cannot. To reintroduce fire in some areas, understory and midstory crowns may require thinning, particularly in pine and mixed-conifer forests. Otherwise, repeated applications of underburning would need to be completed to duplicate historic fire effects and conditions.

17. Understory burning is the most effective treatment for reducing surface fuels, which are the greatest contributor to fuel hazard. Other treatments, especially biomass removal, can be effective at reducing ladder fuels and surface fuels. These treatments may be most useful near urban areas, where smoke concerns may contribute to reducing burning opportunities.

18. Fire should be reintroduced first in areas that have missed the most fire cycles (pine and mixed-conifer, and then red fir forests), areas with the greatest concentrations of remnant old-forest (west and south shore), and forest areas on most erodible soils. The most efficient way to reduce fire risk and hazard is to rank locations with the characteristics above, based on closest proximity to urban interfaces, highest levels of surface fuel loading, and highest proportion or continuity of understory vegetation and ladder fuels. In other words, the best combined strategy for reducing fire hazard and risk and for restoring fire as an ecosystem process is to focus hazard and risk reduction in the urban interface and to emphasize reintroduction of fire into high value old-growth areas and watersheds with sensitive soils.

19. Export items from forests that affect other ecosystem components in the basin can best be expressed, quantified, and monitored as amounts of N and P in litter, soil, or ash, in the rate of litter decomposition, and in the pH or carbon:nitrogen ratio of litter and surface soil. For analytical and management purposes, vegetational taxonomic complexity can be simplified by lumping species into three functional groups that have significant ecological importance—conifer trees, nitrogen-fixers, and shrubs.

20. Complex forest architecture, seral status, and health can be simply quantified and monitored by measuring the density, mortality, regeneration, and canopy cover of just the tree species. The impact of pathogens and herbivorous insects can be monitored in terms of tree growth (trunk diameter change at breast height), leaf area index or canopy cover of the overstory, rate of litter accumulation, and amount of coarse woody debris.

Aquatic Ecosystems

21. Seventeen aquatic ecosystem types occur in the Lake Tahoe basin. These types encompass a variety of flowing and standing water ecosystems, including marshes, bogs, and fens, which are rare in the Sierra Nevada. These aquatic ecosystems have been degraded since the mid-1800s. Principal agents of degradation have included grazing, timber harvest, channel alterations, and the introduction of exotic species. Impacts continue today, although restoration activities and changes in land use policy have counteracted some of their consequences.

22. A substantial proportion of the basin's aquatic ecosystems are of conservation concern. The diversity, rarity, and disturbance of aquatic ecosystem types in the basin appears to be higher in the basin that elsewhere in the Sierra Nevada. Lentic (standing water) types are generally more rare and degraded than lotic (flowing water) types. Aquatic types on the east side of the basin are particularly vulnerable because of their rarity. No strategy currently exists for the conservation of biological integrity in aquatic ecosystems in the basin.

Biological Diversity

23. Ecologically Significant Areas constitute geographic areas, species assemblages, or ecosystem types that are unique or species rich, thus contributing disproportionately to biological diversity in the basin relative to their spatial extent. The nine types of Ecologically Significant Areas identified in the assessment occupy less than 5 percent of the basin. Based on a limited set of conservation criteria, old forests, marshes, bogs and fens, deep-water plant beds, Lake Tahoe, aspen groves, cushion plant communities, and areas with high plant community diversity, and riparian areas with potentially high species richness are identified as Ecologically Significant Areas.

24. Biological diversity in the Tahoe basin has been diminished by losses of native species and the establishment of exotic and invader species. Vertebrate species extirpations, including two known and ten suspected species losses have resulted from regional declines, fire suppression, and the basin's geographic (topographic) isolation. Species additions have resulted from direct species introductions, increased human settlement, and, again, fire suppression and the basin's isolation.

25. Data on the current composition of species in the basin were compiled. A total of 317 vertebrate species are extant in the basin. A total of 1308 vascular plant species are either confirmed or suspected to occur in the basin. An estimated 379 invertebrate families and 339 genera of fungi also occur in the basin. Much basic information on the species composition of the Tahoe basin is lacking, particularly for nonvascular plants, invertebrates, and fungi.

26. Concern about the Tahoe basin's biological diversity is justified based on threats of species extirpations and declines, and continued invasion by exotics, both leading to further degradation of biological diversity and integrity. Many species are also of cultural interest and value, including harvested, watchable wildlife, human conflict, and management agency emphasis species. A total of 272 focal species are identified based on ecological and

cultural criteria, including 162 vertebrates (60%), 15 invertebrates (5%), 57 vascular plants (21%), 16 nonvascular plants (6%), and 12 fungi (8%). Most species are of concern for ecological reasons, and conservation measures will be required to maintain and conserve biological diversity.

27. Several exotic pest species occurring in the basin could cause future ecological damage, primarily through predation on and competition with native species. In many cases, significant damage has likely already occurred. Exotic animals of particular concern include beavers, bullfrogs, introduced trout, bass, opossum shrimp, and crayfish. Noxious weeds of particular concern include tall whitetop, Scotch thistle, and Eurasian watermilfoil. Domesticated species, such as dogs, cats, and cattle, that interact with native species are potentially troublesome.

Social, Economic, and Institutional Conditions

Socioeconomic data proved to be dispersed, and for critical issues, data were nonexistent. For those reasons key findings in this area are likely to be most valuable in suggesting crucial areas for future investigation.

1. After a period of particularly rapid growth from the 1950s through the 1970s, the total permanent resident population in the basin has held fairly constant during the 1990s, reaching around 55,000 at the end of the decade. The full-time resident population of the basin is under eight percent of the population of the four-county region. Growth rates in the surrounding counties are much higher than the rate of growth in the basin.

2. While the basin has eight percent of the four-county region's population, it supplies approximately 24 percent of the jobs. In 1998, the basin employed nearly 48,000 people, earning more than $1 billion in wages and salaries. Property income and transfer payments account for 32 percent of total annual earnings in the basin. Part-time, nonworking residents, defined as persons or families who live in the basin for a minimum of two months each year and who do not report income as basin residents, accrue nearly $97 million each year. Income earned by working part-time residents represents an unknown share of the labor income earned in the basin. Median incomes average about 10 to 15 percent lower in the basin compared to those in the surrounding four-county region. Median incomes from jobs associated with the amenity and recreation sectors are lower than most in the basin.

3. Affordable housing has been identified as a critical need in the basin that can be met with existing housing units and the remaining construction allocations. However, the question of how affordable housing should be equitably distributed among responsible jurisdictions (i.e., "fair share") remains unresolved.

4. Measurements of socioeconomic status, as defined in Sierra Nevada Ecosystem Project, show that the basin ranks lower than other regions in the Sierra Nevada. Nonetheless community capacity scores are among the highest in the Sierra Nevada.

Socioeconomic Indicators

5. Relatively little comprehensive economic analysis has been done in the basin to date. Most economic analyses are focused either by geographic region (e.g., the Tahoe-Truckee resort triangle or the south shore) or by industry (e.g., skiing, hotel, and gaming). TRPA thresholds do not include specific social or economic indicators, although the regional plan and each five-year threshold evaluation has recommended developing a comprehensive socioeconomic model.

6. The Tahoe Truckee Regional Economic Coalition initiated a "community indicators" process in 1993 that provides a foundation for further development of metrics of community well-being and quality of life. No institutionalized process to carry that effort forward currently exists.

Trends in Tourism and Recreation

7. Purchases made by businesses in the sectors most affected by visitor spending generate relatively few jobs and little income in the region's other industrial sectors, indicating fewer multiplier effects of visitation in the economy than might be expected. Personal consumption expenditures by people employed in the sectors most affected by visitor spending generate substantial numbers of jobs and income in the region's other industrial sectors.

8. Average daily per capita spending by Tahoe basin visitors ranges from $166 for winter visi-

tors in the south shore area to $195 for summer visitors in the north shore area. Although the large numbers of visitors increase demands for public services and such demands impose fiscal costs on the basin, relatively little information is available on the fiscal costs imposed by visitors.

9. A number of basic statistics indicate important socioeconomic trends in the Tahoe basin. Basin-bound passenger arrivals at the Reno/Tahoe airport, as well as aggregate skier days, show upward trends. There has been a decade-long downward trend in aggregate gaming revenues, with small gains during 1998 and 1999. There are relatively stable levels in aggregate lodging room nights and occupancy rates. Larger, family-based visitor groups are changing the lodging needs and recreation profiles of visitors. There is increasing ethnic diversity among visitors and evidence that recreation providers and tourist facility owners are trying to meet new and differing cultural demands.

10. A coalition of recreation providers has found increased demand for affordable snowplay facilities and larger campsites (indicating more family-oriented visitation patterns), for recreation trails in urban-suburban areas and in the backcountry, for access to and facilities on the Lake Tahoe shoreline, for youth soccer facilities and programs, and for more diverse single-participant backcountry activities.

11. Recent visitor surveys are finding increasing interest in visits to the basin during the "shoulder" seasons of spring and fall, an increasing preference for recreational driving, and perception of the basin as a full-service resort destination.

12. While residents and visitors perceive lake clarity and water purity as the two most important environmental issues in the basin, almost no information is available on the consumer's surplus that accrues to visitors or on their willingness to pay to protect the clarity of Lake Tahoe or other outstanding basin amenities.

13. Tourism contributes substantially to traffic congestion in the basin and is an important contributor to emissions from wood stoves and motor vehicles, two of the major sources of air pollution in the basin.

14. Noise and water pollution from motorized watercraft continue to have measurable impacts on both the biophysical system and the visitor/resident experience. Personal watercraft use will most likely increase significantly to at least 20 percent of all motorized watercraft use as compliant models are marketed. The combination of education and enforcement of the two-stroke and 600-foot no-wake ordinances produced improvement in watercraft use during summer 1999. TRPA's preferred alternative for buildout of additional piers, slips, buoys, ramps, and floating docks is likely to contribute to an increase in motorized and nonmotorized boat use.

Land Use

15. In 1999, approximately 4,000 parcels of land remained available for development. Under the current parcel rating system, all development allocations will have been authorized by 2007.

16. Nearly $187 million has been spent on public acquisition of 7,561 parcels between 1982 and 1999. Federal funds from the Santini-Burton Act accounted for 47 percent, California state funds for 38 percent, and Nevada state funds for 15 percent of the acquisition dollars. Twice as much Santini-Burton money was spent in Nevada compared to California. In the combined programs, nearly three times more land was acquired in California (12,232 acres) than in Nevada (4,281 acres). The ecological values of the publicly acquired parcels are thought to be quite high, especially in preventing sediments and nutrients from reaching the lake. However, there are almost no empirical data on the ecological functions of the array of public parcels in and adjacent to urbanized areas. The presence of public parcels in urban intermix zones may significantly enhance property values of surrounding homes.

Institutional Characteristics

17. It is apparent that a greater emphasis on interagency cooperation exists at the policy level than at the line and operational strata of the institutions at the center of environmental policymaking. As a result, although significant strides have been made over the last decade in forming effective coali-

tions, interagency cooperation and collaboration lag behind, potentially impeding progress on issues that require broad-based multisector cooperation. Attitudes toward collaborative approaches tend to reflect the kinds of institutional relationships that have evolved over time between local jurisdictions and regional agencies.

18. Due in part to the existence of influential coalitions, levels of political communication and knowledge sharing are sufficiently high to ensure transparency in decision-making and to reduce the problem of local capture of public resources and assets. In addition, key coalitions in the basin create a strong network of social and political communication and are important to building constituencies for regulatory and management actions. In some cases, redundancy in the system among coalitions and interagency cooperative efforts ensures sustained attention to complex problems without creating additional bureaucratic structures. Coalition support of public agencies is often important in garnering resources for those agencies.

19. The Tahoe basin's policy community recognizes and supports the critical role of science in environmental management strategies; however, many in the community are concerned about how scientific information is used in decision-making and whether it contributes to advancing the environmental agenda around which substantial consensus has already been built.

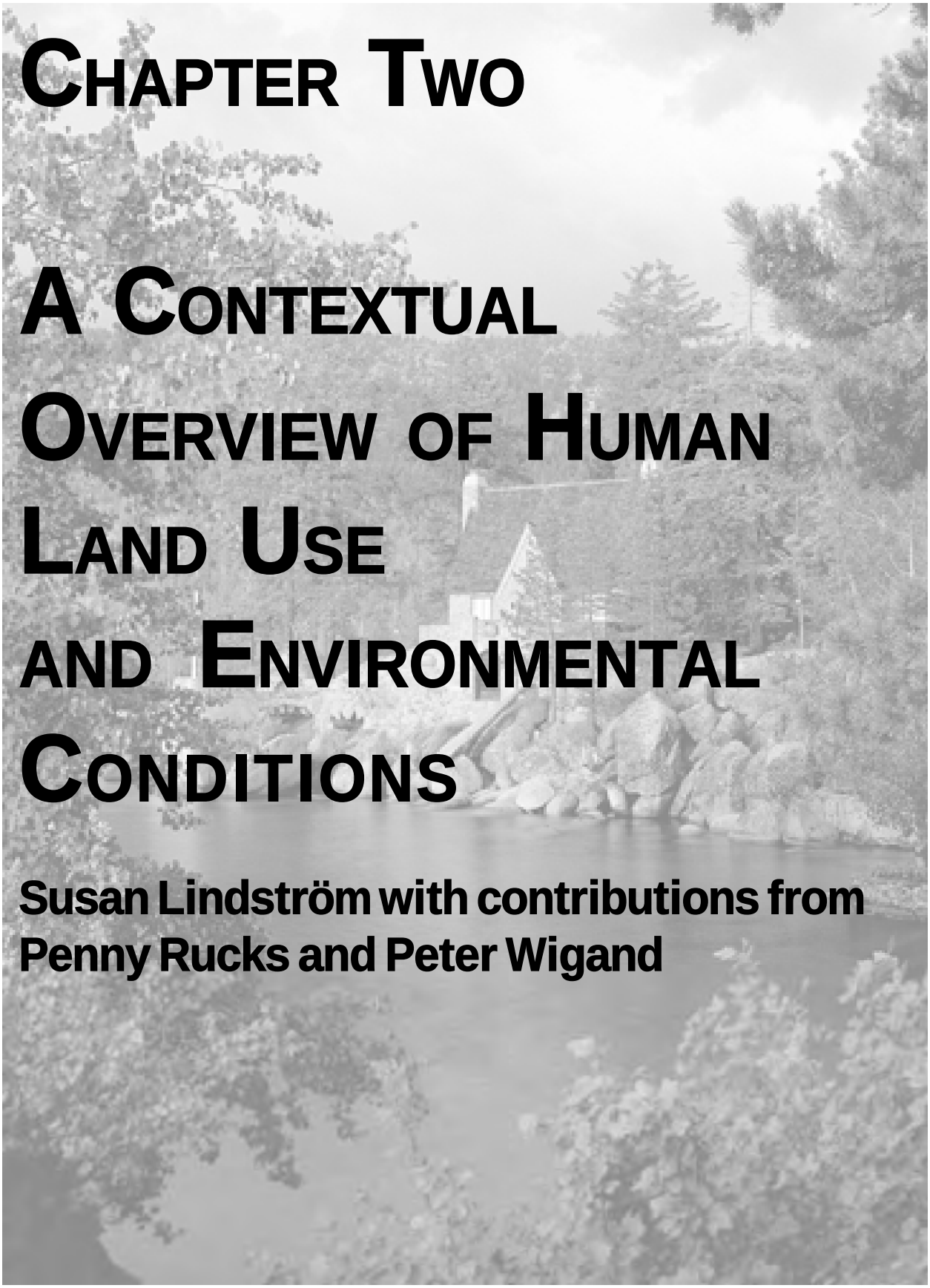
20. Many private business associations are active at a subregional scale; however, business representatives have stressed the need for a basin-wide focus among small business owners.

Concluding Remarks

The many findings in this document provide a substantial empirical foundation that can assist managers and policy-makers in identifying and prioritizing their conservation activities. It is often repeated that Lake Tahoe serves as a model for dealing with conflicting environment and economic challenges. The recent rapid regulatory response of the TRPA to emerging research showing high levels of pollution from personal watercraft supports that contention. Currently, however, the transfer of information from academic and agency scientists to managers on the ground occurs largely in ad hoc fashion, with resulting successes mixed with lesser outcomes. Integration of the broad research agenda presented in this assessment will require a highly developed institutional infrastructure explicitly designed to assure that restoration efforts in the Lake Tahoe basin are maximally effective, efficient, and accountable.

The final chapter in this document describes a means of organizing current information using conceptual and quantitative models, linking management planning with scientifically rigorous monitoring and analysis. Such an "adaptive management" response to Tahoe's complex environmental challenges is the only means to bring the best available scientific information to planned restoration efforts. Adaptive management will call for new interorganizational links to facilitate information transfer—not new layers of government but new procedures for effective delivery of lessons learned by doing, lessons gleaned from management successes and other results. Nothing less than an institutional rethinking will be necessary should we wish to achieve desired environmental results from restoration efforts funded by the expected influx of federal dollars in the coming decade.

The current draft Senate bill calling for good science in prioritizing Tahoe's management and restoration efforts can start with this assessment, but will demand a more responsive dialogue between those who do science and can provide information, and those who make policy and need information.

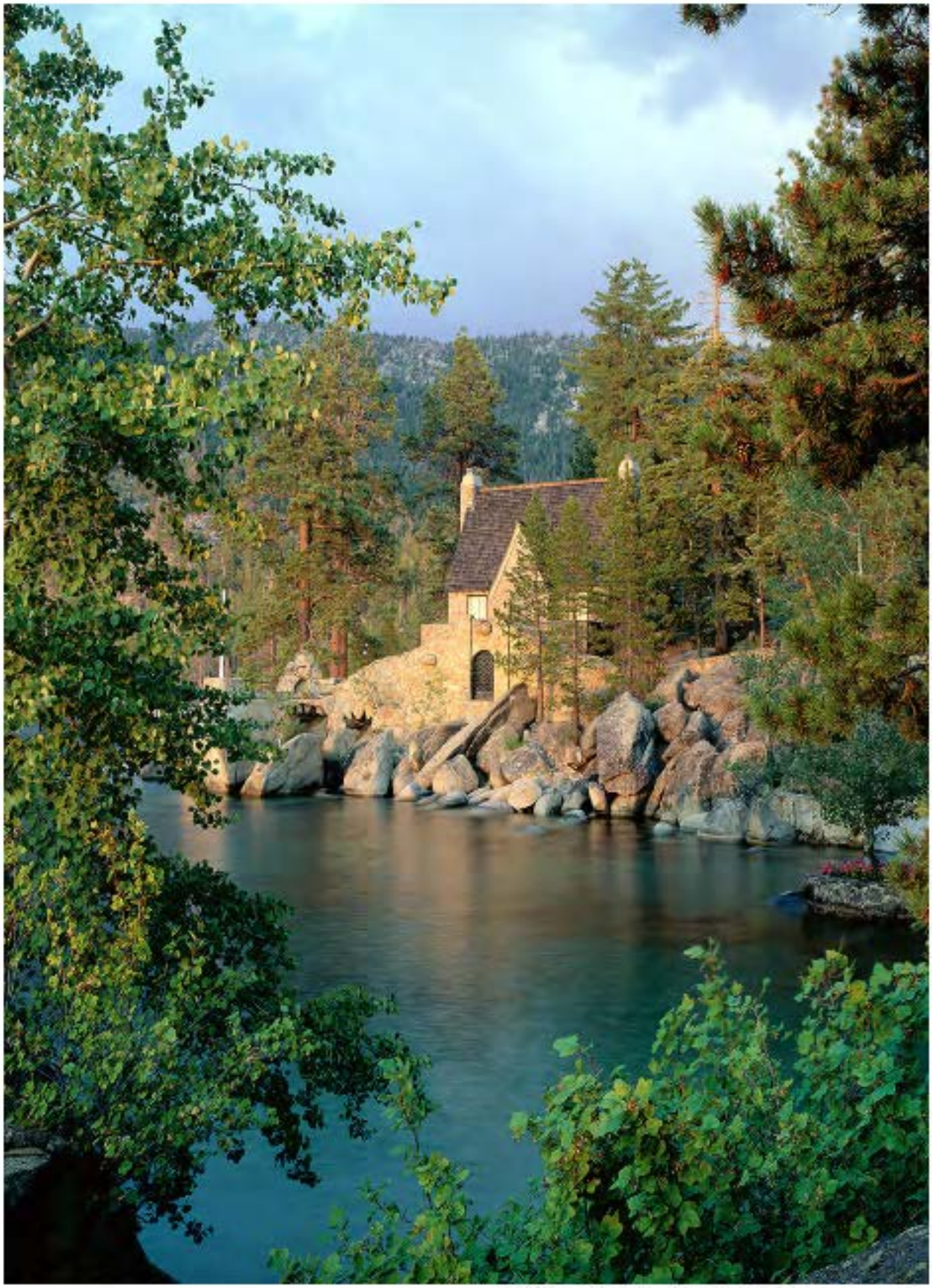


Chapter Two

A Contextual Overview of Human Land Use and Environmental Conditions

Susan Lindström with contributions from Penny Rucks and Peter Wigand

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CHAPTER TWO

A CONTEXTUAL OVERVIEW OF HUMAN LAND USE AND ENVIRONMENTAL CONDITIONS

Susan Lindström with contributions from Penny Rucks and Peter Wigand

Introduction

The Lake Tahoe basin embodies the consequences of a long legacy of human and environmental history. Here, human land disturbances were initiated by millennia of low-intensity land management by the Washoe Indians and their prehistoric predecessors. Within a century's time, indigenous practices were replaced by profound resource exploitation by incoming Euro-American populations. During the last few decades, agency regulation has struggled to control explosive community growth induced by millions of tourists who visit the Lake Tahoe basin each year.

Changing attitudes and assumptions about Tahoe's environment have both enshrined and desecrated its landscape. Native Americans considered themselves stewards of the land and sustained a balanced relationship between human society and the environment. Nineteenth century arrivals viewed the Tahoe basin as a natural setting for Comstock-era capital investment and profit. Devastating practices, such as clear-cutting forests, were acclaimed by a society that celebrated human conquest of nature as progress. During the 20th century, the emerging dominance of the tourism industry was accompanied by a growing awareness of resource protection rather than resource extraction. However, the environmental pressure of large numbers of tourists and the growing residential population that serves them has transformed the Tahoe basin into a landscape that is, paradoxically, increasingly imperiled by its own attractiveness (Elliott-Fisk et al. 1997; Raymond 1992). Tahoe's future well-being depends directly on a healthy physical and socioeconomic environment, not only the public's perception of one. With this latest shift in land use paradigms, the direction of progress for 21st century users of the Tahoe basin is less clear. In this fragile context, the Lake Tahoe environment is becoming intensively managed, partly based on scientific research findings, such as those contained in this assessment of the Lake Tahoe watershed.

Human beings have been a component of the Lake Tahoe ecosystem for at least 8,000 to 9,000 years. Contemporary land management efforts to restore the Lake Tahoe ecosystem benefit from an understanding of the long-term ecological role of aboriginal people and Euro-American settlers in the dynamics of wild plant and animal populations and their physical environments. Past land management practices engendered environmental impacts that vary in space, time, scale, intensity, and consequence. Human disturbances range widely in scale, from pruning a patch of native shrubs to clear-cutting thousands of acres of timberland. Some resources were targeted in a single brief event, while others were affected for decades or generations. Furthermore, prehistoric and historic impacts may not have extended basin-wide, and some areas may have been relatively unaffected.

In order to shape an approach to ecosystem planning and resource management in the Tahoe basin, we ask a number of key questions regarding the physical and cultural conditions that existed in the past and the scope and scale of anthropogenic, or human-induced, disturbances that have altered these conditions:

- How have climate changes affected changes in Tahoe's overall physical and cultural environment? Under varying climatic

regimes, what sustainable environmental conditions are possible in the future and what type and scale of management treatments would be required to achieve them?

- What did pre-Euro-American terrestrial and aquatic ecosystems look like, and how have prehistoric and historic anthropogenic disturbances affected changes in plant and animal communities?
- What were the prehistoric and historic fire regimes in the Lake Tahoe basin?
- What are the past and present sources of sediment and nutrients in Tahoe's watershed that affect water quality?
- How has air quality and atmospheric visibility changed from prehistoric to present times?
- What are the historic underpinnings of causal relationships among the many socioeconomic and environmental factors in the Tahoe basin?
- What are the culturally important locales and biotic species in the basin and what are the threats to these resources?

To answer these and other questions and to establish standards by which environmental health and socioeconomic health can be measured, historical data sources that are uniquely tied to the human dimension of the ecosystem are explored, together with input from the biological, hydrological, and atmospheric sciences. History directs future decision-making by setting a baseline of reference conditions to determine how present conditions differ from past conditions, the reasons for that difference, and what sustainable conditions may be possible in the future. With knowledge of how past peoples interacted with their landscape, scientists and land managers can link this information to restoration and maintenance of current ecosystems. Paleoenvironmental, archaeological, ethnographic, and historic documentation offer great time depth and are used as independent and corroborative tools to achieve a nexus between historic conditions and contemporary research, monitoring, and adaptive management. Thus, using multiple sources of information, it may be possible to achieve an understanding that would not be possible using a single source of information by itself.

To document human disturbances and environmental conditions of the Lake Tahoe landscape and to register the changing human perceptions surrounding them through time, this contextual discussion draws on the existing literature, supplemented by personal notes and experience. The overview is far from exhaustive and data are uneven. Assembled at an earlier time and for a different purpose, data are adapted to fit into the current watershed assessment context; yet, the context is intended to be interpretive and comparative, beyond merely descriptive. Integral historic descriptions are dispatched to the summary time lines at the end of this chapter. Important environmental issues and questions involving biotic health, air and water quality, and socioeconomic well-being, topics that are fully explored in subsequent chapters, are introduced here to provide historical perspective. The deliberate incorporation of paleoenvironmental, archaeological, ethnographic, and historical data into truly multidisciplinary environmental planning efforts treads untested ground. Yet, in the context of ecosystem management, these lines of inquiry reveal the considerable extent to which cultural and environmental history can effectively guide future management.

Paleoclimate and Environmental History

Environmental Change in the Tahoe Sierra

The resolution of fundamental issues concerning the nature and timing of cultural-environmental associations has been influenced by the three-part model of climatic change for the 10,000-year Holocene period (Antevs 1925; Davis 1982). Antevs (1925) subdivided this period into the cool-moist Early Holocene, the hot-dry Middle Holocene, and the cool-moist Late Holocene. Internal details of these periods are not without controversy, especially as they apply to the timing, magnitude, and course of paleoenvironmental change in western North America, in general, and the Tahoe Sierra, in particular. Although details of Middle through Late Holocene climatic and ecosystem history are becoming much clearer in the Great Basin to the east, within the Tahoe Sierra,

current reconstructions lack resolution, and climatic trends are necessarily presented as broad time brackets. Changing aspects of the natural environment, which were of special importance to human populations inhabiting the Tahoe Sierra during the last 9,000 years, are summarized below and outlined in Table 2-1.

Early Holocene (10,000-7,000 Years Before Present)

By the Early Holocene, warming and drying caused glaciers to recede and Lake Lahontan, which flooded much of the Great Basin, to shrink. Although climates were relatively cool and moist compared to those of today, they were considerably warmer than those of the Late Pleistocene. Heavy winter precipitation, which had characterized the Late Pleistocene, continued during the Early Holocene. Pollen studies at Osgood Swamp near Meyers at South Lake Tahoe (Adam 1967) indicate that a cold-dry sagebrush steppe prevailed until about 10,000 BP. A shift to coniferous forest reflects the final arrival of montane woodland at higher elevations. Sparse human populations engaged in a highly mobile foraging economy based on large game hunting.

Middle Holocene (7000-4000 BP)

The Early Holocene was followed by a much warmer and dryer Middle Holocene period which caused many lakes in the western Great Basin to dry up and montane and semiarid woodlands to retreat to elevations higher than those at which they are currently found. Evidence of these changes includes the appearance of Utah juniper and single-leaf (piñon) pine around 5500 BP in woodrat middens (nests) from over 10,000 feet in the White Mountains southeast of the Tahoe basin (Jennings and Elliott-Fisk 1993). Semiarid woodland tree species ceased to be present in woodrat middens from lower elevations in the Virginia Mountains northeast of Lake Tahoe, where they are found today (Wigand 1997). The 8,600-year-old bristlecone pine tree-ring record from Methuselah Walk in the White Mountains also reveals generally drier conditions of the Middle Holocene (Graybill et al. 1994) (Figure 2-1). Locally, the water level of Lake Tahoe and Pyramid Lake declined, but these were among the few lakes that did not dry up completely. Fossil pollen taken from Osgood Swamp (Adam 1967) and Little Valley in the Carson Range bordering the east side of Lake Tahoe (Wigand and Rhode 1999) indicates the presence of more drought-tolerant species by the end of this period. Middle Holocene aridity in the Tahoe Sierra is further documented by the remains of submerged tree stumps, which stand rooted on the floor of Lake Tahoe, as deep as 20 feet below its present surface (Table 2-2; figures 2-2A and 2-2B). These ancient drowned forests date from between 6300 and 4800 BP (Lindström 1990, 1997). Shallowly submerged prehistoric milling features (bedrock mortars) occur lake-wide and may date from this or subsequent droughts (Figure 2-3). About 5500 BP the harshest period of Middle Holocene drought came to an abrupt end, as manifested by the drowned shoreside forests at Lake Tahoe and by the wetter conditions from eastern Washington at Wildcat Lake down to the northern Mojave Desert at Lower Pahranagat Lake (Figure 2-4) (Wigand and Rhode, in press). During this period, prehistoric populations increasingly exerted their influence in altering the landscape and affecting fauna and flora. Archaeological evidence indicates a gradual decrease in overall residential mobility, greater land use diversity, a broadened diet, and intensified use of plant resources.

Late Holocene (4000 BP to present)

The Late Holocene record appears to be punctuated by alternating intervals of cool-moist and warm-dry periods. More intensive human use of the Tahoe Sierra occurred during this period, as increasing populations of mixed-mode foragers/collectors ventured into the highlands on seasonal gathering, fishing, and hunting forays.

Neoglacial Period (4000 to 2000 BP)

Climates became cooler and moister, initiating the Neoglacial (or Neopluvial) period. Climates reached their Late Holocene cool-moist climax by 4000 BP, causing the rebirth of many Great Basin lakes, the growth of marshes, and minor glacial advances in the Sierra. Bradbury, et al. (1989) indicate that Walker Lake began to fill

Table 2-1—Correlation of local paleoclimatic and cultural sequence in the Tahoe Sierra.

YRS BP	YRS BC/AD	Climate	Localized Environmental Conditions	Prehistoric Sequence
	BC		**Late Pleistocene**	
>13,000	>15,000	cold-wet	-ancient Lake Lahontan floods Great Basin	
			-glaciers in Tahoe basin	
			-ice dam(s) dam Truckee R/raise Tahoe 100'	
			Early Holocene	
10-9000	>12-11,000	cold-dry	-cold sagebrush steppe at Osgood Swamp	
9000-7000	11-9000	warmer-dry	-glaciers melt/Lake Lahontan shrinks	Pre-Archaic Period
			-conifers invade Osgood Swamp	(Tahoe Reach Phase)
			Middle Holocene	
7000-4000	9000-6000	warm-dry	-desiccation of many lakes in Great Basin	
			-woodlands retreated to higher elevations	
			-drought-tolerant species at Osgood Swamp	Early Archaic
			-conifers grow 20' below surface of Tahoe	Period
			-Walker Lake and Carson Sink dry up	(Spooner Phase)
5500	7500	wet	-conifers drowned by rise in Lake Tahoe	
4700	6700	wet	-Walker River fills Walker Lake	
	BC/AD		**Late Holocene**	
			"Neoglacial"	
4000-2000	2000BC-	cool-moist/	-rebirth of Great Basin lakes/minor glacial advances	
	0AD	winter-wet	-conifers reinvade Osgood Swamp	Middle Archaic
			-rise in ground water floods Taylor Ck Marsh	(Martis Phase)
			-increased flows in Squaw Creek	
			-increased Truckee R flows/Pyramid L rises	
	AD		**Dry-Wet Intervals**	
~2000-1600	0-400	drought	-xeric vegetation invades Little Valley	
			-rise in fire frequency around Little Valley	
			-Pyramid Lake falls	
1300-1200	800-900	drought	-trees grow on Ralston Ridge Bog	
			-Cave Rock woodrat middens contain xeric plants	
1100	900	wet	-buried sand lens at Taylor Marsh/rise in Tahoe	Late Archaic
1100-900	900-1100	drought	-trees grow in Walker Lake and River	(Kings Beach Phase)
700-500	1300-1500	drought	-Truckee River stream flows reduced/conifers stressed	
			-trees grow in Walker River	
			-conifers grow in Donner and Independence lakes	
370-365	1580-1585	drought	-Truckee River stream flows reduced/conifers stressed	
			-Cave Rock woodrat middens contain xeric plants	
			"Little Ice Age"	
350-175	1600-1775	cold-wet	-lake levels rise	
			-glaciers reach greatest extent since Late Pleistocene	
			-cold conditions in Little Valley and at Lead Lake	
			-"old growth" forests develop in Tahoe basin	Washoe
			Dry-Wet Intervals	
~200-100	1700s-1800s	dry	-retrenchment of forests to higher elevations	
			-increased fire frequency	
			-conifers grow in lakes Tahoe/Independence/Donner	
	1875-1915	wet	-Truckee River flows above average	
	1928-1935	drought	-Tahoe drops below its rim	
	1982-1986	wet	-snowpack water content 200% of normal	
	1994	drought	-Tahoe drops to its recorded low level	
	1995-present	wet	-above normal precipitation	

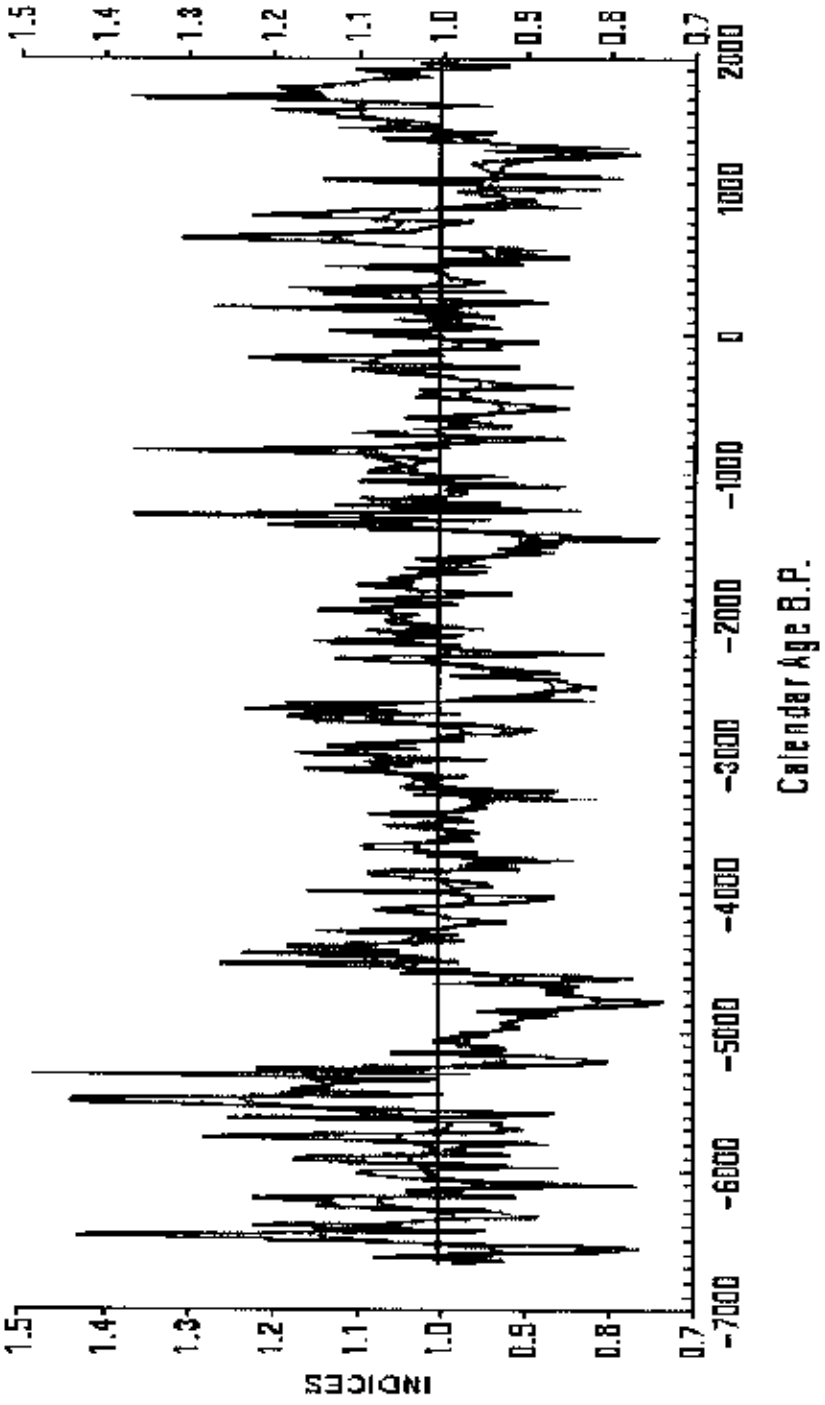


Figure 2-1—Tree ring indices record reflecting Holocene climate variation from Methuselah Walk in the White Mountains of the western Great Basin (Graybill et al. 1994). Value beneath the 8,600-year mean line indicate dry conditions, and values above the mean line indicate wet cycles. Extended drought has characterized several periods of Holocene, especially 7000 BP.



Figure 2-2A—Tahoe's rising waters drowned this tree stump sometime between 5,000 and 6,000 years ago (photograph courtesy of National Geographic Society).



Figure 2-2B—Tree stump submerged nearly 20 feet beneath the waters of Lake Tahoe. The stump pictured is seven feet tall and 3.5 feet across. rising waters drowned this tree about 6,300 years ago (photograph courtesy of National Geographic Society).



Figure 2-3—Prehistoric milling feature (bedrock mortars next to seated woman) exposed during the 1920s to 1930 drought near the outlet of Lake Tahoe (photograph courtesy of Jim Bell, Tahoe City).

Figure 2-4—Drought indices from the northern Great Basin (Diamond Pond, south-central Oregon), from the western Great Basin (Little Valley, eastern side of the east rim of the Tahoe basin), and the northern Mojave Desert (Lower Pahranagat Lake, northeast of Las Vegas). Wetter episodes lie above the mean lines at each site and drier episodes below the mean lines. The Little Valley record appears to be intermediate, reflecting some of the strong Pacific storm-dominated wet episodes of Diamond Pond and at least one relatively strong El Niño episode about 2000 BP.

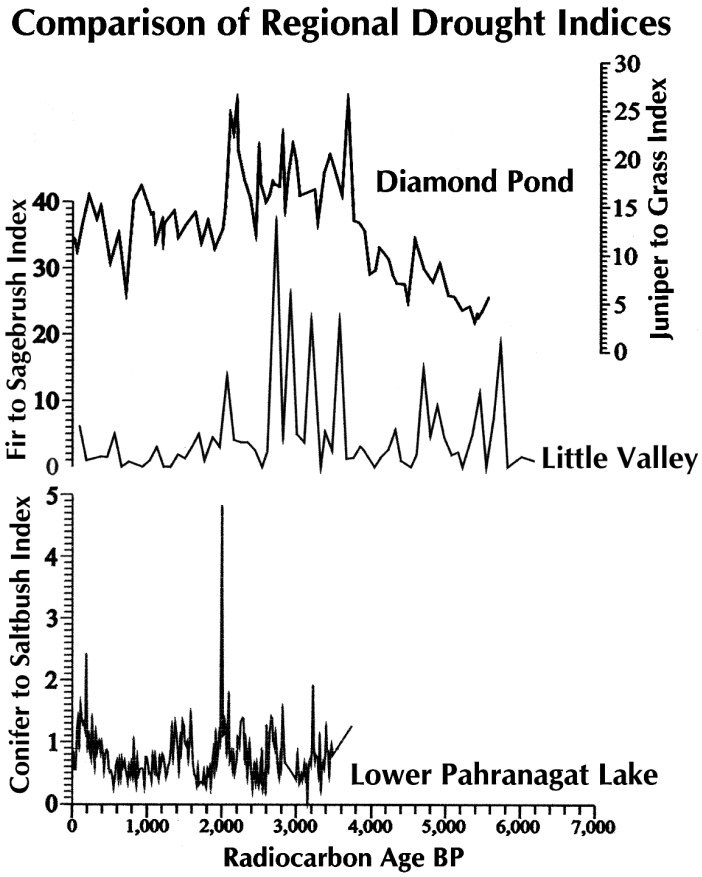


Table 2-2—Locations and radiocarbon dates of submerged tree stumps.
(Collected and Compiled by Susan Lindström)

Location	C-14 Yrs BP	Calibrated Yrs BP	Lab No.	Elevation	
Lake Tahoe					
Baldwin Beach	5510+90		*6304	Beta 33878	6210.87
Emerald Bay		4980+80	*5730	Beta 32851	6218.64
Tallac Estates		4870+60	*5640	Beta 13654	6220.70
Tallac Estates		4790+200	*5527	*no lab no	6222.75
Emerald Bay		4720+70	*5380	Beta 32852	6218.64
Baldwin Beach	4650+70		*5324	Beta 33879	6219.00
Trout Ck	4610+90		*5313	Beta 32847	6222.50
Trout Ck	4610+90		*5313	Beta 32848	6223.25
Trout Ck	4580+60		*5300	Beta 32846	6223.25
Tallac Estates		4520+60	*5197	Beta 13655	6220.70
Trout Ck		4500+60	*5126	Beta 32849	6222.50
Tallac Estates		4460+250	*5149	*no lab no	6222.70
Trout Ck	4370+80		*4931	Beta 32850	6222.50
Tallac Estates		4250+200	*4846	*no lab no	6222.75
Baldwin Beach	4250		-	Beta 56632	6205.83
Emerald Bay		110+60/AD 1840	-	Beta 32853	6225.00
Emerald Bay		50+60/AD 1900	-	Beta 32854	6225.00
Moon Dune Beach	148.5+mod/AD 1802	-	Beta 85132		6223.00
Trout Ck	4590+60		-	Beta 90207	6218.9
Trout Ck	4480+60		-	Beta 90208	6219.9
Up Truckee	230+50/AD 1720	-	Beta 90209	6222.9	
Cave Rock		30±50BP	**AD1695-	Beta 113817	6221.0
			1725/AD1815-1920		
Rubicon Point		1240±40 BP	AD 680-885	Beta 133581	6210.0
Independence Lake					
southwest end	100+mod/AD 1850	-	Beta 32855	-	
southwest end	170+50/AD 1780	-	Beta 32856	-	
southwest end	690+50/AD 1260	-	Beta 32857	-	
Donner Lake					
northeast end		150+50/AD 1800	-	Beta 87324	(-)19
north-central end	490+50/AD 1433	-	Beta 70013	(-)34	
north-central end	469+60/AD 1490	-	Beta 70014	(-)34	
Fallen Leaf Lake					
southwest end	850±50	AD1050-1095/ AD1140-1265		Beta 133580	(-)90

*calibrated yrs bp = University of Washington, Quaternary Isotope Lab Radiocarbon Calibration Program, 1987, Rev. 1.3.
**calibrated yrs bp = Beta Analytic Radiocarbon Dating Laboratory.
Lake Tahoe elevation = 6,223.00 feet is elevation of natural sill of Lake Tahoe.
Donner Lake elevation = feet below dam base elevation; dam base elevation is 5,937.00 feet.
Independence Lake elevation = feet below dam base elevation; dam base elevation is unknown.

rapidly after 4700 BP, reaching its high-level mark 3,000 to 4,000 years ago. At Osgood Swamp and Little Valley, after about 4,000 BP, the onset of the Late Holocene period is marked by a shift from more drought-tolerant vegetation to greater dominance by the conifer species that characterize the Tahoe Sierra today. Radiocarbon dates on encrusting tufa at Pyramid Lake indicate that the lake rose from its Middle Holocene low and was above current levels by 3450 BP (Benson and Peterman 1995). This is confirmed by other data indicating that Pyramid Lake levels rose by about 3200 BP (Born 1972). The Truckee River is the primary tributary of Pyramid Lake, therefore the rise in lake level reflects

increased flows from the tributaries of the Truckee, and a rise in Lake Tahoe where the river originates. Born (1972) suggests that this was the result of a winter-wet climate that prevailed during this period and may have resulted in the renewal of cirque glaciers in the Sierra Nevada between 3200 and 2000 BP (Born 1972).

At Squaw Valley, small stream deposits became coarser, indicating increased flows (Elston et al. 1977). Pollen evidence from Taylor Creek Marsh at South Lake Tahoe indicates the formation of the marsh due to a rise in ground water levels after about 5000 to 4000 BP and before about 2900 BP, with the marsh becoming an open water environment around 2800 BP (West in Lindström 1985). Pollen records from Little Valley and from Lead Lake in the Carson Sink indicate that these cooler moister conditions continued until about 2000 BP, with drier conditions after this time (Figure 2-5) (Wigand and Rhode, in press). This is confirmed by additional dates on encrusting tufa from Pyramid Lake, indicating that lake levels remained high until at least 2100 BP (Benson and Peterman 1995).

Drought Intervals

This time is characterized by strong swings between very wet periods and very dry periods. A dry interval seems to have persisted from 2200 to 1600 BP. Pyramid Lake receded (Born 1972), and the water in Eagle Lake in Lassen County fell after 2000 BP. Relatively dry conditions continued, with summer-shifted rainfall and less severe winters between 1600 and 1200 BP. Wet cycles allowed single-leaf pine to expand significantly into the semiarid woodlands east of Lake Tahoe, with forests becoming more densely packed (Wigand and Rhode, in press). Dry times appear to have coincided with a rise in fire frequency in the montane woodlands at Little Valley in the Carson Range, an event linked with increased slope erosion and channel filling in the central Great Basin (Wigand and Rhode, in press).

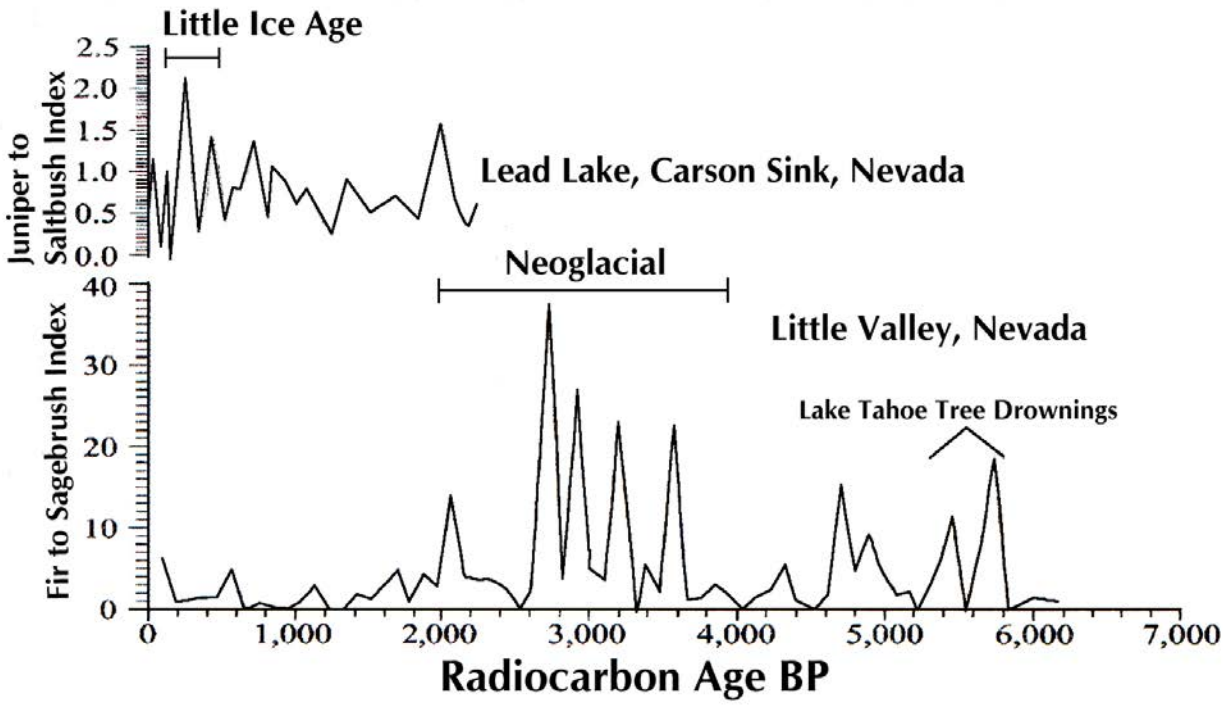


Figure 2-5—Comparison of drought indices from Little Valley, east rim of the Tahoe basin and Lead Lake in the Carson Sink. Event at 2000 BP is clear. Moister climate during the Little Ice Age, although evident in the Lead Lake and other records in the Intermountain West, is not as evident in the Little Valley record. This seems to reflect sample spacing in the top of the Little Valley core.

After 1200 BP increasingly drier conditions caused the retreat of both semiarid and montane woodlands. There is evidence of gradual drying from 1345 to 1145 BP, as trees grew on Ralston Ridge Bog south of Lake Tahoe due to low water tables (Serelj and Adam 1975). Preliminary analysis of ancient woodrat nests, recovered from the upper walls and ceiling of the cave at Cave Rock along Tahoe's southeastern shore, promise to provide some evidence of Tahoe's climate and forest composition during this period that can be tied into on-going research projects examining vegetation diversity and fire history throughout the Tahoe basin. Diagnostic plant remains recovered from the earliest stratum of these middens, dated so far at about 1360 BP, reveal the increasingly warm dry conditions that represented the beginning of the much drier period that has characterized the last millennium (Wigand 1997). However, the occurrence of a brief wet interval around 1,100 BP is suggested by the presence of buried A-horizon soils in association with a sand lens near Taylor Creek, indicating a rise in the level of Lake Tahoe and deposition of lake deposits as sand (Blackard in Lindström 1985).

A period of intense drought occurred from 1100 to 900 BP. Relict Jeffrey pine stumps, rooted in the Walker River stream bed, date to 920 BP and 660 BP (Stine 1992, 1994). Submerged stumps along the Walker Lake shorelands also yielded carbon-14 ages of 980 BP.

Intense drought returned again around 700 to 500 BP. The relationship between tree growth and stream flow in the upper Truckee River watershed indicates that intermittent drought conditions prevailed around 675 BP (Hardman and Reil 1936). Evidence of a dry period around 669 BP is provided by a series of deeply submerged tree stumps in Independence Lake north of Truckee (Table 2-2) (Lindström 1997). In addition, dozens of submerged tree stumps are located up to 30 feet below the present-day level of Donner Lake near Truckee (Table 2-2); carbon-14 samples from one stump date from 517 BP and 460 BP (Lindström 1997).

Another warm period, documented by reduced Truckee River run-off and the relatively narrow tree rings of pines growing in proximity to the river, is dated between 371 and 365 BP and again around 320 BP (Hardman and Reil 1936). A dated woodrat midden stratum from Cave Rock indicates that as late as 360 BP, climates were still very warm and dry in the Tahoe basin. This sequence of drought years and wet years is confirmed in pollen records from as far afield as Diamond Pond in the Harney Basin of south-central Oregon (Wigand 1987) and Lower Pahranagat Lake in the northern Mojave Desert of southern Nevada (Figure 2-4) (Wigand 1997).

Little Ice Age and Formation of Tahoe's Old Growth Forest (AD 1600 to 1775)

Between 350 and 175 years ago (1600 to 1775) a cool-wet climate, comparable to the Little Ice Age event of western Europe, dominated the region; lake levels again rose and cirque glaciers reformed in the Sierra, reaching their greatest extent since the latest Pleistocene. This event is recorded in pollen records from throughout the Intermountain West from as far north as Wildcat Lake in eastern Washington, Diamond Pond in southern Oregon, Lead Lake and Little Valley in western Nevada, and Lower Pahranagat Lake in southern Nevada (Figures 2-4 and 2-5) (Wigand and Rhode, in press). In these records the Little Ice Age is marked by the expansion of both semiarid and montane woodlands. Many of the old growth forests remaining in the Sierra and the Cascades today began to develop during this period.

At the end of the Little Ice Age, about 1825, drier conditions caused forests to retreat to higher elevations. Fire frequency increased, as the lower elevation and water-stressed portions of these forests dried (Wigand 1987).

Beginning about the mid-1700s through the mid-1800s, the level of Lake Tahoe (which supplies about 75 percent of the flow of the Truckee River in normal years) may have contributed relatively little water to the Truckee River. The decline of Little Ice Age climates is documented by radiocarbon dates of currently submerged tree stumps in the Tahoe Sierra (Table 2-2) (Lindström 1990, 1997). These include a stump in Lake Tahoe near the mouth of Upper Truckee River dating from about 1720, one in Emerald Bay dating to 1840, one from Moon Dune

Beach at Tahoe Vista dating from 1802, and one from Cave Rock with a calibrated date of 1695 to 1725/1815 to 1920. In addition, two submerged stumps from Independence Lake date from 1780 and 1850, respectively. Another stump from Donner Lake dates from 1800. (Given the problems of radiocarbon-dating materials that are less than 250 years old, these dates also may include the Little Ice Age event.)

Comstock Era and Beyond (1875 to Present)

The 40 years between 1875 and 1915 were the longest period during the historical record in which the flow of the Truckee River was above average. Tahoe reached its recorded high, with a lake surface level of 6,231.26 feet recorded on July 14 to 18, 1907; this is 8.26 feet above its natural rim, measured at 6,223 feet. This wet interval encompasses all of Comstock era logging and fluming activities and includes the first few decades of post-Comstock era forest regeneration. Relying on above-average precipitation, water reclamation projects were planned and initiated at Lake Tahoe and its tributary lakes and streams. Intensive livestock grazing began during the latter part of this wet period.

During the severe drought of 1928 to 1935, Lake Tahoe ceased to flow from its outlet for six consecutive years. The water crisis prompted several unsuccessful attempts by downstream water users to cut down or blast Tahoe's rim and to dredge the Truckee River channel; all were blocked by Tahoe lakeshore property owners. Eventually a compromise was reached, and millions of gallons of water were pumped out of the lake and into the Truckee River.

Wet years from 1982 to 1986 contributed to an average annual snow water content of up to 200 percent of normal. The year 1983 became the standard "high water year" for virtually all waterways within the Truckee River drainage basin.

Between 1987 and 1994 there was a period of drought in the Truckee River drainage basin. Although of the same duration as the 1928 to 1935 drought, the 1987 to 1994 drought was far worse. In the Lake Tahoe basin, the average annual snowpack water content was recorded at 29 percent of normal. Sustained drought increased the vulnerability of forests to severe insect attacks. By 1991 an estimated 300 million board feet of timber were dead or dying. On November 30, 1992, the surface of Lake Tahoe reached its record low from April 1990 to the present at 6,220.27 feet, 2.72 feet below its natural rim of 6,223 feet.

Although a trend of normal to above-normal precipitation initiated in 1995 continues to the present, drought will inevitably revisit the region. Investigations as part of the 1996 Sierra Nevada Ecosystem Project, revealed that Sierran climate, may be getting drier. Century-long droughts that have occurred within the last 1,200 years may recur in the near future.

The rapid rate of hydrologic response to changes in climate is epitomized by the El Niño cycles of the last 20 years. Even slight increases in precipitation can have amplified effects on runoff, where strong streamflow enhances erosion and delivery of sediments and nutrients to Lake Tahoe. Increased moisture also has promoted plant growth and added to the accumulation of forest fuels. These short-term observations are supported by sediment cores, which hold a record of long-term fire frequency in the charcoal that they contain. Data indicate that the greatest fire severity occurred during the droughts that punctuated the wetter episodes of the Holocene. The typical density of trees in the montane forest at middle and upper elevations assures the continued presence of abundant fuel, and, when coupled with increased susceptibility during a drier climate, both fire severity and frequency will increase.

The Influence of Climate on Environmental Sustainability

Although paleoecological reconstructions are currently incomplete, the scientific record provides compelling evidence of climate change and associated ecosystem change over the last 10,000 years. With this information, we are resolving questions regarding how climate change has affected Tahoe's overall physical and cultural environment. Imagine the constraints and opportunities arising from a drought-induced drop in lake level of 20 feet, as has occurred in the past. Thousands of acres of prime lakeshore could be newly opened for colonization by plants, animals, and humans. The

accompanying reduction in precipitation could radically increase current fire return intervals, stress the basin's biota, alter water quality, and hamper water-oriented recreation and tourism. In an opposing scenario, a rise in the precipitation could jeopardize lakeshore communities and cause certain terrestrial biosystems to shift to aquatic ones; amplified runoff could degrade water quality. In either event the socioeconomic well-being of the Tahoe basin would be undermined. Although hypothetical, both scenarios underscore the human dependency on climate and the importance of understanding climate change in planning for the future.

A growing consensus suggests that the pre-Euro-American condition of Tahoe's forest ecosystem is the desired future state (Elliott-Fisk et al. 1997). The feasibility of ecosystem restoration depends however, on the existence of climatic conditions similar to those that enabled the pre-Euro-American landscape. This may be an impossible goal. To draw an analogy, not only has Tahoe's canvas been altered, but the palette also has been transformed. The pre-Euro-American conditions of Tahoe's forest ecosystem reflect the cumulative influences of hundreds of years of forest dynamics. The clear-cutting of these forests during the last century effectively washed the canvas clean, creating a new landscape for both ancient endemic and new exotic biological species to colonize. These conditions were sustained under the influence of an entirely new series of climatic cycles that have occurred and will continue to occur in different orders, durations, and magnitudes. An examination of the paleoecology of the Tahoe basin will enhance our understanding of how the ecosystem has responded to different climates in the past. The findings may be used to derive predictions regarding the possible paths that the ecosystem may take in the future, under various scenarios of future climate and the impacts of anthropogenic activities. Although we may not be able to control the direction of future climate conditions, we can effect other parts of the ecosystem through the type and scale of our management activities so that we may achieve some measure of environmental sustainability.

Prehistoric Era (Prior to 1850s)

Prehistoric Land Use

The archaeological record suggests that Washoe Indians and their prehistoric ancestors have been a part of the Lake Tahoe ecosystem for at least 8,000 to 9,000 years. Soon after the retreat of Sierran glaciers, people entered the Tahoe basin. Climates warmed and dried rapidly, although conditions remained relatively cool and moist. The earliest archaeological evidence of human presence is found along Taylor Creek at South Lake Tahoe (Martin 1998). Elsewhere in the basin, early populations are represented by scant occurrences of isolated projectile points, typically manufactured from local banded metamorphic toolstone (gneiss) that was procured on Tahoe (Gardner's) Mountain. These sparse prehistoric populations have been equated with a Pre-Archaic mobile foraging society supported by large game hunting and nonintensive plant food processing and storage.

During the subsequent Early Archaic period, between about 7,000 and 5,000 years ago, prehistoric populations increasingly exerted their influence, altering the landscape and affecting fauna and flora. This period is associated with a marked warming and drying climatic trend and great environmental stress. Drying lowlands may have prompted human populations to travel to upland resource zones, such as the Tahoe basin, where prehistoric economies incorporated seed processing and fishing.

During the Middle Archaic period, dating from about 5,000 to 1,300 BP, climates became moister, and, with a return to more optimal living conditions, population densities increased. More intensive prehistoric use of the Tahoe Sierra began during this period, as mixed-mode foragers/collectors ventured into the highlands on seasonal gathering, fishing, and hunting forays. A hallmark of Middle Archaic prehistoric culture is the use of basalt to manufacture stone tools. The lithic landscape is marked by at least 17 distinct basalt flows that were the focus of prehistoric quarrying

activities. Quarriers were drawn to two known sources along Tahoe's north shore. One major flow extends from Martis Peak down to Carnelian Bay; the most prominently exposed within the Watson Creek drainage, it is called the Watson source. The other source, known as Incline Ridge, occurs above Incline Village, near the headwaters of Third and Incline Creeks. Basalt sources have distinctive chemical signatures (or fingerprints), and prehistoric basalt artifacts manufactured from these basalts can be traced back to their original source. The ability to trace the movement of prehistoric basalt artifacts allows us to track the movements of prehistoric populations and to understand ancient trade networks and patterns of cultural interaction and exchange. The importance of basalt from the Watson Creek Quarry as a toolstone source is indicated by its presence along the margins of the Sacramento Valley, about 35 miles to the southwest (Bloomer et al. 1997). Finding Watson basalt at such distances from its source suggests that neighboring groups were drawn to Tahoe's north shore to mine it or that local populations frequented the quarry to acquire toolstone for export.

The Late Archaic period, about 1,300 years ago to historic contact, has been equated with the Washoe, a distinct Native American culture described in ethnographic accounts written by early anthropologists. This period is marked by an overall xeric trend, with cool and moist episodes alternating with extended severe drought. Extreme climatic fluctuations may have allowed people to occupy the Tahoe highlands year-round at some times, but may have prohibited even seasonal occupation at other times. Throughout the Late Archaic, prehistoric populations continued to increase, as reflected in more intensive use of the Tahoe basin.

In broad terms, the prehistoric archaeological signature of the Tahoe Sierra reflects a trend from sparsely populated hunting-based societies in earlier times to growing populations that relied increasingly on diverse resources, especially plant foods, by the time of historic contact (Elston 1982; Elston et al. 1977, 1994, 1995). Sparse Pre-Archaic and Early Archaic populations are thought to have had minimal effects on environmental conditions in the Tahoe basin. Middle and Late Archaic populations are believed to have increasingly modified the landscape within the last 5,000 years until the historic period. This change in adaptive strategy and population size reflects native peoples' growing understanding of their environment and may be attributed partially to changes in the paleoclimate and subsistence base, and to prehistoric demographic change. Disruptions imposed by incoming Euro-American groups caused declines in Washoe population numbers and traditional resource use (Table 2-1).

Estimates of indigenous population vary considerably. Euro-American intrusion into the Tahoe territory apparently devastated the indigenous population; as early as 1859 it was estimated at only "900 souls", dropping to 800 in 1868. During this time, reservation agents resolved that there was no need to provide reservation land for the Washoe "since the tribe was nearly extinct" (Nevers 1976). Exact population figures prior to Euro-American contact are not known. Yet, it is estimated that the Washoe Tribe had one of the highest population densities in the western Great Basin. Relatively high estimates are attributed to the bountiful environment in which the Washoe lived (Price 1962).

Washoe History

The Washoe, or *Wa She Shu*, are part of an ancient Hokan-speaking residual population and have enjoyed a long tenure in their area of historic occupation. Lake Tahoe assumed the center of the Washoe physical and spiritual world, and they regard all "prehistoric" archaeological remains within the Tahoe basin as part of their heritage.

The annual trek to Lake Tahoe by the Washoe and their ancestors to fish, hunt, and gather plants has been well established. Every summer Washoe families revisited base camps that were commonly centered on fishing territories claimed along productive streams. Extended kin groups returned to harvest food, medicine, clothing, tools, and building materials from resource catchments associated with these family camps. Burden baskets were filled annually with resources needed for winter stores, as well as for immediate consumption. Visits sometimes extended through the fall and winter, if piñon pine-nut crops failed in the foothills to the east or if winters in the Tahoe uplands were relatively mild (Freed 1966). Year-round residence at

the lake, an alternative strategy for coping with drought or lower elevation resource failures, would have increased the need to conserve and manage resources at Lake Tahoe. Figures 2-1, 2-4, and 2-5 and tables 2-1 and 2-2 show periods of extreme drought when Washoe over-wintering at Tahoe would have been possible: 6300 to 4800 BP, 2200 to 1600 BP, AD 600 to 800, 900 to 1050, 1260 to 1500, 1430 to 1490, 1579 to 1585, and 1630.

An increasing body of ethnographic data provides an understanding that thousands of summers of sustained and systematic fishing, gathering, and hunting would have exerted at least localized influences on the biotic resources and the ecology of the Lake Tahoe basin. Existing ethnographic data include testimonies from Washoe people about resource use and principles of conservation, but there has been little research focused on specific harvesting techniques or horticultural and conservation practices. Where it has occurred, there is compelling evidence of extensive and systematic ecosystem management. Future ethnographic and linguistic research that is explicitly designed to address the particulars of indigenous land use and manipulation could go far in gaining some measure of the locations where sustained land tenure and management practices may have exerted the most influence in the Tahoe basin, the identification of specific management and conservation practices that may have localized influences on the Lake Tahoe ecosystem prior to 1860, and the identification of an expanded list of plants of cultural interest to the Washoe.

Subsistence and Land Tenure

Some understanding of when and how Lake Tahoe figured in the lives of the Washoe people before Euro-American contact aids in understanding the potential effects of the Washoe people on the Lake Tahoe ecosystem. It may not be the case that every Washoe individual converged on Lake Tahoe every year, as attested to by Downs (1966a) and others; however, it is clear that the Washoe named every stream entering Lake Tahoe, most of which were acknowledged to be camping and resource bases for specific kin groups (Freed 1966; Nevers 1976; Rucks 1995). Lake Tahoe and its tributaries are clearly recognized in multiple sources as the premier fishery in the region, and the Tahoe basin provided a summer residential base for the Washoe from which they collected plant and animal resources to complement fall and winter resources available from the western Sierran foothills and eastern valleys of the Great Basin. The temporal availability of food resources in the Tahoe uplands extended the season in which these resources could be collected far beyond their availability in the adjoining lowlands. In addition, the Washoe were positioned to trade with neighboring tribes, providing such upland resources as fish, deer hides, bracken fern, cedar bark, and medicinal plants (Davis 1961).

In spite of occasional skirmished, the Washoe held the Tahoe/Sierran crossroad for millennia. They granted some of their neighbors direct access, particularly those who were related by marriage. Although certain resources were shared and not claimed by any group, Washoe "ownership" of Tahoe's rich resource base was maintained by and communicated to potential trespassers by word-of-mouth and by occupation or possession. Occupation was signaled by the presence of nearby domestic camps. Permanent site "furniture" at these camps, such as bedrock milling features, further designated tenancy (Freed 1966). Men held claims to premier fishing locations by maintaining fishing "houses" and other improvements on streams. Certain plants needed to be tended, harvested, and cared for, and these activities provided indicators that they, too, were owned by the Washoe and that access was limited. Contemporary Washoe recall the laments of their mothers and grandmothers, worried about the degree to which plants were affected by grazing animals, drought, urbanization, and competing exotic plants, but, also by neglect (Rucks 1989-1999). Shrubs that were consistently harvested and pruned, such as service berry (*Amelanchier* spp.), mountain rose (*Rosa woodsii*), and willow (*Salix* spp.) would have been recognized as "somebody's:"

" . . . in the old days the older people, they had special places where they went . . . everybody had their special areas (for willow) . . . where a family would get . . . my grandmother did and my mother did . . . you know, you couldn't walk into some other area and gather . . ." Amy James and Belma Jones, ITC tapes, 1973).

Plants that were repeatedly harvested, dug, thinned, aerated, and even replanted would have been clearly recognized by others as cared for, tended and managed, and thus "claimed," which entailed finding the owner and asking permission to gather.

"Coyote had a camp by himself. Grizzly also had a camp. Coyote owned a place for getting wild potatoes [yampah], and Grizzly dug up some of them. Coyote abused her." (Bill Cornbread to Robert Lowie, 1926, from Tale 7, "Coyote and Grizzlies," in Lowie 1939.)

Siskin stated in 1939 that, at Tahoe, families owned fishing sites by streams and camped near there every summer. Washoe tended to converge along the south end of the lake where the fishing was best. Named camping locations and resource catchment areas appear in several sources (Dangberg 1927; d'Azevedo 1956, 1986; Freed 1966; Nevers 1976; Siskin 1939, 1984; Rucks 1995; Wright 1931-1972). Their locations allow us to stratify the potential effects of aboriginal resource use and environmental manipulation. It is clear most permanent camps were located at the lakeshore (especially at stream confluences) and in meadow complexes. The remarkably mobile Washoe were incredible trekkers, and the effects of aboriginal resource extraction and management extended well beyond the resource catchments tethered to these lakeshore, streamside, and meadow residential areas. Men and women walked many miles daily, leaving small children with camp tenders. Family groups relocated to higher altitude camps following the progressive availability of valued resources.

Manuel Bender listed some major resource localities in 1963 (Wright 1931-1972) in order of their importance according to "size, capacity and frequency of use for spawning by all the varieties of trout and other food fishes." This hierarchical order is assumed to reflect differential intensity of Washoe settlement and resource exploitation and management, which in turn, is reflected by the greater density of known archaeological sites (see discussion below). Bender's list of desirable drainages in descending order of resource value, from most to least important, follows:

Washoe Rank Order of Importance	*Stream/Watershed*
1	Upper Truckee
2	Blackwood Creek
3	Taylor Creek
4	Ward Creek
5	Incline Creek (Third Creek)
6	Trout Creek
7	McKinney Creek
8	Meeks Creek
9	Sugar Pine (General Creek)
10	Cascade Creek
11	Glenbrook Creek

Siskin's (1939) Washoe consultants went on to designate the best fishing spot on the Upper Truckee, which was maintained by a single family (the Holbrooks) and inherited by men in the family for as long as anyone could remember. Bender's ranking the Upper Truckee drainage as number one is entirely consistent with other Washoe testimony. The Upper Truckee and the Taylor Creek drainages, along with the extensive wetland and meadow system at the south shore, are acknowledged by all sources as particularly valued resource areas. Richard Barrington, a prominent Washoe witness for assessing resources within the aboriginal territory for the Washoe land claim case stated in 1963 that the south shore of Lake Tahoe was particularly noted for "wild potatoes and onions" (Wright 1931-1972), a position reiterated by recent Washoe testimony.

Recent interviews have provided information about the value of Third Creek to Washoe families from the Reno area. Third Creek once fed an extensive wet meadowland, similar to that on the south shore but smaller.

No ethnographic sources emphasize resource concentrations on Tahoe's east-central side and on its north-central shore, a trend that is also borne out by the corresponding lack of sites in the archaeological record. This is not to say that these areas were not used—they were. Washoe noted that the north of Lake Tahoe was particularly good for

deer hunting, for instance, and there were several camps on Watson Creek; however, Washoe recollections of camps on the east-central shore are few. Washoe from Carson Valley, who trekked to the lake up Clear Creek and over Spooner Summit, are said to have bypassed the eastern shore headed south and continued up the western shore.

"Some fishermen, [from the valley], 'good walkers', would go to the western side of the lake and bring fish back to their camp" (Rucks 1989-1999).

The apparent residential emphasis along prime fishing streams and resource catchments on Tahoe's south, west, and northeast shores suggests and that these areas may have been subject to more intensive localized aboriginal land management. The corresponding de-emphasis on the north-central and east-central shores suggests that the resources may have been manipulated less here.

Horticulture and Vegetation Change

It is not known how Washoe horticultural practices at Lake Tahoe influenced the structure and composition of various habitats. Studies to measure these effects have not been conducted, but since Euro-American settlement, the Washoe have felt restricted from harvesting plants on any but sporadic and opportunistic bases. Several unstructured plant collecting trips sponsored by the USDA Forest Service-Lake Tahoe Basin Management Unit (USFS-LTBMU) in 1995 (Rucks 1996) and 1996 (Bloomer et al. 1997) have elicited descriptions and demonstrations of a variety of traditional practices and have indicated the potential of collaborative ethnographic research to produce substantial information about horticulture. Several Washoe specialists were asked to locate an area or areas they would like to see set aside for their use in gathering traditional plants. During the course of collecting trips, gathering practices and traditions were observed and discussed providing information that could be verified by other Washoe (Figure 2-6). Back home, where they took plants for others to identify, the Washoe collectors discussed their trips and were asked to look out for other plants on future collecting trips. These trips began a process of reinforcement and discovery that encouraged recall and experimentation. Washoe observations are incorporated into the appropriate sections below.

Planting and Reseeding

Alan Wallace, the environmental coordinator for the Washoe Tribe, recently stated that certain targeted plants, especially bulbs, were planted "wherever they were needed." Women systematically shook mature seeds from the flower heads as they gathered whole plants. Some of the seeds or the flower heads themselves, such as *Wyethia*, were scattered back into the collecting beds as a little offering performed as an integral part of the harvest. Cultural specialists have asked if they might plant more of certain species native to the Lake Tahoe basin, "the way our ancestors did, to encourage the ones left." One woman recently attested to "poking a little hole with your finger, and sticking the onion under the ground, wherever you are gathering them." Although she was referring to replanting bulbs too small to collect for food or those accidentally pulled when only the greens were sought, it is reasonable to conclude that bulbs were replanted in different areas. Women recently harvesting bracken fern at Meeks Meadow were observed pushing budding rhizomes stripped from segments they were harvesting back into the rich humus, acknowledging they were "giving something back," and "the ground must be pretty good here."

Pruning, Culling, Weeding, and Cleaning

Women spacing their harvest—"take one, leave two" were aware that they were thinning stands and that digging loosened the soil and encouraged regeneration. They consistently restored the ground surface after digging, acknowledging that this enhanced the seed bed. Debris was removed out of "respect" for the local species (d'Azevedo 1986). Straight bracken fern rhizomes, eagerly sought and hard to find due to many years of neglect, are known to need substantial thinning and harvesting to encourage new growth and to maintain beds that are long and thick and easier to harvest. Shrubs harvested for making baskets, fish traps, snowshoes, arrow





Figure 2-6—Washoe plant specialists harvest bracken fern rhizomes from Meeks Meadow (photograph courtesy of Penny Rucks, Reno).

shafts, and fishing poles were systematically pruned to encourage straight and healthy growth with varying degrees of flexibility. Washoe basket-makers state that utility and resiliency of baskets depended on the health of the raw materials; they can identify older baskets "made before the white man" (Rucks 1995) partially from the integrity of the willow itself. Heavy to light pruning was designed to achieve various qualities: a certain amount of shade was needed to achieve the correct combination of strength, length, diameter, and flexibility. The idea of "cleaning" and tending plants included weeding out competitors as part of the harvesting process.

Fisheries and Wildlife

The practice of cleaning and weeding out competitors extended to fishing, the primary focus of food procurement and settlement, at Lake Tahoe. In 1951, Hank Pete stated the following:

" . . . the native trout had black spots on their side. There were also suckers and white fish in various streams. During the spawning season, the women would get into the streams and seine the suckers out, so that the spawn would not be eaten by the suckers . . . at times, the suckers were eaten or dried."

Richard Barrington also reports culling "trash fish, suckers, shiners, and other undesirable fish" and throwing the "seed" of trout back into the stream (Wright 1931-1972).

Late summer/early fall deer hunting figured prominently as a male activity and provided hides and bones for tool-making. Mountain sheep were plentiful and have been described as an important source of meat in the "old days." Porcupine, marmot, chipmunk, yellow-striped and red-striped squirrel, and Belding ground squirrel were also hunted at Lake Tahoe.

" . . . the woodchuck or groundhog [marmot], prized for its fat in late summer; the Goldenhead chipmunk roasted in coals; the prairie dog [Belding ground squirrel], a smaller variety than in the Plains species also formed variety in meat. There were many of these small animals, it was the chore of boys to snare and trap these small animals in season when they are in peak condition. Of the large animals, the Grizzly, the black and brown bears existed in large numbers but were held in reverence and awe by the Indians and were not used as food. The only indigenous rabbit to Tahoe was the Snowshoe, which was hunted in late fall for the white fur and meat" (Manuel Bender in Wright 1931-1972).

Freed (1966) noted camping areas at Blackwood Creek and Watson Creek for trapping "ground squirrels and woodchucks." Hope Valley was mentioned for hunting ground squirrels (d'Azevedo 1955). Water fowl provided an additional resource.

"Water fowl existed in fairly large numbers in the swamp areas around the lake. The giant fowl—the Swan provided, in addition to meat, oil which was used as lubricant for chafing and as a remedy for chest rubs in colds. . . . Canada Geese, the Mallard, Canvasback and the Teal all existed in large numbers and provided plenty of eating which cannot be said to be true today." (Manuel Bender 1963, in Wright 1931-1972)

Bender described the importance and abundance of grouse and mountain quail. Swallow's eggs also were collected (Freed 1966). Both Siskin (1937-1941) and d'Azevedo (1955) make reference to mollusks, identified as "oysters," which were systematically gathered and dried.

"Got some up at the lake [Tahoe] last week in the river by Meyers Station [the upper Truckee] . . . you stick the shell's edge down a sandy hollow, then build a little fire on top, 'til they open. You get them in the summertime when the water's not to [sic] cold on your feet. . . . my grandmother used to dry them and keep them for wintertime . . ." (Clara Frank to Kathy d'Azevedo 1955).

Insects identified as grasshoppers, locusts, and "big green worms," are noted by Freed (1966) as having been collected at Lake Tahoe.

Fire

California vegetation evolved to tolerate fire; some species even require it. This adaptation may have been influenced by millennia of Native American micro-burning. The efficiency and scale of this practice would have varied with the climate and the fuel loads. There is some preliminary evidence that the Washoe deliberately set fires in the forest or valley. The evidence of burning is compelling enough to warrant additional research, and there are indications that the Washoe may now be more willing to discuss this practice than they have been in the past. Omer Stewart's 1963 testimony is the only source that makes an assertion regarding fire management. During testimony for the Washoe land claims case, the attorney George Wright asked Stewart, "What, if anything, did the Washoes do to better utilize the area by themselves and the fish and game?" Stewart responded, "The valleys were cleared by fire and the heavy brush burned off, making more accessible the area, the growth of seeds, feed for animals." (notes from Omer Stewart's Testimony to the Indian Claims Case Commission in 1963 in Wright 1931-1972).

Three Washoe individuals that Stewart (1941) interviewed in 1939 for his culture-trait list denied the practice. Downs (1966:46) maintained, " . . . the danger of range fire in the areas is high and extreme concern evidenced by the local whites has conditioned the Washo [sic] to deny ever having practiced such a 'despicable' habit."

Evidence for burning is inconclusive and d'Azevedo (1986) asserts and agrees with Downs that the Washoe are very likely to have denied this practice in order to maintain employment with valley ranchers on whom they depended after contact.

Siskin (1937-1941) described burn techniques. Deer: hunters lit "little fires of pine needles" behind them to drive the deer toward waiting hunters. The Washoe would prepare extensive piñon nut processing areas by burning off sage patches, approximately eight feet in diameter, to mound and roast cones. Sought-after plants, including sand seed (*Mentzelia dispersa*), are known to grow in burned areas. Fire was used to keep camps clean and to keep the forest open. One Washoe man recalled that when he was a small boy he watched his people burn the brush behind hot springs along the eastern Sierran front. Washoe basket-weavers recently asked the Bureau of Indian Affairs to burn out a willow stand located on tribal land "like our ancestors did" to kill insects and to promote new growth. They also suggested that rank stands of bracken fern in Meeks Meadow be burned off.

Looking at the dense stands of fir and pine near Meeks Bay, one woman asked: "How could a man have shot an arrow through this? You can't even see!" (Rucks 1989-1999). George Murphy, the first white settler in Meeks Bay, is reported to have burned down his cabin after losing control of a fire he set in the meadow to burn off rank weeds, like "the Indians used to" (Van Etten 1996).

The Washoe traditionally burned the camp and dwelling of someone who had died, a practice quickly outlawed by concerned whites in Carson Valley.

Fires caused by lightning may have decreased (or eliminated) the need for intentional burning in the Tahoe basin. "It is, of course, possible that the frequency of brush fires caused by lightning made supplementary burning unnecessary. Certainly, in the Carson Valley two or three such fires a week is (sic) not unusual during the late summer. Or, perhaps because the Washoe usually moved toward Lake Tahoe for the spring fishing, there may have been no point in fall burning to encourage early seed bearing in the valleys" (Downs 1966a).

Intentionally set fires were strategically timed and placed, such that native burning extended the range, increased the frequency, and altered the timing of natural fires. In the Tahoe basin, fortuitous lightning strikes, which often occur in the late summer and along barren ridges, may not have served the needs of prehistoric populations. Fire setting practices concentrated around lakeshore camps and inside prime meadow resource catchments. Systematic and localized micro-burning by Native Americans would have kept down fuel loads, resulting in low intensity fires that may not have left telltale fire scarring on trees. Native burning may not be reflected in the 2,000 year-old fire return intervals established by fire ecologists for the region. However, recent studies along Tahoe's east shore suggest high fire frequencies, more than might be expected without human intervention, with 15-year occurrences, primarily in September and October (Taylor 1997). Although fires set by the Washoe tended to be contained in time and space, it is possible that some of these low-intensity burns spread beyond control, especially during droughts, and caused higher intensity fires that left fire scars. The data are unclear at this point, but they raise questions regarding Native American influence on historic fire regimes in the Tahoe basin (Taylor 1999). Future assessment of the frequency and distribution of fires, density and distribution of aboriginal camp locations, key resource catchment areas, and travel corridors should shed light on this issue.

Conservation

"What things do I think the white culture should adopt from the Indian culture that would enrich it? One of the uppermost things, right now, is in ecology. . . . They've [the Indians] practiced conservation, they've practiced rotation of hunting and such as that. . . . The concept of valuation that the white man has, we feel, is too much in the area of monetary, not so much as preservation of natural life or how the country should be preserved for the next generations, . . . and I think the white society is beginning to realize the fact that much of the things that has been destroyed should be restored, which, I think, should've been planned to begin with." (Dressler 1972)

Persistent harvesting in an area by an extended kin group may have jeopardized resource supply and prompted a need for conservation. Restrictions on harvest from a given area insured the potential for future growth (d'Azevedo 1986). Collectors taught children at a very early age to "leave some."

" . . . Young hunters and fishermen were thoroughly indoctrinated in the importance of leaving "seed" for next year. . . . It was drilled into all providers of food that from one pool with five fish, only two fish could be killed. A female and two males had to be left as seed for next year. The same practice was observed in game. So well established was this rule and so well observed that the white people merely took it for granted that the fish and game were just prolific without any means to perpetuate the source. . ." (Manuel Bender 1963, in Wright 1931-1972).

"Usually Indians left females at spawn-beds. Used as bait so that buck-fish stop there [in non-

spawning season]. . . . Take either buck or female fish" (Mike Holbrook, 1930s, in Siskin 1939-1941).

"Usually, the Indians killed the buck deer, but the dry does or non-bearing does were killed, especially during the winter months. The Indians tried to keep a balanced herd of deer, rather than kill off all the buck deer" (Hank Pete to George Wright 1951, in Wright 1931-1972).

The Washoe rotated collecting areas. The harvest occurred after seeds matured in order to assure future harvests. Prior to gathering, women offered prayers to the plants and for the blessing of their utensils and other equipment.

Archaeological Sites, Resource Catchments, and Environmental Manipulation

In the absence of historical records beyond 150 years, the archaeological record provides information to address the question of potential disturbances of indigenous plant and animal communities. Areas with high densities of archaeological sites may be areas where aboriginal people manipulated resources to a greater extent.

The true nature and extent of the surviving archaeological record of the Lake Tahoe basin is yet to be determined because only a percentage of the area has been systematically surveyed. According to files maintained at the USFS-LTBMU, over 50,000 acres of federal land (32 percent of the nearly 159,000 total acres of federal land) have been surveyed for archaeological remains. The amount of archaeological survey coverage conducted on state and private lands in the basin is unknown. At least 581 archaeological sites and 306 miles of linear features (for example, roads, railroads, and flumes) have been recorded on surveyed federal land. In addition, another 289 sites are recorded on nonfederal land. Many archaeological sites remain to be recorded. Unfortunately, a greater number have been destroyed by historic and modern land disturbance. Preservation problems persist since acidic soils and extreme weather rapidly decompose perishable artifacts. Sites representing the main nuclei of Washoe existence at Lake Tahoe are lost under contemporary community development.

The known archaeological sites and archaeological coverage in the Lake Tahoe basin are summarized by watershed (Table 2-3). Sites of Native American occupation in the Lake Tahoe basin are unevenly dispersed. Archaeological evidence is confirmed by Washoe recollections, which disclose that certain areas were visited more frequently than others.

Variability in the density of archaeological sites is probably caused by proximity to specific aboriginal travel corridors to resource-rich zones. The Tahoe basin's rim of a broad and forested ridge would not have presented an obstacle to travel. Topography alone did not dictate routes of ingress and egress. Social taboos and the relative mobility of prehistoric groups, as determined by the structure of their seasonal migration, also influence the number and placement of archaeological sites (Lindström and Hall 1994).

The highest densities of archaeological sites occur along Tahoe's south shore. Marsh and meadow resources in the middle to lower reaches of the Upper Truckee River, Trout and Taylor creeks were extraordinarily rich, and their fisheries were unsurpassed. Luther Pass was a main travel route. Native American populations entering from Carson Valley took initial advantage of bountiful resources in Hope Valley, within the West Carson River drainage, and then traveled down the Upper Truckee River subwatershed, Tahoe's major fishery. The Upper Truckee River was a travel route for the Washoe's westward trek to the Sierra foothills to gather foodstuffs, to trade, and to visit friends and relatives.

Similarly, the entrance into the resource-rich zones in Tahoe's northwest quadrant may have been channeled along the Truckee River corridor through the Tahoe reach, with its many tributary streams and resource catchments. Although numerous prehistoric sites are recorded within the Truckee River corridor (Elston et al. 1977), Washoe place names are entirely absent. This may be explained, in part, by the fact that the Washoe people were excluded from the Tahoe reach very early in the historic period. As early as 1852, the area served as a

Table 2-3—Archaeological site distribution and density in the Lake Tahoe basin.

Watershed-Meadow Features	Archaeological Coverage	Prehistoric Sites	Historic Sites/Linear
Upper Truckee/Trout/Saxon/Heavenly Valley	fair	70 sites/32 mi linears	
Upper Truckee River	fair	46	
Trout Creek	good	12	
Saxon Creek	fair	4	
Heavenly Valley Creek	good	2	
Emerald Bay/Cascade-Fallen Leaf Lakes/ Taylor Creek	fair	30 sites/10 mi linears	
Emerald Bay	(? - state park)	1	
Tallac Creek	complete	2	
Taylor Creek	complete	30	
Meeks/Rubicon Bays	fair	4 sites	
Meeks Bay	good	3	
Rubicon Bay	poor	3	
McKinney Creek	poor	1	
Sugar Pine Point (General Creek)	(? - state park)	1	
Blackwood Creek	good	12 sites	
Ward Creek	good	11	4 sites/4 mi linears
Page Meadows	none	1	
Truckee River (Tahoe City)	fair	2	1 site
Burton Creek	fair	4	2 sites
Watson Creek	good	28	15 sites/several mi linears
Carnelian Canyon Creek	poor	1	
Griff Creek	good	6	9 sites/several mi linears
(Tahoe Vista)	fair	2	
(Brockway)	none	1	
1st/2nd/3rd/Incline/Mill Creeks	fair		41 sites/~15 mi linears
First Creek	fair	2	
Second Creek	fair	1	
Third/Incline Creeks	fair	39	
Marlette/Spooner/Glenbrook/Logan House/ Lincoln Creeks			92 sites/~100 mi linears
Marlette Lake	good	14	
Secret Harbor Creek	good	2	
Skunk Harbor	good	1	
North Canyon Creek	(? - state park)	1	
Spooner Lake	good	11	
Glenbrook Creek	good	2	
Cave Rock	complete	1	
Marla Bay/Burke/Edgewood Creeks	fair		33 sites/several mi linears
Marla Bay	fair	1	
Elk Point	fair	1	
Burke Creek	good	2	
Edgewood Creek (Rabe Meadows)	fair	8	

major Euro-American travel corridor, containing a wagon road and later a railroad. It was a short-lived mining center in 1863. The Truckee Lumber Company logged the area intensively during the 1870s, using the river channel to raft saw logs; intense logging continued through the 1910s.

Another major travel corridor near Mt. Rose channeled prehistoric populations from Truckee meadows into the Tahoe basin, funneling them directly through the resource-rich zone of the Tahoe meadows and down to plentiful fish, plant, and animal resources along Tahoe's northeast shore (Lindström and Bloomer 1994). High site densities within the Incline/Third creeks drainages are confirmed by recent Washoe testimony (Rucks 1996). The lowest archaeological site densities in the basin occur on Tahoe's east-central shore, although there are clusters of sites around major meadow complexes such as Spooner, Marlette, and Glenbrook. For example, a 12,000-acre survey conducted here disclosed no prehistoric archaeological sites and only six isolated artifacts. The lack of prehistoric remains suggests that this area was not a major travel corridor and that resource-rich zones were relatively limited. This pattern is supported by Washoe recollections. Also, the east shore contains Cave Rock, a key Washoe cultural-spiritual landmark that is to be avoided by all but a few sanctioned Washoe spiritual practitioners.

Tahoe's north-central zone lacks prehistoric sites. An exception is the Watson Creek corridor, which served as a shortcut to the Tahoe reach and was a target of Middle Archaic basalt quarriers. Washoe land use on the north-central shore is poorly documented.

Relatively few archaeological sites have been recorded on Tahoe's western divide. Site clusters are located along Ward and Blackwood Creeks. Exceptions include the documented Washoe trail up McKinney Creek to Georgetown and lakeshore meadows along Meeks Creek, which are significant to contemporary Washoe plant collectors.

Native American presence in the southeast quadrant of the lake, centering within the corridor along Kingsbury Grade, is not well documented in the archaeological record. However, Rabe Meadows along Edgewood Creek is known to be a key Washoe resource catchment.

The present archaeological inventory suggests that the lowest site densities in the Tahoe basin occur along the east-central shore, followed by the north-central and west-central shores, respectively. Site densities are highest along the south shore (especially within the Upper Truckee River/Trout/Taylor Creeks subwatersheds), followed by the Mt. Rose corridor (along the Incline/Third Creeks subwatersheds) and in the northwest (along the Truckee River corridor). Judging from the foregoing data, the potential for prehistoric resource manipulations may have been greatest along Tahoe's south, northeast, and northwest shores in the Upper Truckee River/Trout/Taylor Creeks, Incline/Third Creeks, and Truckee River subwatersheds.

Even after Euro-American "encroachment," the legal term the federal government used to describe the process by which the Washoe gradually lost their territory circa 1848 (Rucks 1996), the Washoe continued their treks to the lake, and some may have sustained limited subsistence traditions in the wake of destructive Euro-American industries, such as logging, grazing, and commercial fishing. The Washoe were intent on remaining on their traditional lands; many Washoe chose not to relocate, so families lived and worked on the fringe of Euro-American settlement (d'Azevedo 1986; Nevers 1976; Rucks 1995). The Washoe maintained links to their ancestral areas around Lake Tahoe by working for loggers, dairymen, fishermen, and, especially, resort owners. The men worked as guides and the women performed domestic labor or made baskets to support the tourist trade. Many Washoe were able to maintain their connections with Tahoe's south shore by supporting multiple resorts established in Lake Valley. Archaeological deposits at the south shore, which contain bedrock milling features and late 19th and early 20th century trash deposits of Euro-American origin, and Washoe oral history both indicate that traditional plant management continued at the south shore well into the 20th century, albeit on a reduced scale (Freed and Freed 1963; Rucks 1995; Siskin 1984). Washoe

families performed wage labor and continued to camp for extended periods along Trout Creek in Lake Valley until the 1940s (Peters and Peak 1984). They also occupied areas in the vicinity of Incline and Third Creeks, partly because subdivisions were not developed there until relatively late in the 1960s (Rucks 1996). Unlike the populations at South Lake Tahoe and Incline, Washoe populations and their traditional land use practices may have been displaced much earlier from other areas around the lake, areas without resorts that could have supplemented Washoe incomes. For example, Washoe recollections contain very few details regarding the north shore; traditional use was probably suspended with the onset of Comstock-era logging from the 1870s to the 1880s. The periodic harvest of mixed conifer stands on the north shore until recent times would have subjected biotic communities to more frequent disruption and might have discouraged the continuation of indigenous subsistence practices. Stands elsewhere that were clear-cut before the turn of the century, especially along Tahoe's east and south shores, were subjected to relatively little or no post-Comstock logging, allowing forests and their associated plant and animal communities to regenerate. Washoe land management traditions may have persisted somewhat longer here.

Culturally Important Plants and Traditional Use Areas

The Washoe Tribe has developed a comprehensive land-use plan (Washoe Tribal Council 1994) that includes goals of reestablishing a presence within the Lake Tahoe basin, revitalizing Washoe heritage and cultural knowledge, protecting traditional properties within the cultural landscape, and harvesting and caring for traditional plant resources (Rucks 1996:3). The Washoe plan aims to reintroduce traditional plant gathering practices and collect oral histories relevant to land and resource use and management, diet, social and economic history, organization, and beliefs (Rucks 1996). Fulfilling some of its federal responsibilities to tribal sovereign governments (USDA 1995), the LTBMU has invited Washoe plant specialists to participate in a series of field trips to begin identifying areas suitable for plant collection and horticultural management (Figures 2-7A and 2-7B) (Bloomer et al. 1997; Rucks 1996). The issues are not simply the presence or absence of traditional plants, but their vigor, their environment, and their physical attributes. Medicinal plants, for instance, are particularly sensitive and may be nurtured by the potential collector for several seasons before they are collected. To be useful for basketry, such plants as bracken fern must have structural characteristics that are promoted by systematic harvesting and thinning.

Prehistoric populations around Lake Tahoe regarded many hundreds of montane plants as significant. (Ethnobotanically important plants of the north-central Sierra Nevada are listed in a number of sources; see Table 2-4 for a compilation.) Some species were intensively collected, conserved, and managed for sustainable harvest. Categories of these important plants include those sought after to fill winter stores (as opposed to those collected primarily for immediate consumption), entire plants harvested for food, plants with seed resources, and plants used for medicinal purposes. There is an overwhelming consensus from all accounts that preparing food for winter stores was a focus of attention. This emphasis is linguistically coded by a specific term that distinguishes storable winter food as "real food" (d'Azevedo 1986). In addition, species in which the whole plant could be harvested for food, such as, *Allium* spp., *Perideridia* spp., *Lewisia* spp., *Lilium* spp., *Calochortus* spp., and *Brodiaea*, were likely to have been affected by aboriginal horticulture. The distribution and relative density and vigor of this category of plants, especially those that also were harvested for winter storage, may most accurately reflect the effects of harvesting and horticulture for sustained yields (e.g., Anderson 1993a). Seed resources also were important; sand seed (*Mentzelia dispersa congesta*) in particular is still actively sought and gathered. Cultural knowledge and interest in medicinal plants persists due to the relatively low profile collectors can maintain when seeking an individual plant, as compared to wholesale "harvests." There is significant concern among plant specialists that medicinal plants are



Figure 2-7A—As part of Washoe goals to reestablish a presence at Lake Tahoe, elders visit an archaeological site on Tahoe's north shore and discuss traditional land use practices (photograph courtesy of Susan Lindström, Truckee).



Figure 2-7B—Washoe elders discuss their surroundings in their native tongue; the session was videotaped as part of the ongoing Washoe Language Project (photograph courtesy of Susan Lindström, Truckee).

particularly vulnerable to over-collection and misuse by non-Washoe people.

A list of plants important to Washoe collectors (Table 2-4), has been compiled from the data of recent field work and published sources (e.g., d'Azevedo 1986; Fowler 1986; Nevers 1976). It also draws heavily from the unpublished field notes of d'Azevedo and Jacobsen, to which Kathleen d'Azevedo, Ed Montgomery, and Juanita Schubert contributed significant ethnobotanical information. The list reflects the information that Washoe practitioners are comfortable sharing. They acknowledge that this is but a small sample of the knowledge of their ancestors and that time and history have badly eroded a vast Washoe botany. They also are concerned about the misuse and appropriation of cultural information but hope that the plants will benefit from focused management and that they can begin a process of recapturing some of their more fragile resources and knowledge by active restoration and management.

Comstock Era (1850s to 1900)

Since John C. Fremont's historic sighting of Lake Tahoe on Valentine's Day in 1844, most early descriptions of the Lake Tahoe basin are framed in terms of its astounding natural beauty and economic potential. The stunning color and purity of the cobalt-blue water, the amazing size and abundance of fish in the lake, and the luxuriant forest in its surrounding basin are all prosaically noted. Though these early commentators were profoundly impressed by this extraordinary natural phenomenon, they mention only in passing the "Indian" inhabitants (Lindström et al. 1998). The philosophy and outcome of indigenous land management went unnoticed by the newcomers, who viewed the landscape as "natural" and "unowned." Such misconceptions supported their justifications for taking Tahoe land and resources from a people who seemingly never owned or managed them in the first place. Although the Washoe were largely excluded from Lake Tahoe, one element of Washoe culture that permanently remained is its name. Variously known as "Mountain Lake," "Lake Bonpland," and "Lake Bigler," the name "Tahoe," adopted in popular jargon early on, is derived from the Washoe word *da'ow*, signifying "lake." Lake Tahoe was not officially named by the California legislature until 1945.

Logging

The history of lumbering in and around the Lake Tahoe basin takes place within the larger history of Nevada's Comstock Lode. The Comstock could not have been so extensively developed without the sources of water and wood that were supplied by the Tahoe basin (Elliott 1973). It has been said that the silver mines of the Comstock are the tombs of the Sierran forests (DeQuille 1877). The urgent demand for fuel wood and construction lumber by the growing settlements and the mines themselves (with their square-set timbering system and steam-powered mills) devastated the supply. Areas east of the Carson Range were depleted of timber followed by harvest in the Lake Tahoe basin. Cutting commenced in the Carson Range on the east side of the lake and spread to the west and north shores and finally to the south shore. The silver mines were the chief consumers of wood and timber, with a secondary consumer being the Central Pacific Railroad (CPRR) and the wood markets it served.

Pre-Euro-American Forest Characteristics

Historical records and photographs (Scott 1957, 1973) indicate that many timber stands of the Lake Tahoe basin were clear-cut (or nearly so), with little regard for streamside areas. Uncut trees served as seed trees for the next generation of forests (Wheeler 1992). Logging techniques of the day relied heavily on cross-country skidding, which damaged existing young growth and thus future stand regeneration. Environmental degradation was compounded by coincident erosion of decomposed granite soils. Soil compaction and the destruction of humus in and around wood camps may have created artificial openings that have survived for over a century. Clear-cutting on hillsides accelerated erosion, releasing sediment loads into the lakes and streams of the basin. Intensive logging probably left forests fragmented and contributed to the decline or extinction of birds and mammals that required structurally complex forest habitat (Elliott-Fisk et al. 1996).

Table 2-4—Washoe cultural plants.

Botanical Names[1]	English Vernacular
Abies concolor	white fir
Achillea millefolium	yarrow
Allium campanulatem biseptrum (S. Watson)—by K. Anderson from specimen	Sierra onion
Allium validum—from specimen	swamp onion
Amelenchia alnifolia—from specimen	western service berry
Angelica breweri—Train	angelica
Arctosatphylos spp. (uva ursi, according to Rowley, but probably *nevadensis*)—not identified by Schubert	manzanita
A. patula—from description	green-leaf
Balsamorhiza sagittata—from specimen	arrow-leaf balsam
Barbarea orthocerus—by K. d'Azevedo from specimen	winter cress
Brodiaea hyacinina—by Rucks from specimen	white brodiaea
Brodiaea lutea—by Rucks from specimen	golden brodiaea or pretty face
Calchortus nuttallii—from specimen*;* cannot find in Weeden	sego lily
Camassia sp.	blue camas
Chlorogalum pomeridiam—identified by description (not specimen). This plant does not grow above 5,000' but is reported at Lake Tahoe	soap root
Cicuta douglassi—from specimen	water hemlock
Descaurania sp.—from specimen	tansy mustard
Fragaria sp.—from description	wild strawberry
Heracleum lanatum—from specimen	cow parsnip
Habernaria spp.—Rucks from specimen	Rein orchid
Lewisia sp.—Rucks from specimen	bitter root
Libocedrus decurrens	incense cedar
Ligusticum grayi—Rucks from specimen	Gray's lovage
Lilium parvum—by Rucks from specimen	alpine lily
Lomatium dissectum—from specimen	fern-leaved lomatium
Lupinus latifolius—Rucks from description	lupine
L. paoyphyllus ssp. Superbus—Rucks from description	lupine
Mentzelia dispersa congesta—from specimen	Nevada stickweed
Montia perfoliata var. depressa (Jepson)—from specimen.	miner's lettuce
Nicotiana attenuata—from specimen	coyote tobacco
Osmorhiza occidentalis—from specimen	western sweet cicely
Paeonia brownii—by Rucks from specimen	Brown's peony
Pedicularis groenlandica—by Rucks from specimen	elephant head

Table 2-4—*(continued)*

Botanical Names[1]	English Vernacular
*Perideridia sp. (*three species (*parishii, howellii,* and *bolanderi* are edible and may account for two of the "unknown potatoes")—by K. d'Avevedo from specimen	yampah, Indian potatoes
Petiphyllum pelatum—by K. d'Azevedo from specimen	Indian rhubarb
Pinus lambertiana	sugar pine
Prunus virginiana var. demissa—from specimen.	western choke cherry
Pteridium aquilinum var.—from specimen	bracken fern
Ribes aureum Pursh.—from description; this spp. not in Weeden	golden currant
Ribes roezeli—from specimen	Sierra gooseberry
Ribes velutinum—from specimen	plateau gooseberry
Rosa californica—from specimen	wild rose
Salix spp.	willow
Sambucus caerulea (*mexicana* C. Presl)—by K. Anderson from specimen	blue elderberry
Sium suave—from specimen	water parsnip
Smilacina stellata—from specimen	false Solomon's-seal
Sphenosciadum capitellatum—from specimen	ranger's buttons
Thalictrum fendleri—from specimen	meadow rue
Typha latifolia—from specimen	cattail
Veratrum californicum—Train	corn lily
Wyethia mollis—from specimen	mule's ear
Zigadenus venenoseus—Train	death camas

Note:
[1]Unless otherwise noted, after Weeden 1986; identifications by Juanita Schubert, 1957, unless otherwise noted.

What did the Tahoe landscape look like before logging took place? In a recent study of forest sample plots along the west side of the Carson Range, "Comparisons of the composition, density, and sizes of Comstock era stumps with live trees on the same sites clearly demonstrate[s] that contemporary forests in the Carson Range are very different from the ones first encountered by early European settlers" (Taylor 1997).

Additional perspectives on characteristics of pre-Euro-American forests can be gained through the climate record, historic period accounts, and archaeological observations of the logging landscape. Although at least two-thirds of the basin was clear-cut, it is important for the purposes of ecosystem reconstruction to know the location of both logged and unlogged areas, when the areas were logged, and how and to what degree they were logged.

Climate Record

Comstock-era harvesting targeted stands that had matured during the mid-1600s to mid-

1800s, a period of generally cooler and wetter conditions coincident with the Little Ice Age. During this 200 to 300 year period, cooler and wetter conditions limited the negative impacts of potential stresses on the forest (for example, droughts, fires, and insect infestations) and favored the growth of conifers in the Tahoe basin. Undoubtedly, these Little Ice Age conditions contributed to the size and vigor of trees that impressed many early observers. The high precipitation noted during the harvest period of the 1870s to the 1890s and subsequent high flows of the Truckee River have been matched only by the flows caused by El Niño events of the early 1980s. Wetter conditions also facilitated steam-powered logging technology and enhanced water supply engineering and the viability of flumes, pipelines, and reservoirs.

Historic Period Observations

Scientific studies indicate that the structure and composition of modern forests in the Lake Tahoe basin are very different from the pre-Euro-American forests (Leiberg 1902; McKelvey and Johnston 1992; Sudworth 1900; Taylor 1997). Overall, virgin stands were more open and composed of trees that varied greatly in diameter. Early explorers described the forests of the Tahoe basin as "dominated by giant pine trees with so much room on the forest floor that riders could travel at full gallop without losing their hats" (*San Francisco Chronicle*, August 21, 1995). Second growth stands are currently 10 times denser with trees that are considerably smaller in diameter (Taylor 1997). Tahoe's pine forests, once dominated by Jeffrey and sugar pine, are now fir forests, dominated by white and red fir. These scientific findings are supported by historic period observations. For instance, Captain James H. Simpson (1883) recorded the following on his 1859 government expedition west through Lake Valley.

"*June 13, Camp No. 38, Genoa.* . . . The ride this morning the most charming I have had for a long while. Lake Valley is like a beautiful park, studded with large, stately pines. The glades between the trees are beautifully green, and the whole is enlivened by a pure, babbling mountain-stream, the most southern and principal branch of the Truckee, coursing along northwardly to its expansion, Lake Bigler. The pines of various kinds are very large, and attain a height of probably from 100 to 150 feet. Their diameter is not infrequently as much as 8 feet, and they sometimes attain the dimension of 10 feet."

With an eye on the understory, George H. Goddard (1855) passed through the same area as Simpson and wrote "*Sept. 2 Sunday*—Walked some two miles down the valley. There were a number of currant bushes near the trail, some of which were loaded down with remarkably fine currants, nearly as large as gooseberries and fine flavored. . . . *Sept. 14*—The ground in many places is literally covered with strawberry vines, or sun-flowers."

Mark Twain (1962) shared similar observations during his stay in the mid-1860s. "It was yellow-pine timberland—a dense forest of trees a hundred feet high and from one to five feet through at the butt."

Prior to the onset of large-scale logging, DeQuille (1877) maintained that "Many of the sugar-pine trees about Lake Tahoe are five, six, and some even eight feet in diameter; all are very tall and straight."

Theodore Judah (1862), who surveyed the route of the transcontinental railroad through the Truckee Basin in 1862, was similarly impressed. "The sugar pine of these lands often runs 125 feet high without a limb, and often measures 8 feet through at base."

Not only were the trees "larger than life," but they grew in unbelievable bounty. In 1883, Edwards's *Tourist's Guide and Directory of the Truckee Basin* boasted "The [timber] supply may be said to be never ending . . . . It is beyond the power of man to estimate when it will be exhausted."

In this setting of superabundance, Comstock-era logging commenced and continued with such voraciousness as to nearly wipe out all of the accessible stands within 25 years. However, not all forests were clear-cut, some trees were harvested selectively to suit varying wood markets. In addition to saw logs, timber was cut for cordwood, railroad ties, charcoal, shingles, lath, boxes, and doors and sashes. Each of these items required specialized and selective timber cutting to make the best product.

In 1947, Galloway wrote "The trees that furnished the lumber and wood for the Comstock

were the conifers, which family includes pines, firs, and cedars. The Western White Pine or Silver Pine, makes a sparse growth throughout the region in elevations from 8000 to 9500 feet. It was worthless for lumber or wood. Sugar Pine is found between elevations 4000 to 8000 feet. It grows to heights from 160 to 180 feet, and in diameter from 4 to 7 feet. It is valuable for building purposes, as being soft it is easily worked and produces a greater percentage of clear lumber. Western Yellow Pine [ponderosa pine] was abundant, ranging from 4000 to 8000 feet elevations. The trees grow to heights from 125 to 140 feet, and in diameters 3 to 4 feet, but in some instances up to 6 feet. Yellow Pine was best for general purposes, having a good percentage of clear lumber and being stronger than Sugar Pine. The Jeffrey Pine, which differs somewhat from Yellow Pine, grows in the region in similar sizes and general characteristics. Generally the two trees are all called Yellow Pine. White or Silver Fir was abundant in the Tahoe region. It was cut mostly into firewood, together with the pine tops left in logging. It takes a long time to dry, and as it warps badly, it was not used for building. The extreme diameter reached 5 feet and the range was from 4000 to 7500 feet. The Douglas Fir, or Douglas Spruce, is found around Lake Tahoe, but not on the eastern slope of the mountains. It reaches heights of 100 to 150 feet, and diameters from 3 to 6 feet. On account of the strength of the wood, it is one of the most valuable of forest trees. Red Fir grows over the entire region, but was not very abundant or accessible, being found between elevations 7000 to 8500 feet, and in diameters up to 5 feet. Red Cedar [incense cedar] was used principally in structures in contact with the ground, the heart wood only being resistant to decay...There is no hemlock or spruce in the Tahoe region, and the only tamarack is the useless Lodgepole Pine, so called" (Galloway 1947).

Although it is apparent that the Jeffrey, sugar, and ponderosa pines were favorites, lumbermen eventually found that there was a market for fir and cedar as well. Fir stands were logged after the turn of the century for paper pulp (Knowles 1942; Wilson 1992). Stands of cedar were harvested for shakes and shingles. Accordingly, some timber tracts were not clear-cut at once; rather, stands such as those at Tahoe's north and northwest shores were reentered over time for different purposes.

Historic Stump Fields

Less than three decades after the forests in the Tahoe basin were initially clear-cut, Leiberg (1902) observed "It is not possible to state with any degree of certainty the quantity of timber cut from the portion of the Truckee Basin [and north and west Lake Tahoe basin] examined. Much was cut so long ago that the stumps have rotted down. . . . "

Yet, over a century after cutting, historic cut stumps remain in certain areas of the Tahoe basin and are a potentially productive avenue of study. Taylor (1997) quantitatively described pre-Euro-American forest conditions and processes in his dendroecological study of sample plots of cut stumps left by Comstock logging on the east shore of Lake Tahoe (Carson Range). He concludes "Prior to Euro-American settlement, forests on well drained sites at high altitude were dominated by red fir and western white pine. Small patches of lodgepole pine were also present in some stands. . . . Large areas may have been covered with mature and/or old-growth stands. . . . In the original forests both large and small diameter stems were . . . typically clumped at several scales" (Taylor 1997). "Pre-Euro-American lodgepole pine forests were less dense and had trees in a wide range of size-classes and stands were a mosaic of stems which were clumped at various spatial scales" (Taylor 1997).

In another study (Lindström and Waechter 1995, 1996), comparisons among six stump fields on Tahoe's north shore and northeast shore, ranging in size from about 10 to 60 acres each, show marked contrasts in stump diameter and density. Stump fields sampled on the north shore, on average, may have been composed of larger trees at least twice as densely packed, and sometimes up to 17 times, as stands on the northeast shore, with average stump diameters being 35 and 30 inches, respectively. These average stump diameters are consistent with log diameters recorded in scaling records dating from 1887 to 1890 in the Trout Creek

drainage in South Lake Tahoe (Figure 2-8). The large diameters of harvested timbers are depicted in period photographs (Figures 2-9A and 2-9B).

Fire Frequency

Fire historically has been a companion to logging, as written records, burned stumps, and log structures attest. After Comstock-era cutting, forests were vulnerable to fires as never before. "There is little litter except on areas logged or culled to considerable extent, where masses of tree tops and rejected portions of trunks form great heaps of debris" (Leiberg 1902).

Some of the most serious fires fed on debris in cutover areas and owed their origins to sparks from steam-powered logging equipment or friction points in cable skidding. Costly fires occurred along the railroad where cordwood, ties, mine timbers, or lumber awaiting shipment were ignited by cinders from wood-fueled locomotives. Very destructive fires also occurred at mills, where burning sawdust and slab piles were constant flammable hazards. Blazes in cut forests ran virtually unchecked through slash and second growth, creating sufficient heat to destroy humus and to harden clay in the soil (Strong 1984). Consequently, forest regeneration was delayed for years due to seedlings and saplings damaged by fire and logging. Seldom was there any coordinated attempt at fire suppression; indeed, many of the residents in the basin evidently looked upon wildfires as useful agents in clearing the land of brush and undesirable trees (Strong 1984).

Eroding Logging Roads as Conduits of Sediment in Tahoe's Watershed

Heyvaert (1998) estimated that during Comstock-era logging, sediment deposition rates into Lake Tahoe increased seven- to 12-fold over rates of deposition before disturbance. One source of sediment may have been from the miles and miles of historic log haul roads, skid trails, and flumes that form dendritic patterns along basin mountainsides. Many of these roads have since eroded into trenches with depths of up to six feet. Some eroded roads are now only recognizable as drainage channels and are appropriately characterized as "sensitive environmental zones" by forest managers. These roads are most densely packed along the east and south shores, with highest densities and most severe erosion along Trout and Saxon Creeks in south Lake Tahoe. Maps depict the focus of past human disturbance (Figure 2-10). Over the century, these entrenched roads likely served as conduits, introducing sediments into Tahoe tributaries (and they may continue to do so). Sediment loading may have been particularly extreme in shallow, decomposing, granitic soils and immediately following Comstock logging events, before the ground surface had an opportunity to stabilize. In addition, the timing of Comstock-era road construction coincided with a period of increased moisture and runoff that would have further aggravated erosion problems. DeQuille (1877), in a historic period account, comments on the negative impacts on the watershed due to Comstock logging,: "The time is not far distant when the whole of that part of the Sierra Nevada range lying adjacent to the Nevada Silver-mining region will be utterly denuded of trees of every kind. Already one bad effect of this denudation is seen in the summer failure of the water in the Carson River. The first spell of hot weather in the spring now sweeps nearly all the snow from the mountains and sends it down into the valleys in one grand flood, whereas while the mountains were thickly clad with pines the melting of the snow was gradual and there was a good volume of water in the river throughout the summer and fall months."

Perhaps the most visible lasting example of such erosion is the North Flume, which flowed from Third Creek to a tunnel above Marlette Lake. Erosion channels generated by washouts appear as tremendous vertical erosion scars on Incline Mountain that can still be seen from across the lake. Increased flows of sediment and silt into spawning gravels, coupled with the diversion of streams, may have been partially responsible for the extinction or decline of native trout (Elliott-Fisk et al. 1996).

Environmental Consequences of Lumber Company Harvesting Strategies

Beginning in 1859, a few individuals staked small timber claims to supply the handful of sawmills established to outfit local needs. The earliest lumber and fluming operations were small-scale and

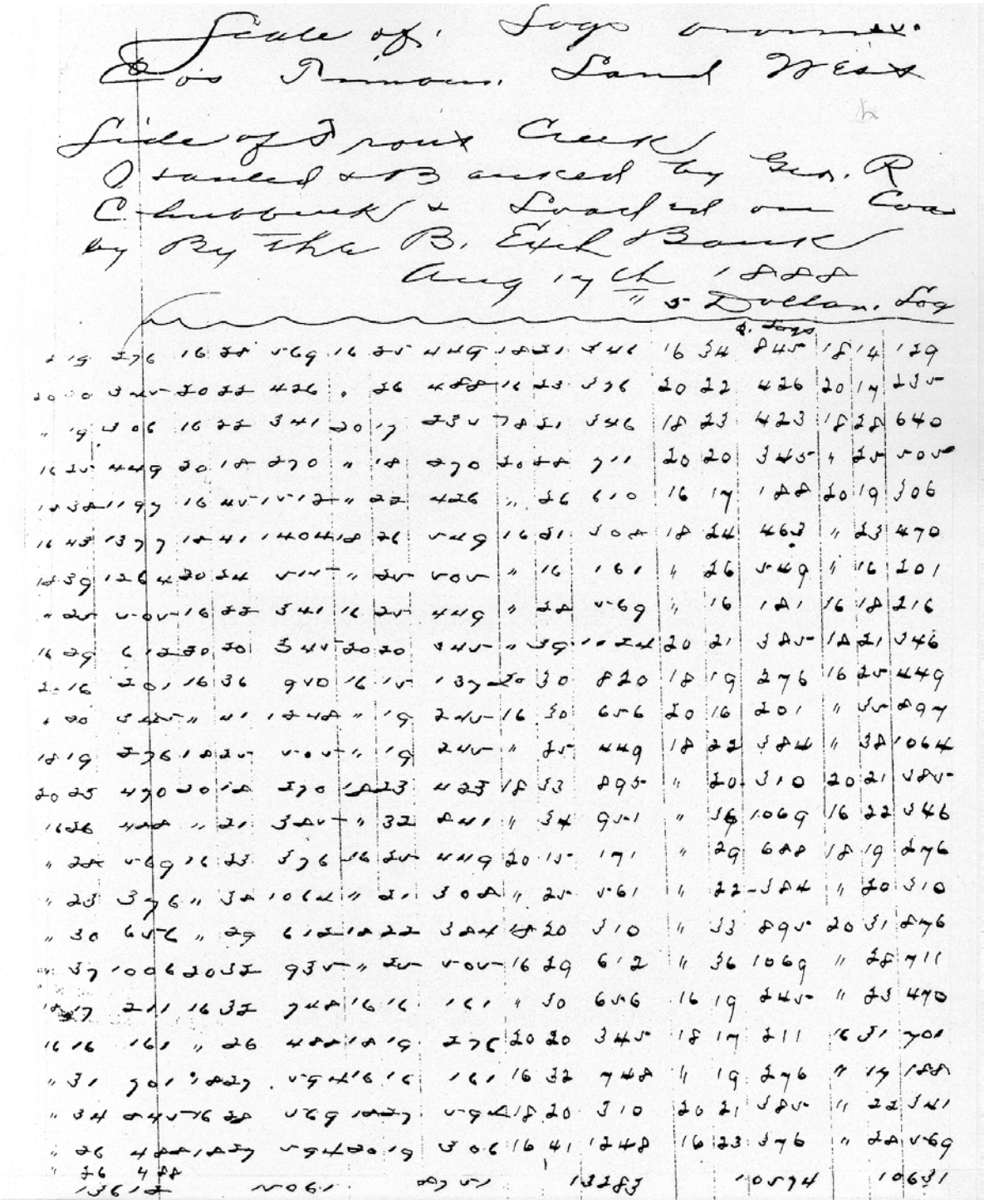


Figure 2-8—Page from Log Scale Record Book 1887-1888, logs scaled on "Co.'s Land West of Trout Creek" (on file CTLFC Records 1864-1946 NC73/9/36,37,38/Box 24); log lengths are presented in the far left column, log diameters in the center column, and volumes in the right column with summed totals.

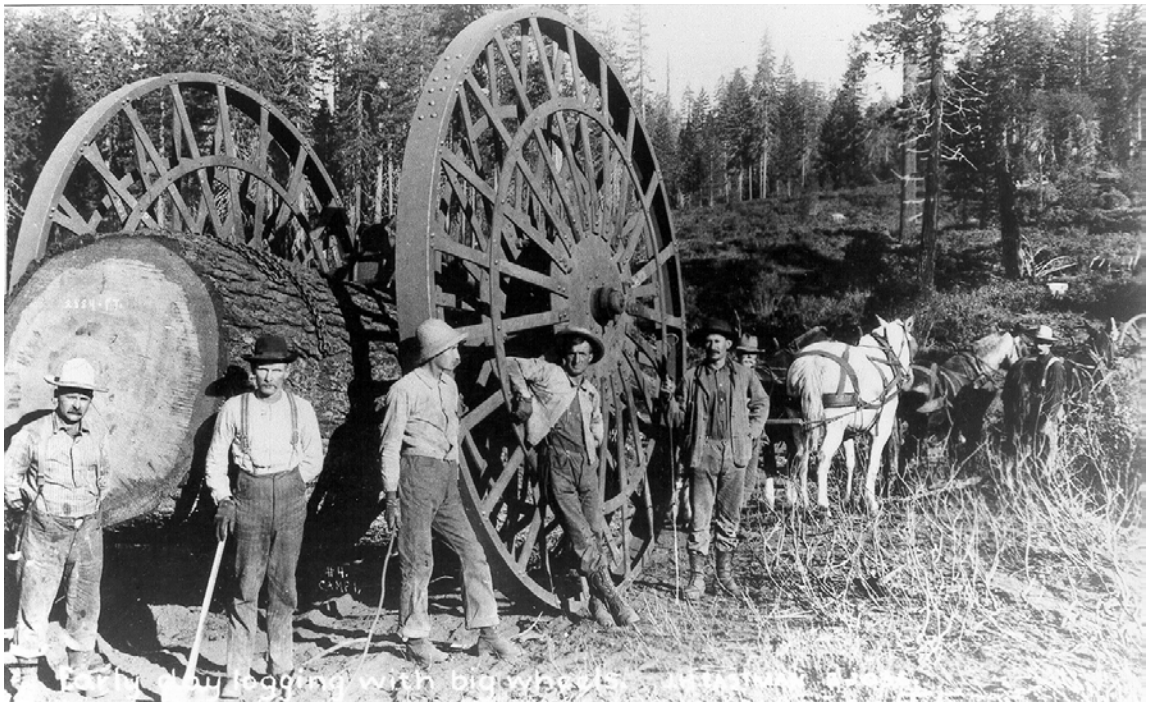


Figure 2-9A—Early day logging in the Tahoe Sierra with big wheels; note the large diameter log (photograph courtesy of Nevada Historical Society).



Figure 2-9B—Logging the Tahoe Sierra in 1895; note the large diameter logs (photograph courtesy of Nevada Historical Society).

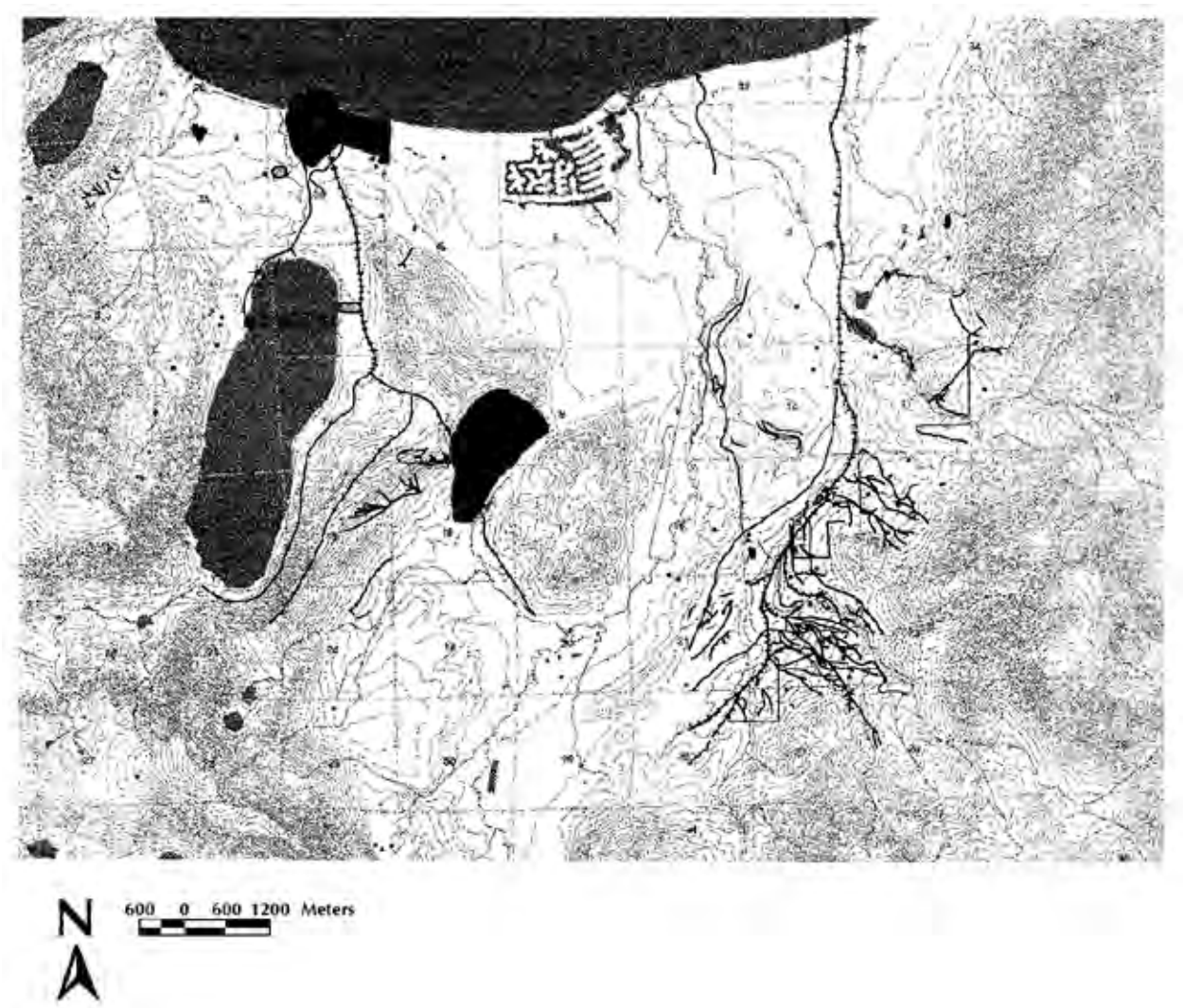


Figure 2-10—Historic logging roads and railroads in South Lake Tahoe; note the density of linear features within the Trout/Saxon creek drainages.

scattered along Tahoe's east shore (around Spooner Summit and Glenbrook) and in Lake Valley (South Lake Tahoe), later expanding to the west and north shores. Mark Twain joined the ranks of these lumber pioneers when he staked claim to a small tract of timber near Glenbrook in the early 1860s, then watched as it went up in smoke after his unattended campfire got out of control. These few small sawmills, established in the Tahoe basin during the 1860s to supply local needs, preceded the large-scale logging to come. Clear-cut logging began in earnest in 1873 with the arrival of large lumber and fluming companies stoked with capital to finance large mills and to establish an elaborate network of logging barges, railroads, wagon roads, V-shaped flumes, water storage reservoirs, and associated wood camps and mills. The system was designed to cut and move the lumber over the Tahoe divide and down to the mines of Washoe and the markets served by the CPRR (Figure 2-11). Timber was largely transported from the basin by V-flume down to the railroads; mutual business ties naturally developed among lumber, water, and railroad interests. To meet the vast labor demands, these companies hired immigrant workers, including a large number of Chinese.

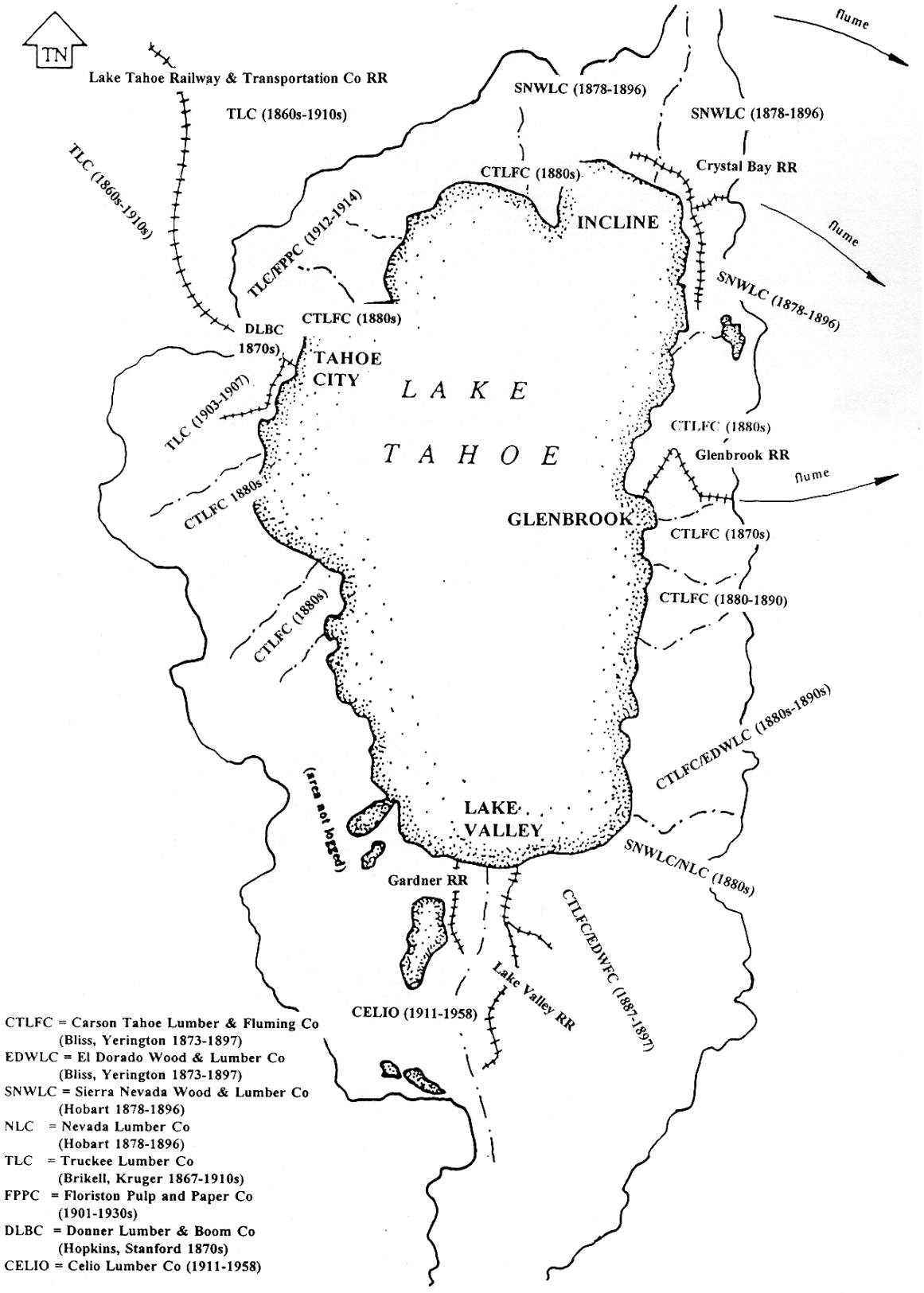


Figure 2-11—Major lumber operations in the Lake Tahoe basin.

The Carson Tahoe Lumber and Fluming Company (CTLFC) emerged as the chief lumber operator under the ownership of D. L. Bliss, J. P. Yearington, and D. O. Mills. Their headquarters were at Glenbrook. From 1873 until 1898, an elaborate "super-system" of rafting operations, railroads, V-flumes, wagon and skid roads, and wood camps supplied their mills at Glenbrook from their basin-wide timber holdings. Logs were rafted to the Glenbrook mills, and lumber was hauled from there to Spooner Summit by railroad and then sent by flume down to storage yards near Carson City for transport by the Virginia and Truckee Railroad (VTRR) (figures 2-12 to 2-15). The company monopolized the Comstock trade and eventually came to control approximately one-fifth of the Tahoe basin's land, including substantial stretches of lakefront (Goodwin 1971). It held vast timber tracts on Tahoe's east-central and south shores, with smaller discontinuous holdings on the north and west shores. As companion organizations, the CTLFC worked closely with the El Dorado Wood and Fluming Company (EDWFC) in logging their lands and later in marketing and leasing their respective holdings. Within 25 years, the CTLFC had cut 750 million board feet of lumber and 500,000 cords of wood in the Tahoe basin.

The Sierra Nevada Wood and Lumber Company (SNWLC), owned by W. S. Hobart, was the second largest logging operation. The company owned approximately 55,000 acres of timberland in the Tahoe basin. Cutting occurred from 1873 to 1896 and was concentrated around Incline in Tahoe's northeast quadrant, with some harvesting on the southeast shore. Company operations included a narrow-gauge railroad, a rafting system on Lake Tahoe, a network of V-flumes and log haul roads, and a mill and tramway at Incline (figures 2-11 to 2-15). Lumber was hauled by tram from the mill to a V-flume, which first passed through a tunnel, built originally by the Virginia and Gold Hill Water Company (VGHWC) to augment its supply of water from the Sierra Nevada. From here lumber was floated down the Lakeview hill to a flume dump and storage yard that was served by a spur track from the VTRR (Elliott 1973).

Logging in the northwestern part of the Tahoe basin was done primarily by the Truckee Lumber Company (TLC). The TLC, under the ownership of E. J. Brickell and W. H. Krueger, maintained holdings along the Truckee River Canyon and on the mountains above Tahoe City, cutting from 1867 until the 1910s (Figure 2-11). The Donner Lumber and Boom Company (DLBC), headed by CPRR managers Mark Hopkins and Leland Stanford, also operated in the Truckee River corridor. The company was granted authority in 1870 to construct a dam at Tahoe's outlet to impound water used to float logs and cordwood down the Truckee River channel to Truckee (Figure 2-11).

The Pacific Wood, Lumber and Flume Company (PWLFC) operated between 1877 and 1888 under the direction of the mining conglomerate Flood, Fair, Mackay, and O'Brien. The company owned timber stands in the extreme northeastern area of the basin near Mt. Rose, cutting in the Hunter and Evans Creek drainages (Figure 2-11). Wood was transported in a 15-mile V-flume all the way to Huffaker's Station on the VTRR.

Lumber company records, supplemented by the archaeological remains of logging activities, guide the assessment of changes in plant and animal communities by revealing where and when anthropogenic disturbances occurred. History and archaeology delineate the subwatersheds where logging disturbances were relatively short-lived (lasting perhaps a single season), as well as such locales as Glenbrook and Incline that endured intense impacts for decades and the areas that escaped impacts altogether.

The scale and intensity of Comstock-era logging, as well as the timing of harvest, was not uniform throughout the basin. The progression of harvest was tied to the proximity and accessibility of timber stands. Figure 2-16 shows the irregular distribution of logged lands. Specific dates of cutting in Tahoe's subwatersheds are listed in the logging timeline on Table 2-5 and are shown on Figure 2-17. Large stands of timber initially were cut during the mid-1870s on Tahoe's east central shore around Spooner Summit, and clear-cutting was complete by the 1880s (Taylor 1997).

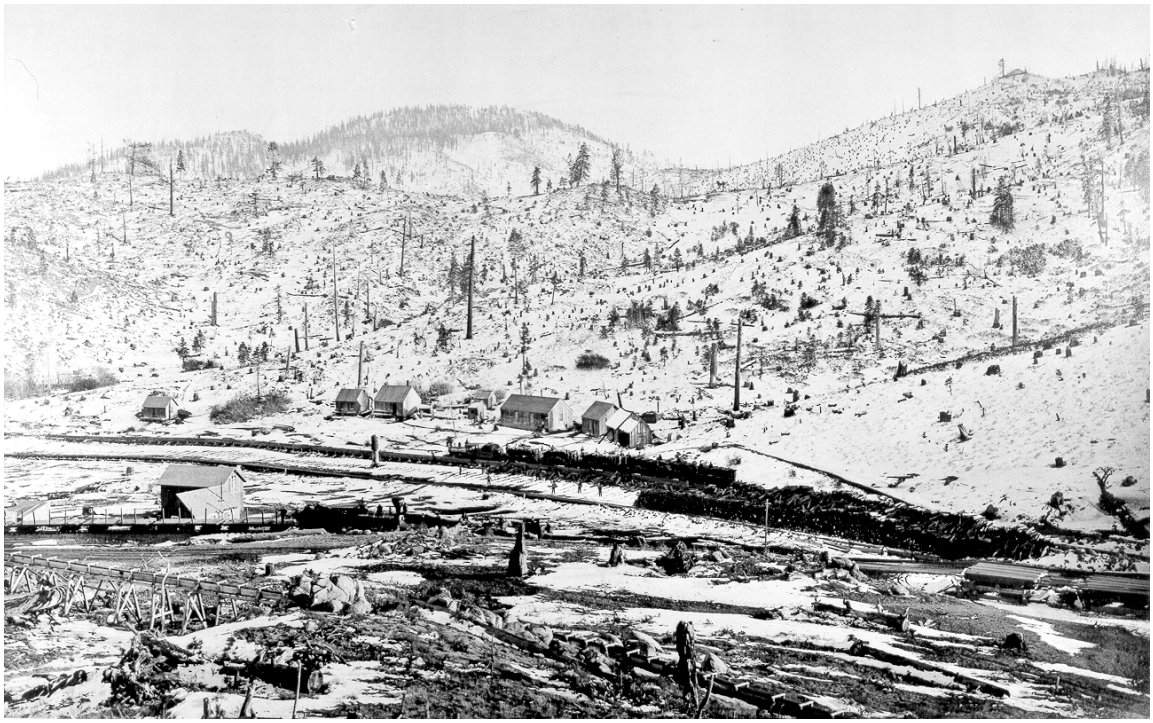


Figure 2-12—Spooner Summit 1876, looking northwest from a point now located on the north side of Highway 50; Glenbrook Railroad is unloading milled lumber for transport to Carson City via V-flume; note cutover slopes (photograph courtesy of Nevada Historical Society).



Figure 2-13—Spooner Summit ca 1870s, looking southeast; Highway 50 now passes through the foreground; note cutover slopes (photograph courtesy of Nevada Historical Society).



Figure 2-14—V-flume on Spooner Summit ca 1870s, looking northwest from a point now located on the north side of Highway 50; view is a closeup of logging train and lumber loading decks shown in Figure 2-13; note cutover slopes (photograph courtesy of Nevada Historical Society).



Figure 2-15—Mill at Incline ca 1880s to 1890s; note cutover slope (photograph courtesy of Nevada Historical Society).

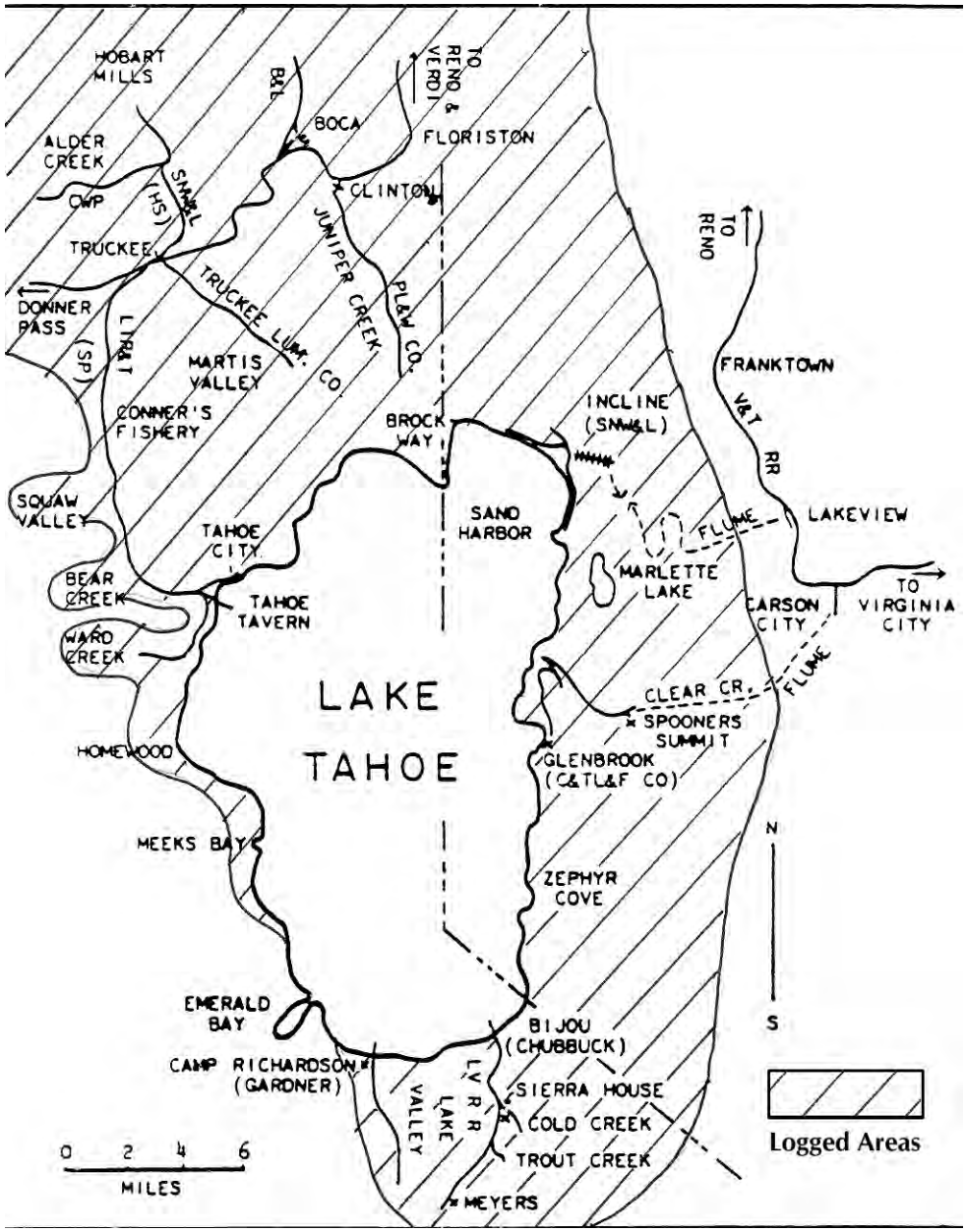


Figure 2-16—Schematic map showing estimated extent of historic logging in the Tahoe basin (map template modified after Myrick 1962:417).

Table 2-5—Summary of logging in the Lake Tahoe basin.

Area	Small-scale Cutting (Date/Individual)	Large-scale Cutting (Date/Company)
South Shore		
Lake Valley	1859-1887 (independent)	-
	1885-1886 (Chubbuck for CTLFC)	1887-1897 (CTLFC/EDWLC)
Camp Richardson/Tahoe Mt	-	1875-1885 (Gardner for CTLFC)
Meyers	1911-1958 (Celio Lumber Co)	-
Upper Trout Creek	1946 (Placerville Lumber Co)	-
West Shore		
McKinney Bay	1867-1877 (contractor for CTLFC)	-
Meeks/Rubicon Bays	1878-1884 (contractor for CTLFC)	-
Sugar Pine Point	1878-early 1880s (contractor for CTLFC)	-
Blackwood Canyon	1890 (contractor for CTLFC)	-
Northwest Shore		
Ward Canyon	1863-1877 (contractor for CTLFC)	1903-1907 (TLC)
Tahoe City/Burton Creek	1880s (contractor for CTLFC)	1912-1914 (TLC/FPPC)
	1927-1933 (independent)	-
	-	1992 (USFS Twin Crags TS)
North Shore		
Agate Bay	1864-1878 (independent)	-
	1878 (contractor for CTLFC)	-
Tahoe Vista	1881 (contractor for SNWLC)	-
Dollar Point	1884 (contractor for CTLFC)	-
Griff Creek	1920s-1927 (independent)	-
Watson Creek	-	1947 (Fibreboard)
Martis Peak/Brockway	-	1960s (Fibreboard)
	-	1989 (USFS Watson TS)
	-	1992 (USFS Brockway TS)

Table 2-5—*(continued)*

Area	Small-scale Cutting (Date/Individual)	Large-scale Cutting (Date/Company)
Northeast Shore		
Incline to Mt. Rose	1876-1878 (Marlette & Folsom for SNWLC)	1878-1896 (SNWLC)
	-	1960s (Boise Cascade)
East Shore		
Spooner/Glenbrook	1861-1873 (independent)	
east shore Marlette to Daggett Pass	-	1873-1890s (CTLFC)
White Hill (Spooner Summit)	-	1873-mid-/late 1870s (CTLFC)
Logan House/Lincoln Cks (upper reach)	-	mid-1880s (CTLFC)
Slaughterhouse Canyon	-	1885 (CTLFC)
Logan House Creek (lower reach)	-	late 1880s-1890 (CTLFC)
Marlette Lake	1950s (commercial logger)	-
Southeast Shore		
Edgewood	1860s-early 1870s (independent)	-
Edgewood/Kingsbury/Daggett Pass	-	1880s-1890s (SNWLC, NLC; CTLFC, EDWLC)
Kingsbury	1949-1954 (Placerville Lumber Co)	-

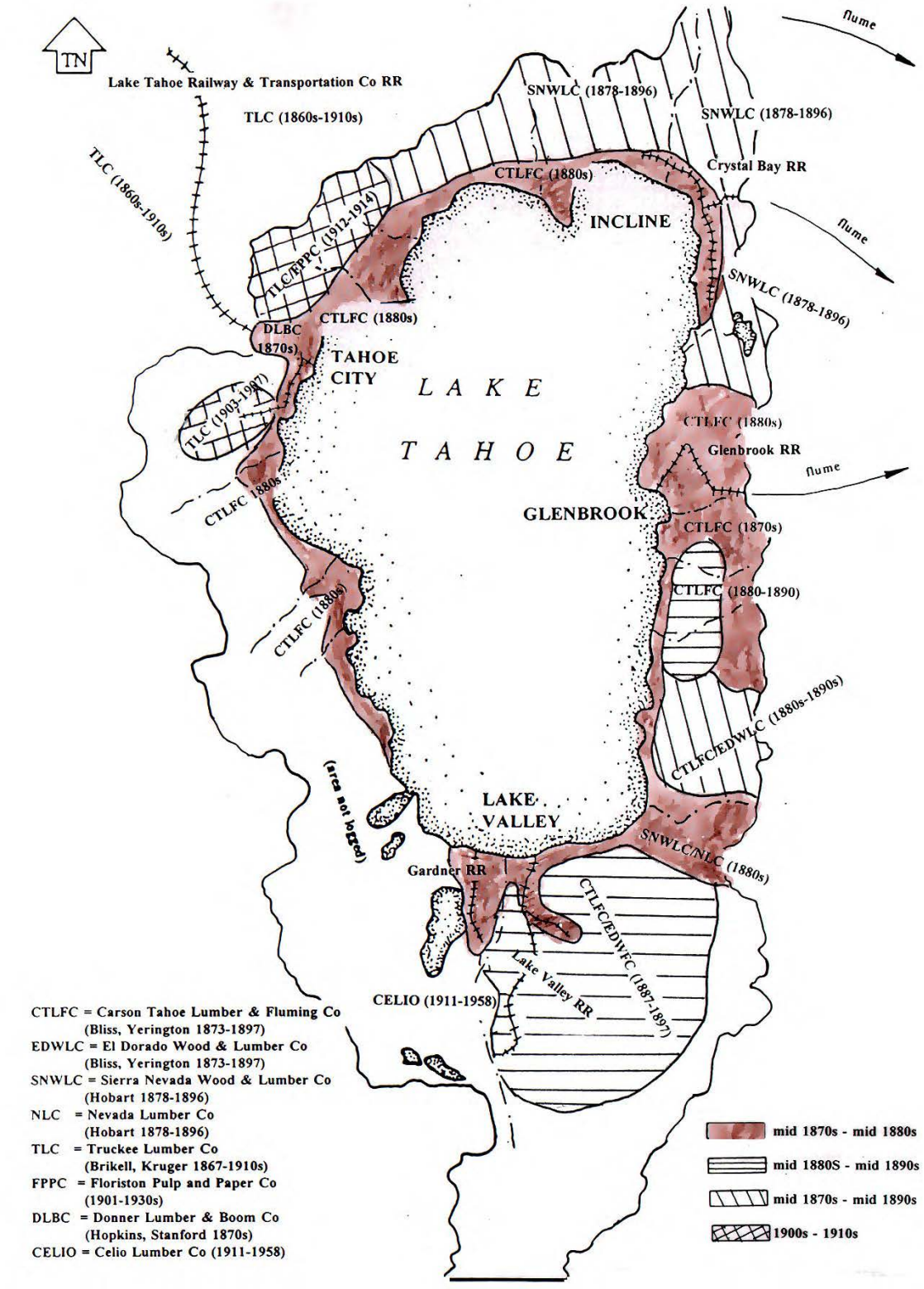


Figure 2-17—Schematic map of large-scale cutting (based on archival/archaeological/dendrochronological data).

During the late 1870s to mid-1880s, more distant stands were tapped, with more limited harvest occurring in selected pockets along Tahoe's west shore and in discontinuous tracts on the north shore above Agate and Carnelian bays and on the southeast shore around Kingsbury. The 1880s also saw the extensive clear-cutting of large timber tracts above Incline. Vast stands in Lake Valley on the south shore were not clear-cut until the very late 1880s and 1890s. Less desirable fir stands were logged during the 1900s to 1910s for paper pulp. Throughout the period, a few minor independent operators harvested cedar for shakes and shingles and cut pine for local use. Marked differences in company harvesting strategies in the Tahoe basin have been considered by Lindström and Hall (1997) in terms of chronology, geography (topography, hydrology, vegetation), land ownership, corporate structure, available markets, technology, labor, socio-cultural organization, ethnicity, and archaeology. The activities of the CTLFC in all quadrants of the basin provide an example of these differences, as presented by Lindström and Hall (1997) and summarized below.

To facilitate their east shore operations, the CTLFC commanded immense, contiguous timber blocks, on which an impressive network of transport and milling operations was located. Steep terrain prohibited conventional railroad logging, and a small narrow gauge railroad functioned more like a tram. East shore harvests were among the company's most intensive and extensive, with correspondingly severe environmental impacts. East shore operations were also the company's earliest, with most cutting occurring during the 1870s and 1880s. (Logging by the SNWLC in its vast holdings between Incline and Mt. Rose may have been similarly intensive and extensive.)

Logging by the CTLFC in Lake Valley on Tahoe's south shore occurred relatively late; largescale logging didn't begin until the later 1880s and ended in 1898. As with earlier east shore operations, the CTLFC owned large, contiguous timber blocks within which it developed a complex harvest and transport network. Level terrain accommodated railroad logging and an accompanying system of wagon haul and skid roads. In addition, the CTLFC enjoyed the advantages gained by new steam technologies. Support services provided by local suppliers and a local labor force increased production. Accordingly, the vast timber resources on the south shore were fully exploited in less than 10 years.

In contrast to east and south shore operations, CTLFC's north shore holdings consisted of largely disjunct timber blocks of smaller size, juxtaposed in checkerboard fashion with plots owned by competing lumber companies. Harvest and transport were accomplished by a variety of small-scale independent contractors. Company-sponsored logging occurred here during the 1880s, and impacts were considerably less intensive and extensive.

Similarly, west shore operations were accomplished by independent contractors without the benefit of an integrated log harvest and transport infrastructure. Harvest was confined to accessible stands near the lake and more distant forests were not penetrated. Cutting was relatively early (late 1870s to 1880s), and stands on the west shore, overall, were the least affected in the basin.

From the standpoint of Comstock-era logging interests, mixed conifer stands of pine, fir, and cedar on the north and south shores were generally more productive than homogenous pine forests on the drier east shore. Also, north and south shore stands were more accessible than forests on the steeper east shore or the rugged west shore. Harvest commenced in the late 1870s on the north shore, and between 1888 and 1889 on the south shore.

Overall, second growth north shore forests could be reentered sooner than south shore stands. With a market demand for cedar shingles and the opening of a pulp and paper mill on the Truckee River in 1901, loggers reentered mixed stands on the north shore to cut fir and cedar left by Comstock-era loggers. The Lake Tahoe Railway and Transportation Company (LTRTC) established a tourist railroad, which also transported wood products down the Truckee River canyon to the mainline at Truckee. In general, forests on Tahoe's north shore experienced recurrent logging disturbance, whereas second growth stands elsewhere in the Tahoe basin were largely left to regenerate for many decades following their initial disturbance.

Patterns in the geography, land ownership, technology, and chronology of historic logging operations are mirrored in the density and distribution of archaeological logging remains. Despite comparable archaeological coverage, far more sites have been inventoried on the south and east shores than the north and west shores. For example, a 700-acre survey for the Pioneer Timber Sale on Tahoe's south shore disclosed an intensive Comstock-era logging network that includes a 13-mile railroad that was fed by 16 miles of wagon haul roads, one V-flume that extended 2 miles, and at least 28 railroad camps and wood camps (Lindström and Hall 1997). A survey of 5,600 acres for the North Shore Ecosystems project on the north-central shore (an area eight times larger than the Pioneer Timber Sale area) resulted in discovery of one historic logging camp dating from the 1910s, a cedar sawmill from the 1920s, two Comstock-era logging chutes, and several isolated artifacts (Lindström and Waechter 1996). A 12,000-acre survey of the Spooner-Big Gulp Timber Sale on the east-central shore (only twice the size of the north shore survey) revealed a vast inventory of Comstock-era logging remains, including a nearly 9-mile railroad, more than 80 miles of wagon haul roads, flumes, and skids, 60 wood camps, and three saw mills (Lindström and Hall 1994).

Forest Conservation Ethics

Published documents, company records, oral histories, and physical evidence suggest that logging interests did little to conserve the natural environment, and for the first several decades, logging practices were unregulated. Yet, the entire Tahoe basin was not clear-cut. At least 38 old-growth stands have been located within Tahoe's upper and lower montane forests. Inaccessible stands, excessively large trees, and deformed trees were left due to difficulty in transport or milling. Stands around resorts were preserved for aesthetic reasons. Some laudatory accounts characterize D. L. Bliss, principal of CTLFC (the largest Comstock-era lumbering firm in the Tahoe basin), as a conservationist in that even during the height of the demand for timber, he took steps to preserve the Tahoe basin's natural beauty, requiring that trees under 15 inches diameter be left standing and exempted "particularly scenic" parts of the forest from any cutting at all (McKeon 1984; Wheeler 1992). Shaw et al. (1948) comment on the company's cutting practices at Tahoe.

"We gladly record his [D. L. Bliss's] far-reaching operations which were productive and always mindful of conserving Nature's gifts for the continued enjoyment of coming generations. Few are the lumbermen earning such a reputation."

The extent to which Bliss' conservation ideas were actually put into practice and the degree to which they had enduring effects on the landscape are presently unclear.

Fishing

The two great lakes joined by the Truckee River—Lake Tahoe and Pyramid Lake—are the only lakes within the Lahontan drainage system of the western Great Basin that did not dry up over the past 10,000 years. While fisheries within other drainages of the Lahontan system were depleted, Lake Tahoe retained an extraordinarily productive and stable native fishery for thousands of years (Hickman and Behnke 1979; Hubbs and Miller 1948; La Rivers 1962; Snyder 1917). Yet, in a matter of decades, the native fishery—once blithely regarded as inexhaustible—was reduced to a fraction of its former abundance, and the Lahontan cutthroat trout became extinct.

Washoe Fishing

Fish constituted one of the most important subsistence resources for the Washoe and their prehistoric ancestors (Lindström 1992, 1996). Native cutthroat trout and a variety of sucker, chub, and "minnow" species commonly inhabited upland drainages. Trout weighing 10 to 20 pounds were common in Lake Tahoe and its tributaries, and the Washoe speared, netted, and trapped the fish. The spawning runs were times of intense activity. The Washoe, carrying baskets waded into the streams, scooped up fish, and tossed them onto the bank (Downs 1966). As the fish migrations tapered in the summer and water levels dropped, the Washoe built dams to divert small streams and to collect stranded fish (Downs 1966a; Freed 1966). The effects of the

aboriginal diversion of streams within the Tahoe basin were far more subtle than Comstock-era water engineering feats, yet they did influence localized stream flows and fishery. Freed (1966) recorded 32 Washoe fishing camps around the shores of Lake Tahoe, most near the mouths of tributary streams. As part of the Washoe Land Claims Case, Manuel Bender (Manuel Bender 1963, in Wright 1931-1972) named Tahoe's most productive fisheries in the order of their importance: the Upper Truckee, followed by, Blackwood, Taylor, Ward, Incline (Third Creek), Trout, McKinney, Meeks, Sugar Pine (General Creek), Cascade and Glenbrook, respectively. Siskin's (1939) Washoe consultants also placed greatest emphasis on the Upper Truckee River (named "trout stream") and Trout Creek (named "whitefish stream") (Mike Holbrook, 1930s, in Siskin 1939).

The Washoe took all types and sizes of fish; apparently large trout were most highly valued. They distinguished two types of "big trout" in the Truckee River system: an early summer spawner (*imgi*), weighing up to 50 pounds with a prominent humped head and snubbed nose ("like pig"), and a spring spawner (*imgi cahat*), smaller and darker in color, weighing not more than 10 pounds (Siskin 1939). George Snooks reported that during the spring of 1925, he " . . . took 17 in one day. From 3-4 ft. each. 6 largest weighed 110-125 lbs" (George Snooks in Siskin 1939). Whitefish were reported to be large and abundant. In Trout Creek, whitefish (*matishau)*, measuring up to two feet long and weighing 10 to 15 pounds, appeared "by the thousands in October." At first, the Washoe strongly resisted Euro-American incursions into their fishing grounds during the 1850s to 1860s, but as a market developed, some Washoe attempted to compete by selling fish commercially and were admonished for doing so. In the 1860s, H. C. Blackwood allegedly shot a member of the Washoe Tribe for setting a fish trap on Blackwood Creek. Elsewhere, Washoe fish traps were removed.

" . . . We drove to Griff's Creek, a tributary of Lake Tahoe. O'Neill had located an Indian fish trap [weir] on the creek several days before. . . . It was a most ingenious contrivance for catching fish, made from woven green willows. The Indians who were working this engine of destruction for numberless spawn fish, were camped beside the creek. We ordered them to leave the lake and took out their trap. We worked over an hour and a half to get it out of the water. . . "(*Wadsworth Dispatch*, December 3, 1892).

Size and Structure of Tahoe's Fishery

While the fishing practices of Tahoe's native inhabitants often went unreported by early Euro-Americans, comments on the bountiful fishery appeared in numerous writings. Tahoe was characterized as a "piscatorial bonanza," and, until the 1920s, the size and abundance of Tahoe trout and fantastic catch records were consistently reported. In 1863, W. H. Brewer (Brewer, August 23, 1863, in Brewer 1974), a member of the California State Geological Survey, was amazed at the 20- to 30-pound trout in Lake Tahoe. The largest trout recorded as caught up until 1872 was a native cutthroat at 29 1/2 pounds. A 31 1/2-pound cutthroat was taken at Tallac (South Lake Tahoe) in 1911 to set a new lake record (Behnke 1979; Calhoun 1944; Juday 1906; 1911 Tallac Brochure in Scott 1957; Snyder 1917). Unconfirmed reports of trout weighing in at 45, 50, and even 70 pounds were made (Scott 1957). The following historic period observations allow us to assess how this aspect of Tahoe's aquatic ecosystem has changed from historic times to the present (Figures 2-18 and 2-19).

"In the summer of 1875, C. F. McGlashan of Truckee estimated that 20 to 25 market fishermen were working the lake, averaging 45 to 60 pounds of fish each day on deep line" (Scott 1957).

"[1878] Five hundred pounds per day is not unusual work for a single spearman in a stream just north of McKinney's forks, about 400 yards above its mouth" (*Sacramento Daily*, June 1878 in *Sierra Sun* October 18, 1984).

"[1881] J. Ballard of San Francisco landed 33 silvers in two hours before breakfast. William Pomin's catch of 25 'pogies' [trout] the same day was barely considered newsworthy. Finally two fishermen outdistanced their rivals when they set



Figure 2-18—Large cutthroat trout caught at Tahoe ca early 20th century (photograph courtesy of Jim Bell).



Figure 2-19—Fishing at Tallac in 1893; everyone has a fish, including the dog (photograph courtesy of Jim Bell).

an all-season record—65 trout in four hours, aggregating 115 pounds in weight" (Scott 1957).

"[ca. 1880s] Fishing guides Mayo and Hurley, along with Pomin and Morgan, were consistent producers, each man regularly averaging 75 pounds daily during the summer season" (Scott 1957).

"The 'Great Sweepstakes of 1881' took place in August of the year. Ten young ladies and their escorts brought 112 fish to boat in a three-hour period with the winning "high line" among the group taking 25 of the combined total using a single hook only" (Scott 1957).

The *Carson Appeal* reported an incident one June evening where nearly 1,000 pounds of lake trout were taken. "The fish crowded around the submerged light by the hundreds, whereupon Dalles just pulled his [gang] hooks to the surface through the milling mass, hauling one or more trout in each time he retrieved the line" (Scott 1957).

Juday's (1906) data suggest that sport and commercial catches at Tahoe approached 75,000 pounds in good years (Cordone and Frantz 1966). Similar fantastic catches were reported in other tributary lakes and streams within the Truckee River drainage system. However, most of these accounts date from between the 1870s and the 1920s, a time when abnormal concentrations of fish became impounded behind dams and when representation of various age classes in each catch was affected by the obstruction of spawning runs. In these unnatural aggregations of fish, old and large adults were overrepresented relative to juveniles (Lindström 1992, 1996).

Trout were not the only abundant species in the lake. Snyder (1917) commented on masses of tui

chub feeding, but not spawning, in the shallows around Lake Tahoe.

"Large schools of lake [tui] chubs gather around wharves, fallen trees, and other sheltered places. At the mouth of Fallen Leaf Creek (Taylor Creek), Lake Tahoe, at times the rising water slowly spreads out over the meadows and when covering the ground but a few inches is invaded by great schools of this species. After sundown they appear in countless numbers, thrashing about in the grass and rushes. When approached, they either scurry off in great haste, sometimes diving into a bunch of grass or settle down perfectly still. On the approach of daylight they return to deeper water."

Snyder (1917) also described spawning Lahontan redside at Tahoe in abundant numbers.

"While examining Fallen Leaf Creek [Taylor Creek], a tributary of Lake Tahoe, on June 10, large schools of this species were observed making their way up the smaller tributaries, progressing chiefly at night, when they might be seen or heard struggling over the small rapids and leaping the miniature falls . . . "

Historical Decline

" . . . why is it that the Truckee River, once known throughout the country as the grandest trout stream in the West, is now one of the poorest?" (*Reno Evening Gazette* March 1908).

Like its timber, Tahoe's fisheries were thought to be limitless. As early as 1858 the fishery supplied local markets and, with the completion of the transcontinental railroad in 1869, markets as far away as San Francisco and Chicago. Cutthroat trout, along with whitefish, were abundant in sufficient numbers to support a commercial fishery from 1859 until 1917 (Scott 1957). By the 1870s 25 commercial operators were using long seines and large trawlers to harvest tons of trout. In 1880 alone, 70,000 pounds of Tahoe trout were shipped by railroad from Truckee, and wagon loads of fish, each weighing from 1,000 to 2,000 pounds, were marketed at Comstock settlements. In 1904 up to 80 commercial fishing boats were operating on Tahoe.

Harvesting methods were wasteful. The underlying principle prescribed removing the maximum amount of trout in the minimum amount of time. Nineteenth and early 20th century fishermen commonly used techniques such as poison, traps, dams, nets, grab hooks, and dynamite. A series of laws was passed beginning in the 1860s in an attempt to halt the wholesale slaughter of fish. The laws limited the timing and method of catch, and placed constraints on dumping sawdust and other pollutants into waterways. After 1911 the catchable limit was reduced from 100 pounds per day per fisherman to 50 pounds (Scott 1957). Finally, in 1917, the California legislature banned commercial fishing at Tahoe to protect the endangered trout, but the irreversible damage was done. Since the 1860s excessive commercial fishing, dam construction, disturbance of spawning grounds, obstruction of spawning runs, pollution of the watershed, and competition from introduced species combined to cause the demise of the native cutthroat trout (Lindström 1992, 1996; Townley 1980). By 1929 the cutthroat trout could no longer migrate up the Truckee River, and by 1938 both the Lake Tahoe and Pyramid Lake strains of cutthroat trout were extinct.

With the demise of native fish populations, attempts were made to restore the sport fishery by stocking exotic aquatic species. The unanticipated but subsequent hybridization, competition, predation, disease, and taking of spawn completely decimated the native population of cutthroat trout (Behnke 1979; Juday 1906; La Rivers 1962; Moyle 1976; Scott 1957, 1972; Snyder 1917; Townley 1980). Exotic introductions between 1875 and 1920 focused upon apex (top) predators, such as Mackinaw and golden trout. Between 1920 and 1965 Mysis shrimp and lower trophic level fish were introduced. Introductions from 1965 to the present involved illegal efforts to establish angling possibilities with such species as bass. (Specific dates and locations of fish stockings are listed in the fisheries timeline.)

Water Management

"Piscatorial bonanza" aside, Mark Twain appears to have had poor luck luring the large Tahoe trout to his bait, as the crystal clear waters exposed his line.

"We fished a good deal, but we did not average one fish a week. We could see trout by the thousand winging about in the emptiness under us, or sleeping in shoals on the bottom, but they would not bite—they could see the line too plainly, perhaps" (Twain 1962).

Twain was greatly impressed by Tahoe's extraordinary clarity. Adrift on a small boat along Tahoe's north shore, he found Tahoe's water to be as transparent as Tahoe's air (Twain 1962).

"So singularly clear was the water that when it was only twenty or thirty feet deep the bottom was so perfectly distinct that the boat seemed floating in the air! Yes, where it was even *eighty* feet deep. Every little pebble was distinct, every speckled trout, every hand's-breadth of sand . . . . Down through the transparency of these great depths, the water was not *merely* transparent, but dazzlingly, brilliantly so. All objects seen through it had a bright, strong vividness, not only of outline, but of every minute detail, which they would not have had when seen simply through the same depth of atmosphere. So empty and airy did all spaces seem below us, and so strong was the sense of floating high aloft in mid-nothingness, that we called these boat excursions 'balloon voyages.'"

Tahoe water has been coveted and controlled since the construction of the first dam by the DLBC near its outlet in the 1870s. Since that time, a series of water diversion schemes to empty Tahoe water via tunnel and conduit into the growing municipalities of San Francisco and Carson Valley were unsuccessfully proposed. To accommodate logging and water supply engineering, meadow systems above Lake Tahoe were strategically dammed to form reservoirs, and water was diverted before ever reaching the lake. Spooner Meadow was transformed into a reservoir during the 1870s to supply water for flumes to transport wood. In 1876, to meet the growing needs of the Comstock, the VGHWC drew water from Marlette Lake, flumed it inside a tunnel through Tahoe's eastern divide, and piped it down to Virginia City. That same year, an early predecessor of Pacific Gas and Electric (PG&E) constructed a tunnel through Tahoe's western divide and diverted the waters of Echo Lake into the American River basin. The construction of the North Flume by the VGHWC further augmented Virginia City's water supply by tapping Third Creek and all intervening drainages in Tahoe's northeast quadrant, south to Tunnel Creek, where waters were transported via flume through a tunnel in the divide. The North Flume operated year-round from around 1877 until the 1950s. The artificial raising and lowering of lake levels with the construction of dams at Lake Tahoe's outlet since 1870 have altered the composition of lakeshore plant and animal communities, inhibited fish migrations, and accelerated backshore erosion.

The high level of water clarity and quality is one of Lake Tahoe's most notable characteristics. Early on, sawdust and slash contributed to the degradation of water quality in lakes and streams, and growing human populations have continued to pollute the lake's water with the introduction of minerals and organic substances that have upset the aquatic community developed under the natural regime. Recent studies of Tahoe's lake sediments (Goldman and Byron 1986; Heyvaert 1998) have detected two distinct periods of disturbance, as measured by a surge of organic deposits. One coincides with historic clear-cutting between the 1870s and 1890s, and the more prominent other episode of mass sedimentation correlates with the tenfold increase in the population of the Tahoe basin since 1960. The sediment data suggest that the lake's water quality recovered rather quickly when clear-cutting ceased, unlike the chronic and sustained effects of erosion caused by post-1960s urbanization.

Transportation and Community Development

Tahoe's proximity to wood, water, mineral, rangeland, and recreational resources justified the investment of a significant amount of capital and energy into transportation to and within the basin. Between 1852 and 1855, an emigrant route was established along Tahoe's north shore (now Highway 89 and Highway 28), connecting Auburn and Virginia City through Squaw Valley. The Placer County Emigrant Road traversed the Truckee River Canyon (Highway 89) and Tahoe's north shore (Highway 28). During this same time, the Georgetown-Lake Bigler Trail was forged westward from McKinney Creek, passing through Rubicon

Springs and terminating at Georgetown. By 1860 the Tahoe Truckee Turnpike (Highway 89) opened through the Truckee River Canyon. The Placerville Road ("Johnson's Cutoff"), constructed between Placerville and Virginia City in the 1850s, followed earlier emigrant and wagon routes over Echo Summit and along Tahoe's south shore (Highway 50). In 1852 to 1854, the Carson Emigrant Ridge Road connected with Johnson's Cutoff, crossing over Spooner Summit (Highway 50). Between 1858 and 1859 Luther Pass (Highway 89) became the favored route through the Tahoe basin, bypassing lower Lake Valley. Its popularity was short-lived, as traffic was siphoned away in 1860 to 1861 by the new Kingsbury-McDonald Grade (Highway 19/207) over Echo Pass and Daggett Pass, the trail taken by the Pony Express. In turn, this route was superseded by the Rufus Walton Toll Road, which opened in 1862, from Glenbrook over Spooner Summit (Highway 50). Construction of the new Lake Bigler (Tahoe) Wagon Road in 1863 further channeled the flow of travel over Echo Pass and through the Tahoe basin, away from Kingsbury Grade and over Spooner Summit.

The opening of the transcontinental railroad in 1869, which reached Truckee and was connected to Tahoe's north shore by stage in the 1860s and by rail in 1901, fostered a fledgling tourist economy. That same year, the Truckee-Hot Springs Road (Highway 267) was constructed over Brockway Summit between Truckee and Brockway Springs, giving further access to the railroad. The first continuous road was built over Mt. Rose in 1891, connecting the Reno area and Lake Tahoe ("The Road to Incline"/Highway 27/431). Within the Tahoe basin steamships were the primary mode of transportation from 1864 until the 1910s when the first automobiles traveled to the Lake Tahoe basin. A summary of the development of transportation in the Lake Tahoe basin is presented in Table 2-6.

Fremont's sighting of Lake Tahoe in 1844 heralded the population growth to come. Later that year, six members of the Stevens-Murphy-Townsend emigrant party became the first Euro-Americans to stand on the shores of Lake Tahoe; they detoured from the main party headed for Donner Pass and instead crossed the Sierran divide above McKinney Creek. After the discovery of gold in California in 1848, thousands of Americans trekked westward, some passing through the Tahoe basin. By the mid-1850s, during the height of the gold rush, trading posts and way stations were established on the southern lake route. Land patents were filed by enterprising persons—ranchers, hostelers and commercial fishermen moved in to take advantage of the lucrative business opportunities. The area became a crossroads between the adjacent mining regions of California's Mother Lode and Nevada's Comstock Lode. The first log cabin was built in Lake Valley at the south end of the lake in 1851, and by 1854 a permanent trading post was established there, with a post office designated in 1861. The first log cabin was not built at the north end of the lake until 1861.

During the 1860s, traffic east from California, lured by Nevada's Comstock silver mines, brought more hordes of treasure seekers over the southern lake route. New roads were opened along Tahoe's north shore. Thousands traveled along these roads with hundreds of freight wagons loaded with supplies for the growing mining centers. By the 1860s settlements had sprung up along these routes (Table 2-7). By 1865 up to 15 hostelries had been established to supply customers with hay, vegetables, dairy products, and fish. At first, small meadows and family vegetable gardens supplied the needs of the individual toll stations and inns. As demands escalated, meadowlands were quickly preempted (usually in units of 160 to 320 acres), wherever wild hay (*Phleum alpinum*) could be harvested and beef and dairy cattle could be grazed. With hay selling by the pound and fresh food at a premium, land changed hands rapidly and speculation prevailed. Some ranchers neglected even to acquire legal title (Strong 1984). By the 1870s at least 13 commercial dairies were in operation around the basin, producing butter and milk both for local consumption and for export. Commercial hay production reached over 800 tons annually. The ranching industry was seasonal, and the Tahoe basin was typically used as summer range for livestock. Horace Greeley described this seasonal pattern in an article published in the *New York*

Table 2-6—Summary of transportation developments in the Lake Tahoe basin.

Date	Historic Name	Location	Modern Highway
1850s	Georgetown-Lake Bigler Trail	McKinney Ck(Rubicon) Georgetown	-
1852	Johnson's Cut Off	Echo Summit(Lake Valley) Spooner Summit	Highway50; Pioneer Trail
1852-1854	Carson Emigrant Ridge Road	Echo Summit(Lake Valley) Spooner Summit	Highway50; Pioneer Trail
1852-1855	Placer County Emigrant Road	Truckee River Canyon(North Shore	Highway89; Highway28
1858	Luther Pass	Echo Summit(Luther Pass	Highway89
1860	Tahoe-Truckee Turnpike	Truckee River Canyon(Tahoe City	Highway89
1860	Kingsbury-McDonald Grade	Echo Summit(Lake Valley(Daggett Summit (Pony Express Trail)	Highway50; Highway19/207
1862	Rufus Walton Toll Road	Glenbrook(Spooner Summit	Highway50
1863	Lake Bigler (Tahoe) Wagon Road	Echo Summit(Lake Valley(Spooner Summit	Highway50; Pioneer Trail
1869	Transcontinental Railroad	Donner Pass(Truckee(Reno	-
1869	Truckee-Hot Springs Road	Truckee(Brockway Summit(Brockway Springs	Highway267
1860s-1910s	(steamer travel)	Lake Tahoe	-
1891	Road to Incline	Reno(Mt Rose Pass(Incline	Highway27/Highway431
1901	Lk Tahoe Railway Trans Co RR	Truckee(Tahoe City	-
1910s	(auto travel)	Tahoe basin	-
1914-1915	Lincoln Highway	Echo Summit(Lake Valley(Spooner Summit	Highway50; Pioneer Trail
1925	(road encircles Lake Tahoe)	Tahoe basin	-
1928-1935	(major road upgrades)	Tahoe basin	-
1935	(paving of Highway 50,89,28,27/431)	Tahoe basin	-
1950-1960	Mt Rose Highway	Reno(Mt Rose Pass(Incline	Highway27/431
1959	Kingsbury Grade paved	Kingsbury(Daggett Pass(Gardnerville	Highway19/207
1964	Interstate 80	Donner Pass(Truckee(Reno	Int 80

Table 2-7—Summary of community development in the Lake Tahoe basin.

Date	Location
	Settlements
1860s+	Lake Valley, McKinneys, Tahoe City, Lake Forest, Agate Bay, Tahoe Vista, Kings Beach, Glenbrook, Edgewood
1870s+	Carnelian Bay
	Resorts
1860s+	Lake Valley, Tahoe City, Brockway, McKinneys, Glenbrook
1880s+	Emerald Bay, Sugar Pine Point, Blackwood
1890s+	Homewood
1910s+	Homewood, Meeks Bay
1920s+	Marla Bay
1950s-1960s+	Stateline, Crystal Bay (casino-hotels)
	Subdivisions
1920s+	Lake Valley, Tahoe City, Kings Beach, Tahoe Vista, Brockway
1930s+	Lake Forest
1950s-1960s+	West Shore, North Shore, Southeast Shore
1970s+	Incline Village, Glenbrook

Tribune recounting his trip through Lake Valley during this early period (*Tahoe Tattler* V.4, No. 2, July 8, 1938, "Meadow to Marsh: Tahoe '38"):

"There is fine grass on Lake Bigler and several hundred cows are kept there in summer, making butter for the California market; when snow falls, these cattle are driven down to the valley of the Sacramento, where the rains are now commencing, and there they live without hay until June. Business is very lucrative, land costing nothing and being unfenced. Taking into account gold, timber, and grass, the Sierra Nevada is probably the richest and most productive mountain chain on earth."

Lake Valley, located along the Placerville Road, became the largest producer of hay, dairy, and agricultural products in the Tahoe basin. The *Sacramento Daily Union* (July 7, 1857) reported: "Messrs. Gilbert & Garrish, who recently arrived from Salt Lake, with some 600 head of cattle, have driven them to Lake Valley to summer there."

In the summer and fall of 1862, 400 tons of hay were cut in Lake Valley's meadowland (Scott 1957). In 1870 the "California Products of Agriculture" census showed that 228 tons of hay had been baled in the Lake Valley Township (Scott 1957). In 1875, C. F. McGlashan noted in his "Resources and Wonders of Tahoe" that Lake Valley annually turned out 14 tons of butter and cheese, for which two cooper shops manufactured butter firkins from the local white fir. Butter sold at the high price of 42 cents a pound and was, according to McGlashan, "in great demand for epicures." During the productive season from June to November, butter was kegged, eggs crocked, beef cattle fattened, and hay baled. Lake Valley was characterized as a "hay and dairy producing center, dotted with fertile ranches" where ranchers contributed most of the 800 tons of hay cut along Tahoe's shoreline in 1875 (Scott 1957). That year hay was no longer sold by the pound but brought the "deflated" price of $30 a ton in Carson. In 1880 a period correspondent reported that "The valley affords pasturage for 1800 cows" (Scott 1957).

Similar dairying and haying operations were conducted at locales other than Lake Valley during this period, but on a much reduced scale. Hay and dairy enterprises were based around meadows surrounding Burton Creek/Antone Meadows (near Tahoe City and Lake Forest), on Meeks Creek at Meeks Bay, around Griff Creek near Tahoe Vista and Kings Beach, along Glenbrook Creek at Glenbrook, on Edgewood Creek at Rabe Meadow, and at Marla Bay.

Tourist resorts, integral elements of these growing communities, were newly established in Lake Valley, Tahoe City, Brockway, McKinneys, and Glenbrook (Table 2-7). By the 1880s tourism was flourishing, with more resorts established in Lake Valley, Emerald Bay, Sugar Pine Point, Blackwood, and Tahoe City.

Impacts on Lakeshore Meadow Systems

The pathway of human disturbance in the Tahoe basin is chronicled by the movement of people, goods, and services through the area. The evolution of road systems mirrors the development of Tahoe's forest lands and adjacent communities. This history can be traced on maps depicting the routes of transport. Accompanying human impacts likely corresponded to the growing number of travel corridors and associated communities. Agriculture and seasonal stock grazing largely centered on lakeshore meadows in proximity to settlement. Vegetable farming and stock grazing beginning in the 1850s likely altered the composition and vigor of native plants. The primary impact to upland meadows was large-scale sheep grazing after 1900.

Post-Comstock Era (1900 to 1950s)

By the turn of the century, the Lake Tahoe basin had been stripped of marketable timber, and large-scale cutting ceased. As the Comstock mills "devoured their birthright," they were forced to close. Approximately two-thirds of all marketable timber in the Tahoe basin had been harvested, with an estimated 60 percent of land in the Lake Tahoe watershed clear-cut. Remaining lands were largely alpine, barren of useful timber or inaccessible. Logging continued in the post-Comstock era on a reduced scale and within a more restricted range. Lumber companies leased or sold for as little as 50 cents per acre cutover lands to grazing interests or

abandoned them to obtain back taxes (Manson 1899). Logging railroads were salvaged as tourist railroads with capital and energy funneled into a growing summer tourist economy. The Washoe continued their treks to the lake and maintained connections to ancestral areas, largely under the employ of resorts and the growing tourist industry. Traditional plant management continued on the fringe of "white" settlements, but on a very reduced scale.

Suppression of Washoe Ways

Throughout the first part of the 20th century, the formerly close Washoe associations with Lake Tahoe were made distant and difficult by the new exclusionary laws and general intolerance of Tahoe residents. The Washoe were discouraged from maintaining native lifeways, as tribal members were forced to live in colonies away from the lake, converted to Christianity and sent to government-sponsored schools.

"After the passage of the General Allotment Act of 1887, 160-acre plots 'scattered . . . in the most desolate and waterless sections of the Pinenut Range, or elsewhere on lands not already claimed by White settlers' were granted to individual Washoe. Lands around Lake Tahoe and in fertile valley floors had been petitioned, but none were included. In 1891 the Carson Indian School (later known as Stewart Indian School) was opened through federal legislation and enforced enrollment of hundreds of Washoe, Paiute and Shoshone children. During WWI, Washoe men 'were urged by Indian agents and local White citizens to register for the draft. Some objected . . . [since] they had never been granted citizenship or the right to vote.' In 1917 the federal government purchased small tracks of land for the Washoe. Forty acres in Carson Valley was placed in trust, becoming the Dresslerville colony, and another 40 acres on the outskirts of Reno became the Reno-Sparks colony where 'many northern Washoe were compelled to settle.' Citizenship was granted in 1924, although segregation in public facilities and schools was maintained until the 1950s. During the 1920s Indian Agents were actively involved in abolishing 'heathen' traditional Washoe ceremonies and medicinal practices. In 1936 the Tribe's Corporate Charter was ratified, a Tribal Council formed, and a constitution adopted, achieving federal recognition under the provision of the Indian Reorganization Act of 1934. In 1970 their land claims case, initiated in 1951, was settled, awarding them five million of the 42.3 million requested as compensation for their homeland, approximately 10,000 square miles surrounding the Tahoe basin" (after various publications by d'Azevedo and summarized in Rucks 1996).

On December 2, 1970, the Indian Claims Commission awarded the Washoe Tribe just over $5,000,000 for the whole of their traditional territory, which included Lake Tahoe at its center. The Washoe were awarded compensation for the value of the natural resources at the date they "lost" their territory, considered to be December 31, 1862. Timber in the Nevada portion of their territory, including the Pine Nut Hills, was valued at $300,000, while minerals from the Gold Hill Mining District were valued at $2,401,500 (Washoe Claims Case 447:448). This ended an 11-year court battle. The docket included findings that:

"From 1848 to 1863 [their territory] was overrun by miners, settlers, and others with the approval, encouragement and support of the United States government. Encroachment continued with increasing intensity until by December 31, 1862 the tribe had lost all of its lands" (Washoe Claims Case 447:448).

Since the 1870s Washoe leaders formally protested to government officials (including the President of the United States) complaining of the loss and destruction of their lands for which title had never been extinguished by treaty. Petitions, demands, and trips to Washington continue to the present. The 1950s marked a period of Washoe protest, during which the people registered their objections to the nontraditional usage of cultural/spiritual locales in the Tahoe basin (for example, Cave Rock) and the despoliation of ancestral resources (Lindström et al. 1999).

Logging

Only a handful of small companies operated during the first decades of the 20th century,

harvesting stands ignored by Comstock loggers (also see Leiberg 1902). One shingle mill used cedar stands from Griff Creek during the 1920s, and a small sawmill operated on Burton Creek from 1927 to 1933). Neither of these operations cut more than half a million board feet annually. C. G. Celio & Sons operated a larger local lumber mill between 1911 and 1958, cutting around Meyers on lands they had not leased or sold to the CTLFC. The Placerville Lumber Company also was involved in small-scale logging in Upper Trout Creek in 1946, and, in 1947, Fibreboard logged lands near the mouth of Watson Creek (Carnelian Bay).

Localized logging in the northwest quadrant of the Tahoe basin commenced after construction of the Floriston Pulp and Paper Company's (FPPC) mill along the Truckee River in 1901. Fir stands overlooked during Comstock era lumbering were targeted for the production of paper pulp (also see Leiberg 1902). Construction of the LTRTC's tourist railroad along the Truckee River and through the Tahoe Reach in 1901 afforded a means of timber transport for renewed logging in proximity to the line. Between 1903 and 1907 the TLC built a logging railroad up Ward Canyon and intensively logged the area. Stands also were harvested in Squaw Valley and Alpine Meadows around this time. From 1912 to 1914 the FPPC logged fir stands on TLC land in the Burton Creek watershed north of Tahoe City.

Post-Comstock-Era Forest Characteristics

In 1902 John Leiberg surveyed and reported on cutover lands in the northern Sierra Nevada as part of a study of forest conditions by the Department of Interior, US Geological Survey. Lands examined included the California side of the Lake Tahoe basin from Rubicon Bay (on Tahoe's west shore) north to State Line Point (between Agate and Crystal bays on Tahoe's north shore). He described the forest types and compositions and briefly discussed destructive activities and reforestation.

"The areas logged clean or culled comprise 170,000 acres, or nearly 59 per cent of the forest land [from Rubicon Bay north to State Line Point]. The areas not cut over or unculled are, with a few large exceptions, situated in places difficult of access or carrying timber not fulfilling the requirements of the loggers. . . .Nearly all of the terraces bordering Lake Tahoe and the accessible mountain slopes and canyons have been logged, the cut varying from 10 to 99 per cent. . . . The summits and slopes of Mount Pluto Ridge from Mount Pluto eastward have been logged, with the exception of a few hundred acres on the crest of ridges directly north of Agate Bay. The timber on those summits was exclusively Shasta fir, 70 per cent logged. On the lower northern slopes of Mount Pluto Ridge the cut has been from 70 per cent to nearly total, culls of white fir being the only species of tree left. From the lake outlet down the canyon of Truckee River, on all the areas between Truckee and Mount Pluto Ridge . . . the cut of merchantable timber has been total" (Leiberg 1902).

Professor Marsden Manson, civil engineer and conservationist, made similar notes in 1899, just three years before Leiberg's visit (1899).

"Around Lake Tahoe the timbered areas have been entirely swept off with the exception of a few thousand acres around Tallac and some at the north end, reserved by the owners for later use. The mountain sides around the Hot Springs [Brockway], and nearly all of the moraines and flats around the south and east side of the lake, have been denuded.

A year later, Sudworth (1900) reported a "general lack of herbaceous growth, an irregular reproduction of timber species, and general absence of small-sized timber intermediate between seedlings and the large timber." Leiberg (1902) believed climate, fire, insects, logging, and grazing to be "the forces of destruction at work in the forest."

"If the present rate of cutting and grazing is continued, the general condition of the forests at the end of the century, or even fifty years hence, will be about as follows: The . . . basins will have been wholly denuded of large timber, and in its place will have come a sapling growth, heavy and close set in some places, open, under sized, and brushy in others. Most of it will consist of white fir, for the yellow pine which has given the present forest its chief value will form a comparatively small percentage of it" (Leiberg 1902).

Leiberg observed a near absence of sugar

pine, with yellow pine forfeiting its former dominance to red and white fir, lodgepole pine and incense cedar. He classified the "shore terraces of Lake Tahoe from Frosts [Rubicon Bay] to State Line Point" as containing "Yellow pine, 3 to 5 per cent; white fir, 60 to 80 per cent; now and again a sugar pine of small size . . ." (1902).

"In past times, before logging operations commenced, it [yellow pine] may have been the dominant species as regards the number of trees, but owing to the vast amount of cutting it is so no longer. It has been more exhaustively logged than any other species in the type except the sugar pine, and restocking has not kept pace with the cutting" (Leiberg 1902).

"Along the western and northern shores of Lake Tahoe there formerly existed a narrow belt of heavy forest having sugar pine as one of its component trees. At the present time few scattered trees of the species still remain, but most of them were long ago cut out. The proportion of young sugar pine in the reforestation on these closely logged tracts is insignificant. . . . The tree is losing ground at a rapid rate on all the areas logged. . . . In place of its former ratio of 20 to 25 per cent the coming forest will contain only 2 or 3 percent at the most, while on the unlogged tracts it is maintaining its present ratio" (Leiberg 1902).

"White fir is increasing its ratio in the restockings, partly at the expense of the yellow pine, partly as an offset to a lessened percentage of sugar pine. . . . In the Truckee Basin it is largely replacing the yellow pine on the logged areas, and in the coming forest will amount to 60 to 75 per cent of growth, against 25 to 40 per cent in the original uncut stands. Its increase throughout the region examined is due to exhaustive logging of yellow and sugar pine and sparing of white fir" (Leiberg 1902).

"This species [red fir] is abundant and vigorous in all reforestation of the yellow-pine type, whether after logging or fires" (Leiberg 1902).

Leiberg attributed the increasing numbers of incense cedar (a species he found "valueless," due to worm holes) to the abnormally large number of seed trees remaining on the cutover areas (Leiberg 1902).

Leiberg observed considerable chaparral in the post-Comstock forest. "The timber is invariably set in heavy undergrowth, which has come in as a sequel to extensive forest" (Leiberg 1902). Most of the chaparral grew on the shore terraces of Lake Tahoe (Leiberg 1902). James (1914) also noted that chaparral covered slopes and prevented the growth of tree seedlings.

Sterling (1904), reporting to the US Bureau of Forestry two years after Leiberg's visit, also observed that Jeffrey pine was rare and that considerable areas had reverted to brush, with original forests remaining only on inaccessible slopes.

"The forest is much reduced in density; brush and reproduction are competing for possession of the openings. The sugar pine has disappeared almost entirely. . . . The finest of the Jeffrey pine and yellow pine and white fir has been removed, fir production in general [is] replacing the pine; while considerable areas have reverted entirely to brush" (Sterling 1904).

In his study of forest sample plots in the Carson Range, Taylor (1997) confirmed these early 20th century observations. Jeffrey pine forests are primarily 100- to 130-year-old second growth stands in which trees less than 50 centimeters in diameter at breast height (dbh) are nearly 10 times more dense than pre-Euro-American forests and lodgepole pine has regenerated prolifically (Taylor 1997). These dense, white-fir dominated forests experienced significant insect attacks during the severe droughts of 1921 and 1937 (Elliott-Fisk et al. 1996) and during the drought of 1987 to 1994.

Grazing

During the 1850s over 500,000 sheep crossed Nevada on their way west to California markets. From 1865 to the 1890s millions of California sheep were herded east from California over the high Sierra to mining camps of the Great Basin and railheads in the plains (Douglass and Bilbao 1975). Bands were large, 1,000 head at a minimum, and most herds contained an average of 1,000 to 1,500 ewes (Mallea-Olaetxe 1992). By the 1860s to 1870s, sheep bands were moved from western foothills into the high Sierra over Tahoe's western and northern divides. When logging ceased at the turn of the century, cutover lands along Tahoe's south, north, and east shores were leased or

sold to ranchers for grazing. A livestock business developed around the lush meadows and the growth of vegetation in cutover areas provided at least temporary sources of stock feed. Lake-level lands generally supported cattle, and high meadows were used for sheep. With no restrictions on grazing, sheepherders grazed their livestock at will, sometimes too early in the season. Shepherds started persistent small fires in order to improve forage for the following season. These practices had a variety of negative ecological consequences. In an effort to control overuse by regulating the timing and location of herds, grazing in the Tahoe basin was restricted in the 1930s to allotments assigned to individual permittees (Elliott-Fisk et al. 1996).

Itinerant Basque shepherds left their personal mark on the Tahoe landscape in the form of aspen carvings (Figure 2-20). They chose crossroads, streamlands or popular sheep camps as strategic locales to carve "billboards" in the aspen groves. These served to mark territories, and the names and dates carved on trees document the years sheep were grazed and identify the roads and trails they followed (Mallea-Olaetxe 1992). In the Tahoe basin, carvings commonly date after the turn of the century and represent the months of June through September. Most carvings date from the 1920s and 1930s, and continue into the 1950s, indicating sheep grazing activities to be most intense during these times. The lifespan of the aspen tree marks the effective lifespan of the aspen art. Stands of quaking aspen may persist for more than 200 years (Jones and Schier 1985); however, longevity of aspen stands is usually less due to climate, fire, soil, disease, succession to conifers, and impacts from livestock and logging. The messages of over 13,000 carvings have been entered into a computer data base in the Basque Studies Department at the University of Nevada. Basque scholars have interpreted the handwriting on trees and compared it with the growing list of Basque oral histories to trace historic stock trails, grazing areas, dates and intensity of use, and the herders/ companies involved. This is an extraordinary historical resource for further research.

Vegetation Change and Incidence of Fire

Increasing human populations in the Tahoe basin and surrounding region were supplied with meat, milk, butter, and cheese from sheep and cattle that denuded high elevation alpine areas and lower elevation wetlands, meadows, and forest floors. Sheep were thought to be more destructive than cattle. The Washoe were especially affected by the impacts of livestock grazing in the basin, which caused declines in many plants important to their people (Elliott-Fisk et al. 1996). Early season entry into rangelands and excessive overgrazing exterminated native browse species in many areas, increased erosion, slowed forest regeneration, and altered forest stand structure (Leiberg 1902; Sudworth 1900).

"Excepting in high mountain meadows, all of which are fenced and which are grazed by cattle, the principal forage for sheep and cattle on the open forest range consists of a few hardy shrubs and low broad-leaf trees. There are practically no grasses or other herbaceous plants. The forest floor is clean. The writer can attest the inconvenience of this total lack of grass forage, for in traveling over nearly 3,000,000 acres not a single day's feed for saddle and pack animals was secured on the open range. . . . It is evident that formerly there was an abundance of perennial forage grasses throughout the forest in this territory. . . . It would seem that this bare condition of the surface in the open range has been produced only through years of excessive grazing by millions of sheep—a constant overstocking of the range" (Sudworth 1900).

"The trampling of thousands of sheep pastured on these slopes during summer and fall reduces the soil, to a depth of 6 or 8 inches, to the consistency of dust. Rain washes this dust into the creeks and rivers, and heavy winds lift it up and carry it far away. . . . [Tree] seeds are largely shed in July and are trampled into the ground and destroyed. All seedling trees on the sheep runs are either cut off below the ground by the sharp hoofs of the animals or uprooted and trampled. In these runs, where trees have succeeded in establishing themselves, they are bent and stunted. Nothing whatever except excessive sheep grazing prevents a uniform stand of timber of medium density on these grassy glades, and while sheep are pastured there they never will return to forest cover" (Leiberg 1902).





Figure 2-20—Basque aspen carvings (arborglyphs).

Sheep herders were criticized for deliberately setting fires to improve the range and to facilitate movement of sheep through the forest. Upon leaving "fed-out" seasonal grazing lands, Basque shepherds set fire to high elevation meadows and shrublands and burned many large downed trees.

"Shorn of its wealth and beauty, [the Tahoe basin] has been partly burned over to give a few sprouts to hungry hordes of sheep" (Manson 1899).

". . . All the fires observed during the last summer closely followed the sheep camps" (Leiberg 1902).

"No less than seventeen such fires of this kind were found on the trail of one band of sheep, covering a distance of 10 miles" (Sudworth 1900).

"The belief is generally held that the sheep herders fired the country in all directions and have been responsible for most of the fires of recent years" (Leiberg 1902).

"The chaparral areas will be brush covered, very much as they are, because they will be burned now and then so as to furnish fresh browse for the sheep, and the burnings will serve only to increase the density of the next stand of chaparral" (Leiberg 1902).

Not all meadows were subject to over-grazing, however. Photographs taken in 1930 of "Rowland's Marsh" (now the site of Tahoe Keys in South Lake Tahoe) show an extensive and virtually unfragmented meadow/wetland system (Orr and Moffitt 1971). Many bird species associated with wetlands and meadows were recorded in Orr and Moffitt (1971) during this period, suggesting that these surviving and intact systems provided valuable habitat in the basin.

Although overgrazing in many wetlands and meadows and on forest floors throughout the basin during the first half of the 20th century produced lasting changes in communities of grasses, forbs, and shrubs (McKelvey and Johnston 1992), erosion caused by grazing in the 20th century was not nearly as great as that which occurred during the 19th century Comstock logging era. Impacts of grazing are not detected in lake sediment cores. The sediment record does not reflect a significant rate of increase in lakebed deposition between 1900 and 1950, as was the case between the 1870s and 1890s (Heyvaert 1998).

Water Management

A long history of conflict, litigation, and policy making surrounds the prized water resources of the Lake Tahoe basin (Jackson and Pisani 1974). After the Comstock era, controversy over the fate of its waters intensified. Tahoe had become a critical water source for adjoining lowlands to the east. "Excess" water initially was appropriated for hydroelectric power and reclamation projects for desert communities under the 1902 National Reclamation Act, sponsored by Senator Newlands of Nevada. This necessitated variations in lake level that were incompatible with the interests of upland resorts and navigation, all of whom relied on a constant high lake level for the tourist industry (Landauer 1995). Subsequent negotiations for water appropriations were controversial and politically charged.

In 1913 the original dam on the lake's outlet at Tahoe City (built by the DLBC in the 1870s) was upgraded by a power syndicate supported by the US Department of the Interior. Periodic droughts prompted attempts by downstream users to dredge, cut, and blast the lake's outlet; these actions were averted by court injunctions obtained by Tahoe property owners. Water crisis during the droughts in 1924 and in 1930-1931 occurred when the lake level dropped so low that no water could leave the lake to supply Nevada farmers with water via the Truckee River. Ultimately, water was pumped over the lake's rim to supplement Nevada's water supply. Continuing conflicts between property owners at Lake Tahoe, power suppliers, families and farmers depending on access to the water downstream, and the Pyramid Lake Paiute Tribe (who were entitled to Truckee River water by treaty) reached a peak during the 1930s. Compromise was achieved in 1934 with the Truckee River Agreement, which provided for the conservation and control of the Truckee River drainage basin and led to the construction of Boca Reservoir and the development of alternative supply strategies. Accelerated population growth after the World War I made earlier compromises unworkable, and in 1955 the California-Nevada Interstate

Compact Commission was established to reach mutual water apportionment between the two states. The commission was a prelude to the subsequent joint management and regulation of Lake Tahoe's geographically bounded ecosystem by a series of local, regional, state, and federal groups.

Transportation and Community Development

In terms of community development, the post-Comstock era is characterized as a period of "boom and bust." After the Comstock lumbering boom, the basin's population declined, and the area experienced a deep economic depression from which it did not completely recover until the tourist boom following World War II (Strong 1984). In the post-Comstock era, land values plummeted so that cutover tracts could be purchased for back taxes or for no more than $1.50 per acre. Roads were neglected and became impassable, inns and post offices went out of business, and logging camps, mills, flumes, and railroads lay abandoned to deteriorate among the rotting stumps of the cutover land (Strong 1984; Scott 1957).

Yet, against this backdrop of environmental devastation, a fledgling tourist industry began to develop. Some of the vast capital reserves accumulated from timber interests were invested in the construction and operation of lakeshore resorts. Logging railroads and steamers were converted to tourist transport. To many 19th century tourists, Tahoe's natural beauty was hardly compromised by deforestation; viewsheds marred by abandoned lumber mills and vast tracts of timberless land were featured on the local scenic touring agenda right along with Emerald Bay and Cave Rock. Lake Tahoe became an increasingly popular recreation destination, and the area's economy gradually began to rely on tourism rather than logging (Strong 1984). For four prosperous decades, between 1860 and 1900, settlement was dictated by lumbering; communities mushroomed quickly around almost every sawmill. As the mills shut down, many of the associated settlements were deserted. However, the handful of lumbering centers that built their future on tourism continued to prosper, initiating the trend toward urbanization and year-round residency in the Tahoe basin.

To accommodate community development and the influx of visitors in the post-Comstock era, travel networks were expanded throughout the basin. Tourism around the turn of the century was the pastime of the wealthy elite who frequented elegant resorts for extended periods. Travel to Tahoe by train and then across the lake by steamer was time consuming and expensive. The LTRTC established a tourist railroad through the Tahoe Reach in 1901, connecting the transcontinental railway station at Truckee with Tahoe City. From Tahoe City, the company provided public transit to other points around the lake by steamers. This system, the only means of public transport to Tahoe until 1942, fostered tourism and promoted the development of a year-round community at the lake (Landauer 1995).

The state of California authorized the survey of new roads over Echo Summit in 1895 and over Donner Summit in 1909. As greater ease of passage to and through the Lake Tahoe basin was permitted by increasing availability of automobiles, the face of tourism was radically changed. Motorized vehicle traffic increased after 1913, with the nation's first transcontinental road, the Lincoln Highway. It routed along Tahoe's south shore (along the historic Pioneer Trail). By 1925 an auto road circled the lake. Paving of or improvements to highways 89, 28, 27/431, 19/207, and 50 during the 1930s opened the western, northern, eastern, and southern shores, respectively. Highway 50 opened year-round after World War II. Gradually, the intrabasin road system was enlarged to link communities and to open access into back country areas for recreation and Forest Service administration. Air travel also became a popular way to reach the basin after the Sky Harbor Airport (southeast of the lake) opened in 1946 and began landing DC-3s full of tourists. In the late 1950s this was replaced with a larger safer airport, which operated until 1995.

Middle class auto tourists visited for shorter periods and desired less elegant accommodations than their elite 19th and early 20th century counterparts. The old luxury resorts closed by the mid-20th century. New opportunities for recreation and entertainment arose as access to the area

improved. As people of more modest means camped or vacationed in rustic hotels and cottages, Tahoe's backwoods were explored and enjoyed by increasing numbers of recreationists. In response, the USFS initiated patrols for visitor safety and established fire lookouts, along with remote guard stations and outpost ranger stations. Outlying forest service facilities were linked with main offices by a fairly extensive system of improved horse trails and telephone lines. In addition to the long-established recreational attractions, such as hiking, fishing, sightseeing, sailing, and speedboat racing, small ski resorts opened during the 1930s and 1940s. By 1949 ski lifts were operating at Granlibakken, Meyers, and Echo Summit (Landauer 1995). The gaming industry took hold in 1931, when the Nevada Club casino opened on the state line at the south end of the lake, followed in the next two decades by Cal-Neva, Harvey's, Harrah's, and other casinos.

To accommodate the growing numbers of seasonal visitors and permanent residents, development kept pace with demands. During the 1930s, "building booms" were reported in the *Tahoe Tattler* (August 16, 1938, July 21, 1939, August 18, 1939), with 2,000 people visiting the lake during a high season that lasted between July and August. Tahoe boosters continued to actively draw visitors, mainly by seeking the patronage of various transportation companies. The title and content of the Tahoe Vacation Guide for 1940, published by the *Tahoe Tattler*, draws attention to this link between transportation and development in the content and title of their guide, "Tahoe Business: Improved Transportation, Communication Bring Growing Tahoe Trade."

"From such humble beginnings . . . Tahoe business and trade has grown to an annual $5,000,000 level. . . . Earliest lake travelers came by horseback or afoot. In the early 60's the Pony Express route crossed the Lake Valley [South Lake Tahoe] plain. . . . The first Tahoe City-Truckee highway was built in 1861 as a toll road. . . . For a time an old wagon road led into Tahoe from Rubicon Springs and Wentworth, El Dorado county, but since 1910 it has fallen into disrepair and is currently being patched up again. The lake exit via Mt. Rose was built in 1916. Not until 1927 did paved highways circle the lakeshore. And at the same time the first oil was sprinkled over the gravel path from Tahoe City to Truckee. . . . Paved highways meant a big upsurge of business. Daily bus service penetrated the lake that year [1927]. Only two years before, the old narrow gauge railroad had given way to broad gauge standard railway cars connecting with Southern Pacific mainliners at Truckee. In 1934, the Clear Creek grade from Spooners summit to Carson City gave Tahoe a first class exit to Nevada. The Mt. Rose road was rebuilt in 1935. The growth has been steady, though marked by decades of unusual expansion. . . . The Twenties probably saw the greatest business expansion in Tahoe's history. In those short thriving years, Chambers and Meeks Bay resort came into being, a $200,000 wing was added to the [Tahoe] Tavern, among many other expansions. The last five years, Tahoe commercial expansion has taken another spurt. Notable are the growth and development of Kings Beach, Bijou, the Tahoe Valley "Y," and scores of small attractive markets, eateries, and small service institutions. Today, approximately 150 businesses operate around Tahoe's 97 miles of shore. . . . The peak summer population is estimated at about 30,000. Winters, some 2,000 remain to play in the snow. Tahoe real estate with improvements is valued at upwards of $20,000,000, with Placer County, Calif., in the lead. Of the future, no Tahoe businessman will predict. . . . All agree, however, that much room is still available for continued expansion, mindful at the same time of preserving natural scenic beauty unspoiled by signs and shanties."

Closing comments in this article reflect a noticeable shift in attitudes during the 1940s. The drive to develop it is now tempered by the desire to preserve natural beauty.

In the 1950s the Lake Tahoe Realty Board was established to standardize building codes around the lake. The spirit of post-war boosterism led local businesses and a newly formed Chamber of Commerce to promote the area aggressively (Strong 1984). With the initiation of the two most important service industries in the basin—legalized gambling began in the 1930s, and the ski industry's expansion

after the Winter Olympics at Squaw Valley in 1960—Tahoe's threshold rate of growth reached new levels (LTAC 1963). Subdivisions, hastily planned and built, accommodated a new population of permanent residents employed by the ski and gaming industries.

Throughout the 1940s and 1950s, community development put more pressure on the basin's limited sewage disposal system, as sewage effluent was sprayed directly onto the land in many watersheds and subsequently was released into the basin's streams and lakes (Strong 1984). In this era of unchecked development, unregulated use of the Lake Tahoe basin was coming to an end.

Agency Regulation

Preliminary regulation of resources in the Tahoe basin began as early as 1883, when the California Legislature created the Lake Bigler Forestry Commission specifically to address the problem of overcutting in the Tahoe basin and the need to protect the lake and its surrounding land for the use of tourists. The commission also called for the creation of a "park," to be formed by the transfer of state, federal, and private land to the state of California. In 1913, following controversy over the use of the lake's water, the Lake Tahoe Protection Agency was organized as the first environmental group dedicated to the preservation of Tahoe's beauty, providing added impetus to the efforts to declare Lake Tahoe a national park (Landauer 1995). After several of these campaigns failed, a final proposal was defeated by Congress in the 1930s on the grounds that the proposed area was already degraded and over-commercialized (Landauer 1995). Objections to land transfers that would ultimately profit the CPRR prevented further action to protect Tahoe as a national park (Pisani 1977).

A forest reserve, which included lands within the present Tahoe and Eldorado national forests, was established between 1893 and 1900 (Landauer 1995; Strong 1984). No effective management plan or organization existed until the national forest system was created in 1907, when the Tahoe basin was divided and portions were allocated to the jurisdictions of the Tahoe, the Toiyabe, and the Eldorado national forests. Although a "multiple use" policy was implemented, logging and water management remained the primary concerns. In 1911, the first USFS ranger station was established near Meyers. During the 1910s rangers in the reserve were charged with preventing and halting fires, enforcing fish and game regulations, overseeing timber sales, and conducting experiments in reforestation (James 1914). In 1933, the USFS was authorized to manage its forests intensively and to suppress fires (Elliott-Fisk et al. 1996).

The historic concentration of land ownership in the hands of the giant lumber companies set the stage for the transfer or sale of large blocks of land to private buyers or to the state and federal governments for incorporation into parks and national forests (Mackey 1968). Large blocks were available on the Nevada side of the lake; fewer large parcels were available on the California side of the lake, where lumber interests had not secured as many large tracts. Because cutover timberland (and even lake frontage) in remote mountainous country had little value, there was little incentive for the companies to subdivide their holdings for piecemeal sale after the timber was gone. Thus the millionaire George Whittell acquired a continuous strip of former CTLFC and SNWLC timber holdings that stretched from Crystal Bay all the way south to Zephyr Cove.

In contrast to the 19th century national policy of transferring land out of the public domain for the purposes of private enterprise, 20th century policies shifted to the acquisition and retention of public lands for park and conservation purposes. Until the 1920s and 1930s, most of the basin's land (especially lakefront property) was privately owned (Elliott-Fisk et al. 1996). Gradually, resource management agencies began to acquire more land for public trust. In 1920 the USFS acquired 115 acres of private land at Echo Lake and other land on Tahoe's north shore. With these acquisitions, it owned 25 percent of the land in the basin, although some was leased for homes, resorts, and businesses. In 1927 California officially established a parks commission, and, by the 1950s, both California and Nevada began acquiring and managing land around the lake (Landauer 1995). Nevada created its first

park at Sand Harbor in 1958 (Landauer 1995).

Agency control in the Tahoe basin dramatically changed land use patterns after 1900, especially with regard to fire suppression. The greater vulnerability of Tahoe forests to fire in the post-Comstock logging era fostered the philosophy that fire was a destructive force to be eliminated if possible. A member of the US Bureau of Forestry (Sterling 1904) visited the Tahoe basin in 1904 and reported on the aftermath of Comstock-era logging. He noted that fires had disproportionately affected the regeneration of lakeshore stands and that heavy litter and abundant chaparral in other areas created significant fire hazards. Fire suppression was increased after 1910 when a special gasoline-powered boat patrolled the lake to spot and attempt to control fires from June through September (James 1914). By the mid-1920s all national forests (and national parks) in California and the Sierra had fully developed policies, procedures, and organizations to suppress fire in their jurisdictions. These policies were forged despite post-Comstock-era observations by foresters, who acknowledged the frequency of both natural and human-caused fires in the Tahoe basin.

"Fires ravaged the forest long before the American occupation of California. The aboriginal inhabitants undoubtedly started them at periodic intervals to keep down the young growth and the underbrush. When the miners came, fires followed them. Contemporaneous with the advent of the miners, or soon after, came the flock masters with their sheep" (Leiberg 1902).

"Commencing in the southern part of the basin, all the slopes leading to Rubicon Bay are badly burned; 40 to 60 per cent has been destroyed, and the slopes are covered with heavy brush growths. Going north from Rubicon Bay, all the shore terraces have been burned over; many of the fires appear to have followed the logging camps, others antedate them. From the lake shores fires have spread into the adjacent mountains in all directions, burning lanes through the forest or thinning the stands, brush growths replacing the forest in some localities, grassy or weedy swards in others. About 38 per cent of the timber has been destroyed. The next big burns are found in the canyon of Truckee River from the lake outlet down on the southwestern slopes of Mount Pluto, on the terraces back of Carnelian Bay, and on the high ridges north of Agate Bay. Extensive fires have swept all these tracts, rarely, however, involving total destruction, but thinning the forest from 30 to 70 per cent and creating extensive brush growths" (Leiberg 1902).

Charles H. Shinn, a USDA Forest Service agent, visited the basin in 1902 and reported sighting many small and smoldering fires, especially on the California side of the basin, viewing "four to ten in one day's travel." In his dendroecological study of sample plots in the Carson Range, Taylor (1997) found that "Between 1160 and 1871 fires burned somewhere within the Jeffrey pine zone every three years. . . . These data suggest that both small and large fires were common in pre-Euro-American Jeffrey pine forests. . . . The cumulative effect of these low intensity fires on forest stands was to create open (low density) patchy forests where patches of relatively large diameter trees varied widely in size."

Leiberg (1902) seemed to recognize the positive effects of fire and his observations of logged stands in the north and western portions of the Tahoe basin in 1902 prompted him to question the validity of fire suppression.

". . . Let anyone . . . examine the sapling stands now springing up in old-growth forests where fire has been kept out during the last twelve or fifteen years. . . . These sapling stands, composed of yellow pine, red and white fir, and incense cedar, singly or combined, are so dense that a man can with difficulty force his way through. But for the stature of the species composing them they would constitute chaparral."

In 1924 a congressional act was passed clearly establishing fire exclusion as a national policy. Fire suppression formed the basis of forest service policy until the 1960s, after which time doubt over the merits of total suppression led efforts to reintroduce fire as a management strategy. Controlled burn in the modern setting is problematic, both in terms of public health and safety and visual qualities.

Prior to the agency adoption of a fire

suppression policy, a debate ensued whether to allow "light" or "Indian burning" instead of total suppression. The Washoe and their prehistoric ancestors had been practicing resource management through fire for generations, but their example was ignored. Some perspective on changing fire management policies is gained from a public relations article that appeared on a 1930 map of the Tahoe National Forest. (At that time the northern half of the Tahoe basin was under the jurisdiction of the Tahoe National Forest.)

"The fire-protection policy of the Forest Service seeks to prevent fires from starting and to suppress quickly those that may start. This established policy is criticized by those who hold that the deliberate and repeated burning of forest lands offers the best method of protecting those lands from the devastation of summer fires. Because prior to the inauguration of systematic protection California timberlands were repeatedly burned over without the complete destruction of the forest, many people have reached the untenable conclusion that the methods of Indian days are the best that can be devised for the present. This argument assumes that controlled burning of forests, either in the spring or fall, is easily practiced at slight expense, with negligible damage to the forest, and with relatively complete removal of the accumulated debris which inevitably forms in any growing forest. It has been found, however, that actually to carry out controlled burning in our diversified mountain topography is exceedingly difficult and costly. Experience has shown that 'controlled' fires costs between 35 cents and $1 per acres. And since this must be done every few years, the cumulative cost soon becomes prohibitive for any but the holder of a very small parcel of land. Again, while in theory selecting the proper time of year for burning seems simple, practice demonstrates that rarely are conditions such that fires will start without developing into devastating conflagrations with all the characteristics of the summer fires which the practice seeks to prevent."

"The stock argument of those who advocate the 'light burning' of forests is that fire exclusion ultimately leads to the building up of supplies of inflammable material to such an extent that the uncontrollable and completely destroying fire is certain to occur. The experience of the Forest Service in California, after 20 years or more of fire fighting, does not lead to any such conclusion."

"The contention of the 'light-burning' advocates that periodic fires improve grazing conditions, kill the 'wood-beetles,' and make hunting easier also can be proved incorrect. While at first periodic burning may increase the stand of forage, continuation of the practice kills out the less hardy plants, fosters the growth of weeds and shrubs, and turns the range into a brush patch.

"The 'wood-beetles' spoken of by 'old-timers' are not destructive to green timber, but live entirely in dead trees. Entomologists have proved that the destructive insects which live in green and not dead trees readily attack trees weakened by repeated fires.

"Brush in the forest undoubtedly makes hunting difficult, but it furnishes a home for game. When the brush and forest are destroyed, the homes and breeding places of the wild life are destroyed, along with countless thousands of game birds and animals. Even with the present methods of forest protection the yearly loss of wild life by fire is enormous. How much more would be this loss were fires regarded with indifference or as necessary evils!

"The existing policy of the Forest Service in fire prevention and suppression has not been reached on the basis of guesswork. It represents continuous and critical study of forest fires. Fire exclusion is the only practical principal on which our forests can be handled if we are to protect what we have and insure new and more fully stocked forests for the future" (excerpted from "The 'Light Burning' Fallacy," USFS Tahoe National Forest Map, California-Nevada, 1930—forest visitor comments on the back of the map; map on file Special Collections, Shields Library, University of Nevada, Reno).

Urbanization (1950s to Present)

Discussions of water and sewage problems occupied increasing amounts of space in Tahoe's local papers by the 1950s. During the early 1960s, Tahoe planners were speculating about a "saturation population," expected to occur in about 2010, when all useable land would be occupied and no new

growth could occur (LTAC 1963).

Building on the rapid growth of the recreation and tourism industries after World War II, several events during the 1960s stimulated new levels of development in the Tahoe basin. In 1960 the Winter Olympic Games at Squaw Valley attracted millions of people to the area, most for their first visit, and generated enormous enthusiasm for winter sports (Landauer 1995). Shortly thereafter, Interstate 80 was completed—designed and built to facilitate snow removal and to maintain winter access to Lake Tahoe and Reno. Its opening in 1964 ensured access to and from the Tahoe basin not only for skiers but also for tourists and potential permanent residents (Landauer 1995). Reflecting this social and economic shift, summer homes were converted into year-round residences for seasonal employees of the recreation, service, and gaming industries. In 1965 South Lake Tahoe became an incorporated city, indicating signs that Tahoe's economy and communities were stabilizing. Between 1960 and 1980 Tahoe's population multiplied five times, with the number of homes increasing from 500 to 19,000 units (Strong 1984). Several major housing developments were built on converted wetlands. The most notable and extensive was the Tahoe Keys subdivision, which required 750 acres of functioning wetland at the mouth of the Upper Truckee River to be dredged and filled. Another notable development in the 1960s, Incline Village, was built on parts of a 9,000-acre tract at Crystal Bay, formerly owned by George Whittell.

Improvements in facilities within the basin greatly increased the area's capacity for development (Landauer 1995). In 1968, after a decade of controversy and logistical problems, sewage export from the basin was finally achieved. By 1975 almost all the basin's wastewater was exported, effectively stimulating further subdivision and development of land and increasing the demands on the basin's resources (Elliott-Fisk et al. 1996). By 1970 49,000 subdivided lots and hundreds of miles of new access roads existed in the basin. The 1970s also saw a turn toward Tahoe's more ethnically diverse populations of the 1870s. In 1990 the basin supported 52,591 residents (TRPA 1996) and an estimated 200,000 tourists on peak holidays (Elliott-Fisk et al. 1996). More than 30 ski areas operated in or near the basin every winter, supplemented by year-round activities, such as gambling, boating, and other outdoor sports. Together, these industries formed a $1 billion recreation-based economy, employing more than 20,000 people in 1996 (Elliott-Fisk et al. 1996). Based on projections from the 1990 census, it is estimated that by 2005, there will be 47,855 housing units in the Lake Tahoe basin and a population of 57,588. Although the basin's population has remained relatively stable over the past decade, growing numbers of residents in the adjoining counties create additional pressures on Tahoe's environment and economy.

Logging

Logging occurred through the 1960s, especially on private lands along the north shore where second-growth pine was harvested. In the mid-1980s drought increased the vulnerability of many stands to severe insect attacks. By 1991 an estimated 300 million board feet of timber were dead or dying (Elliott-Fisk et al. 1996) and salvage logging began on the east, north, and southwest sides of the lake. Thinning of stands, prescribed fire, and mechanical brush treatments were initiated and continue to be used to reduce fuel loads and to restore the forests' ability to withstand natural disturbance (Elliott-Fisk et al. 1996; USFS 1998).

As of 1991, approximately 68 percent of the land area in the basin was forested. Isolated stands in steep and inaccessible areas and stands within viewsheds surrounding lakeshore estates escaped logging and are considered old growth. At least 38 old growth stands have been located within Tahoe's upper and lower montane forests and remain as a valued and visible part of the basin ecosystem. About 95 percent of the total area of forest in the basin is second growth conifer stands, of which approximately 40 percent is mixed fir (with a dbh of 12 to 24 inches). Approximately 12 to 15 percent of the basin's land area is developed with residential or commercial buildings. Approximately 70 percent of this developed land is in forested areas. Most of the forest today is accessible via dirt roads or hiking trails.

In this urbanized forest setting, biotic

structure and function have been simplified and significantly altered by the removal of trees, creation of roads, and landscaping with nonnative plants. Although the full impact of urbanization on forest biodiversity in the basin remains unknown, it is clear that the modern forest has been shaped by historic circumstances involving climate, timber harvesting practices, and fire suppression policies. All have combined to create a vegetational change and ecosystem response over the last century that have become the focus of contemporary forest health concerns in the Tahoe basin.

Grazing

Grazing has continued on private land and on allotments throughout the urbanization period. In the 1990s four USFS allotments totaling 31,600 acres (13,000 acres of which are in riparian zones) supported 336 cow/calf pairs and 50 horses or mules each summer (Pepi 1999). Livestock impacts on public lands have varied from year to year, as grazing is allowed only when the ground is judged to be dry enough to support livestock.

Wetlands and meadows have experienced rapid change during the urbanization period. Since 1900 approximately 75 percent of marshes and 50 percent of meadows have been degraded. Around 25 percent of the basin's marshlands were developed between 1969 and 1979 (Elliott-Fisk et al. 1996). The Tahoe Keys project, for example, filled, fragmented and highly altered 750 acres of the once intact "Rowland's" Marsh. The marsh, located at the mouth of the Upper Truckee River, originally occupied about 1,300 acres and extended 4.3 kilometers (2.6 miles) along the shoreline of Lake Tahoe, from Al Tahoe to Camp Richardson's Jamison Beach. It remains the largest marsh in the Lake Tahoe basin, but its hydrologic function has been compromised by the Tahoe Keys development. Since the early 1980s, agencies such as the USFS's the Santini-Burton program and the California Tahoe Conservancy (CTC) have been involved in efforts to purchase and restore environmentally sensitive lands, especially wetlands and sites of significant erosion, like Rowlands Marsh near Tahoe Keys (Elliott-Fisk et al. 1996).

Air Quality

The local generation of airborne pollutants by wood stoves, wildfires, and vehicle emissions (especially during periods of high tourist visitation), combined with increasing pollution generated by out-of-basin sources , such as those coming from urban areas adjoining Tahoe to the east and west, have combined to create a significant environmental concern in the last few decades. Summer visibility may have been poor during prehistoric times, as on the average, 30 acres or so were burning somewhere in the basin every day from May through October. Small lightning-caused fires and microburns by Native Americans would have rarely reached to tops of trees but probably did deposit a smoky haze layer over the lake each morning. Later in the day, this smoke would have dissipated and would have been blown eastward into what is Nevada by the midday winds. Still, in the morning, the view along the length of the lake would have been obscured, although the mountains and ridges above the thin haze layer would have been sharp and clear.

Historic information on air quality is available through 19th century first-hand observations. For instance, an anecdote by Mark Twain, although somewhat fanciful, conveys a message:

"The air up there in the clouds is very pure and fine, bracing and delicious. And why shouldn't it be?—it is the same angels breathe" (Twain 1962).

Unlike Twain, some historic accounts note smoky skies and the incidence of fires during the historic period. Photographs taken during Comstock-era logging show smoke in the air.

Visibility between roughly 1900 and 1960 was probably better than it had ever been before or since, due to fire suppression efforts by public agencies.

Water Quality

Lake sedimentation records that reflect disturbance caused by Comstock-era logging indicate that, in the absence of extensive road building and

development, the watershed recovered quickly from this disturbance with minimal effect on the lake's water quality (Heyvaert 1998). However, the cumulative effects of development in the Tahoe basin over the last few decades have proved deleterious. The lake has responded to increased nutrient loading from the streams, atmosphere, and ground water with steadily increasing algal growth (eutrophication) and a progressive loss of transparency.

Concern for the basin's water quality has steadily increased since the 1960s, as research continues to reveal the impacts of urban pollution (particularly sewage and runoff) on the basin's subwatersheds and on Lake Tahoe itself. Most sources of pollution have had long-lasting effects. For example, in the 1970s Heavenly Valley Creek still carried high nutrient loads, five years after sewage effluent was no longer released nearby (Strong 1984). In addition, human-induced soil erosion and development of Tahoe's lakeshore wetlands and marshes are primarily responsible for the historic decline in Lake Tahoe's clarity, accelerating the release of nutrients from the watershed and a reducing the lake's capacity to cleanse itself (Elliott-Fisk et al. 1997). Since the 1980s the USFS has initiated numerous erosion-control and stream-restoration projects.

Regional Planning

In this context of urbanization and rapid growth, the modern era of regulated regional planning began. As the Tahoe basin was undergoing its latest boom of development, a number of research studies disclosed evidence of serious degradation of many aspects of Tahoe's environment. This news prompted the states of California and Nevada to sign the Bi-State Compact in 1969, creating the Tahoe Regional Planning Agency (TRPA). TRPA is a government agency intended to serve as administrative lead in establishing a regional approach to land use planning and regulation. A number of auxiliary planning agencies, conservancies, and special interest groups and coalitions have since emerged in response to the management policies of TRPA and due to the indeterminate administrative responsibilities of federal, state, county, and municipal governments and the private sector (Elliott-Fisk et al. 1997). In 1982 TRPA established a series of thresholds, which set limits for the use of the basin's natural resources and in 1987 enacted a Code of Ordinance, which severely curtailed areas for future development, as well as the type of development allowed.

Although controversy and confrontation arising from the rapid rate of social and economic growth and the equally rapid rate of environmental degradation have characterized this era of urbanization, the dependence of the economy on a relatively healthy natural environment has finally been widely acknowledged (Elliott-Fisk et al. 1996). The purchase and regulation of land by agencies has set the stage to ensure that forested communities are conserved into the future. In the late 1960s the USFS, facilitated by the Land and Water Conservation Fund Act of 1965, began acquiring private estates around the lake. In 1964 Nevada passed a State Parks Bill and turned 5,000 acres of the Whittell Estate into the Lake Tahoe Nevada State Park (expanded to 13,000 acres in 1967). The LTBMU was created in 1973 to administer portions of three adjoining national forests in the basin as a single entity. In 1974, the USFS purchased 10,000 acres in the northwest sector of the basin and 645 acres at Meeks Bay. In 1989, the Nevada Wilderness Protection Act preserved land north of Incline now known as the Mount Rose Wilderness Area (Landauer 1995). By 1980 the USFS owned 65 percent of the land in the basin, and by 1996 USFS holdings had increased the total to 77 percent (Elliott-Fisk et al. 1996). Current public ownership now stands at 85 percent of the 202,250 acres total land area.

Human Dynamics, Economic Health and Social Well Being

In his two books on the environmental history of the Lake Tahoe region, Douglas Strong describes the emergence of concern about the relationship of environmental quality to economic activity (Strong 1984, 1999). In its earliest forms, this concern did not fully articulate the link between ecology and economy. There was a manifest desire to protect private property rights and to make

profits. Those goals certainly were driven by the knowledge that the region's character gave value to property and drew customers to businesses. But, only in the last few decades has there been a conscious and continuing discussion about how communities can best sustain or improve their economies to support high quality environmental management.

In this discussion all parties acknowledge that the stunning beauty and wide range of recreational opportunities at Lake Tahoe drive the basin's economy. Residents, business people, land owners, and environmentalists are now asking questions about the quality of community life. Many believe there are measurable relationships among a healthy community, a healthy economy, and a healthy environment. History informs this concern. It is common knowledge that human use of the Tahoe basin has left lasting scars on the environment. But community action, with the help of state and national support, has mitigated some of those scars. The concern of the people of Tahoe together with the wealth and support of the state and nation form the foundation for environmental protection.

Individuals who have long experience in the basin—through jobs with public agencies, through ownership and stewardship of private land, or simply through loving and visiting the place—provide an important "institutional history" that lends perspective to the debate about balancing economic vitality, community well being, and environmental quality. They have witnessed the mistakes. They have participated in the restoration. Their combined historical knowledge suggests that environmental quality does not have to be sacrificed for economic vitality and community health. On the contrary, strong communities support strong economies and healthy environments. The evolving discussion over what makes a strong community now goes beyond the obvious and important factors, such as good schools, good libraries, good health services, and good recreational facilities. The current discussion embraces the questions of affordable housing, the integration of minority ethnic groups, and the serving of a growing retirement population, to name just three. It includes the facts that increasing wealth will drive up land and housing prices and that year-round traffic overload diminishes the quality of life for both resident and visitor.

Scientific Research and Humanistic Applications

In the Tahoe basin the scientific community has long been recognized as an important participant with regulatory agencies in the policy-making process. During the 1970s, academic and government institutions initiated long-term and systematic scientific research on the Tahoe basin to enhance regional planning efforts; the research continues to the present day.

Initially, the focus on lake clarity drove environmental decision-making in the Lake Tahoe basin; but growing concern over the entire ecosystem has identified other sources, such as biological diversity, forest health, air quality, and socioeconomic health. Lake clarity depends on the larger system and it indicates the status of other linked elements. This watershed study marks the first explicit attempt to synthesize all these issues and to address long-term sustainability for the total system.

Ecosystem History and Paleoenvironmental Studies

Paleoenvironmental investigations being conducted by Quaternary scientists use a variety of data to address issues crucial to current and future environmental health of the Tahoe basin and surrounding areas. From a knowledge of past climate patterns and ecosystem response, a sense of sustainable vegetation conditions is gained. Paleo-environmental data contribute to understanding the frequencies, durations, magnitudes, and rates of climatic change and the environmental responses to these changes. In particular, these data indicate the norm. Issues related to landscape evolution, drought, floods, changing fire regimes, and long-term water quality are addressed from the perspective of long-term ecosystem processes. Information derived on each of these issues has economic, aesthetic, and health impacts on the people that visit and live at Lake Tahoe, and it can be used in public education programs to enhance visitor appreciation of Lake Tahoe's natural environment. Work currently being conducted includes the following.

1. Pollen, plant macrofossil, and charcoal studies around Lake Tahoe and the western Great Basin are being used to reconstruct climate and vegetation histories. These show the close connection between climate and forest dynamics over thousands of years.
2. Reconstructed vegetation histories for the last thousand years highlight the decrease in biodiversity of Lake Tahoe forests since European settlement. This decline has led to the forest's greater sensitivity to drought, disease, and fire.
3. Long-term relationships among forest fuel buildup, climate, and changing fire regimes (to include the potential role of human-induced fires) are being clarified as the dates and densities of charcoal recovered from sediment records are analyzed. These records suggest that future potential global warming will result in significant increases in fire frequency in the Tahoe basin.
4. Reconstructed vegetation histories are providing evidence for past wet and dry cycles and their return intervals. Within the last few decades the great variation in the level of Lake Tahoe has affected both upland and lowland users of Tahoe water. Radiometric dating of forests submerged up to 20 or more feet below the current surface of Lake Tahoe reflect periods of drought during the last 6,500 years, and even the last 1,000 years, that dwarf those of today.
5. Sequences of tree rings from forests in the region of Lake Tahoe furnish a record of past stream flow for drainages entering and leaving Lake Tahoe. In addition, correlation of these records with other paleoflood sequences from the Truckee, Carson, and Walker rivers indicate the kinds of climates under which frequencies and magnitudes of floods increase in the drainages of the central Sierra Nevada and suggests the role that Lake Tahoe may play in these events.
6. Finally, studies of present and past molluscan assemblages are providing proxy data for reconstructing past changes in water chemistry/quality resulting from paleoclimatic variation.

Water and Air Quality

The extensive research and monitoring programs of the Tahoe Research Group (TRG) have provided clear evidence for the onset of cultural eutrophication in ultra-oligotrophic Lake Tahoe. This continuous, long-term evaluation of lake chemistry and biology since the early 1960s has shown that algal production is increasing at a rate greater than 5 percent per year and clarity is declining at the alarming rate of 0.5 meters per year. Scientific investigations during the period 1959-1996 demonstrated that multiple stressors—such as land disturbance, habitat destruction, air pollution, accelerated erosion, extensive road networks, drought and flood hydrology, timber and fire management practices, urban runoff, creation of impervious surfaces, introduction of exotic species, and heavy use of road salt—have interacted to degrade the basin's airshed, terrestrial landscape, and streams, as well as the lake itself.

The first scientific observations of Lake Tahoe were made as early as the 1880s by John LeConte of the University of California at Berkeley. Intensive studies began in 1959 by Charles Goldman at the University of California at Davis, who founded the TRG. During this period, TRG scientists began their now continuous sampling of water temperature, chemistry, light transmission, zooplankton, and phytoplankton productivity and were able to make important discoveries concerning such phenomena as algal growth, eutrophication, changes in water clarity, lake nitrogen and phosphorus chemistry, and nutrient limitation. This project was one of the earliest to use the watershed approach to water quality and limnology and to incorporate sociologic, economic, and regulatory concerns. These surveys have provided information for efforts to arrest the decline in Lake Tahoe water quality. With the need to acquire a more extensive data base for land use planning and watershed management, the Lake Tahoe Interagency

Monitoring Program (LTIMP) was established in 1979 to collect water and air quality information on Lake Tahoe necessary to support the extensive regulatory and research activities in the basin. This program enables long-term effective monitoring and measurement necessary for detecting trends in dynamic ecosystems of lake and stream water quality and atmospheric nutrient loading.

Heritage Values

Efforts to restore Lake Tahoe's ecosystem benefit from an increased understanding of the long-term ecological dynamics between historic human communities, plant and animal communities and the basin's physical environment. Archaeology and ethnography rely on the interpretation of heritage remains, resources that offer information with great time depth and serve as independent and corroborative elements with which to link historic conditions and contemporary research, monitoring, and adaptive management. Heritage resources are uniquely tied to the human dimension of the Lake Tahoe ecosystem and guide future decision-making by setting a baseline of reference conditions to determine how present conditions differ from past conditions, the reasons for that difference, and the sustainable conditions that may be possible in the future. A knowledge of how people shaped past ecosystems is then directly applied to the restoration and maintenance of future ecosystems. Heritage resources require preservation, conservation and appropriate management.

Archaeology

In the absence of historical or oral history records beyond 150 years, the archaeological record offers information to address the question of potential disturbances of indigenous plant and animal communities in the prehistoric past. Here, associations may be found between the distribution and density of archaeological sites and the relative degree of anthropogenic disturbance, with locales containing higher site densities being some indicator of locales subject to greater disturbance by prehistoric and historic peoples. Accordingly, archaeological remains are viewed as more than the evidence people left on a landscape; they are the expressions of human interaction with that landscape. Forests in the Tahoe basin, then, are both "habitat and artifact" (Forney 1995), a repository of information about the human-induced changes in the Lake Tahoe basin and their corresponding environmental conditions.

History

When conservatively interpreted, first-hand accounts from period observers provide a reliable view of the past, with observations on the size, structure, and species composition of the pre-Euro-American forest. Other archival sources, such as lumber company records, contain quantitative data on species mix and stem diameters. Some data are adequately precise to facilitate the identification of environmental reference conditions for specific areas (located by township/range/section) and times (by season and year of harvest). Historic deeds and assessors records document land transfers and may indicate the year lands were cut (or grazed) and the amount of timber harvested. Comparisons of historic and contemporary photographs illustrate point-specific landscape changes and general environmental conditions.

The Ethnographic Past and Washoe Present

Prior ethnographic research has not focused on traditional Washoe resource harvesting techniques or horticultural and conservation practices, topics of timely concern in present ecosystem restoration efforts. There is compelling evidence of extensive and systematic management. Future research along these lines promises the disclosure of specific management and conservation practices that may have influenced the Lake Tahoe ecosystem in the past and that may contribute to its future management.

Washoe people and their tribal government are eager to renew their ties to Lake Tahoe and to participate in the restoration and maintenance of a healthy watershed, inclusive of the human enterprise. Recognized as a sovereign nation, the Washoe Tribe is working in partnership with federal agencies to reestablish more than a "place name" presence in the

Lake Tahoe basin for the 21st century. In 1994 the Washoe Tribal Council developed a Comprehensive Land Use Plan that includes goals to reinstate ancestral land management practices at Lake Tahoe, including the harvest and care of traditional plant resources (Washoe Tribal Council 1994). The tribe is sponsoring an oral history program that incorporates, as a key component, on-site visits and interviews with elders at traditional areas around Lake Tahoe (Wallace 1999). The USFS has engendered interest in identifying anthropogenic landscapes resulting from traditional Washoe land use practices. Although detection of these landscapes is hindered by the profound landscape alterations caused by succeeding Euro-American populations, contemporary Washoe plant specialists can still share traditional information and reintroduce practices that once contributed to sustainable ecosystems in the Tahoe basin. One objective of compiling this Washoe botanical knowledge is to promote management, including watershed restoration, that would favor plants targeted by contemporary people and engage Washoe plant specialists and land managers in active adaptive management strategies. Another objective is to identify the traditional plants most likely to have been heavily managed in the past and whose populations and vigor would be most affected by systematic harvesting and horticulture. The ultimate goal is to document indigenous harvesting and management practices, to reintroduce some, and to design research that might enable the effects of aboriginal horticulture to be quantified (Anderson 1993a, 1993b).

Increasingly, vocal tribal overtures demand that the Washoe be considered serious stakeholders in land management issues at Tahoe. At a presidential environmental summit in 1997, members of the tribe were praised for their long history of stewardship in the Tahoe basin. In turn, the Washoe Tribe asked that all people who now share, live upon, or use their ancestral resources also be responsible guardians of their traditional lands. In the wake of President Clinton's visit to Lake Tahoe, the Washoe Tribe and the USFS signed a landmark agreement to return the use of more than 400 acres of land within the Tahoe basin to the tribe under a special use permit. Clinton is the sixth president since 1877 that the Washoe have petitioned to return their lands for traditional use. The Washoe desire to demonstrate actively their philosophy on resource stewardship and land restoration at Lake Tahoe. These "reacquired" areas will be used to reinstate ancestral land management practices and to return Indian people to their ancient homeland for cultural renewal.

Changing Land Use Paradigms and Ecosystem Consequences

Past land use ideals have been physically transposed upon Tahoe's present landscape—Native American stewardship engaged a balanced relationship between human society and the environment. Climate change, 19th century clear-cutting, and decades of fire suppression have combined with increasing urbanization during the 20th century to diminish lake clarity and forest biodiversity. The resulting "greening" of Lake Tahoe and the demise of about one-fourth of the second growth forest within the last two decades presents an awesome challenge to land managers and conveys a powerful message to the public that carries impending social and economic costs. Thus, each decade of the last 150 years of human history at Tahoe has sharpened the dilemma of how to have a decent way of life without spoiling this place, confounding the direction of 21st century users of Lake Tahoe.

Leaders and observers now recognize the very complexity of the web of relationships among the elements of social well being, economic vitality, and environmental quality. It is more than timbering and erosion, more than burning and smoke, and more than personal watercraft and noise. Acknowledging this complexity has established Tahoe as a powerful laboratory for learning. The Tahoe region no longer exports a product, but rather an "experience" (TRPA 1996). Increasingly, the Tahoe experience offers residents and visitors the beauty of mountain scenery and the pleasure of recreation and the intellectual opportunity to learn about its biophysical and cultural heritage dimensions. As knowledge and information become more a part of the lives of visitors and residents, the lake and surrounding forests will become more an object of learning and source of information.

Tahoe is a world model for advice on how to move understanding and attendant management of complex human-environment systems to a new and more effective level by using the history of place in an informed way. The Lake Tahoe basin management experience is evolving to be one of the best examples of adaptive ecosystem management in the world. It has become an especially useful model for ecosystems elsewhere that are also undergoing change from historic logging and grazing, fire suppression, forest overstocking and declining forest health, degradation of riparian corridors and wetlands, restoration activities, recreational pressures, declining air quality, and the many forms and impacts of urbanization (Elliott-Fisk et al. 1997). An understanding of these historic disturbances can effectively guide future management in the Lake Tahoe basin.

Time Line of Paleoclimate and Environmental History in the Lake Tahoe Basin

<13,000 BP Glaciers occupy much of the Tahoe Sierra, especially the valleys lying southwest of Lake Tahoe; a large glacier dams the Truckee River at the mouth of Squaw Valley, raising the level of Lake Tahoe at least 100 feet above its current level; many of the basins east of the Sierra are flooded by extensive lakes; the largest of these, pluvial Lake Lahontan, floods much of the western Great Basin and is fed by the Truckee, Carson, Walker, Humboldt, Smoke Creek, and Quinn rivers; around the Lahontan Basin, sagebrush steppe with scattered juniper woodland, occasionally mixed with stands of white-bark pine, blanket the slopes surrounding these lakes.

13,000 to 11,500 BP Great Basin pluvial lakes shrink by 11,500 BP, reaching their lowest stands since 27,000 BP; down-cutting of river channels to new base levels follows the drop in lake levels; glacial melt begins in earnest; between 13,000 and 12,000 failure(s) of the ice dam at the mouth of Squaw Valley result in several catastrophic floods that sweep down the Truckee River Valley, altering its morphology by eroding huge swaths of sediment and depositing it in the Fernley Basin; drier climate results in the retreat of white-bark pine from lower elevations and the movement of desert scrub into abandoned lake bottoms.

11,500 to 10,000 BP Colder climate corresponding to the Younger Dryas period of Europe results in a brief, relatively minor resurgence of Sierran glaciers and of pluvial Lake Lahontan and in retrenchment of warmer climate vegetation; a cold-dry sagebrush steppe prevails until about 10,000 BP, when there is a shift to coniferous forest; at lower elevations in the Great Basin to the east, a juniper woodland with a more xeric shrub understory clings to the slopes surrounding these shallow lakes and marshes; ancient hunting peoples live in the area and probably hunt the remnant herds of Pleistocene herbivores, which include two kinds of horse, camel, bison, shrub ox, and Columbian mammoth.

10,000 to 7000 BP (Early Holocene) Climates warm and dry rapidly, reaching their Holocene maximum by 9000 BP; glaciers retreat to near their Holocene minimum, and lakes and marshes in the basins east of Lake Tahoe shrink to their smallest extent and, in some cases, even disappear; eolian erosion of dry lake and marsh areas commences on a large scale in the Great Basin; much of this material accumulates as downwind dunes or as blankets of eolian sediment on the mountain ranges of the Great Basin; slope erosion on a massive scale begins due to much reduced vegetation cover; as a result, many stream channels fill with stacks of sediment; montane forest species arrive en masse from the south and from lower elevations west and east of the Lake Tahoe basin, transforming the landscape cover from shrub steppe to forest; in the Great Basin to the east, juniper woodlands retreat from their Pleistocene extent to positions near their current limits.

7000 to 4000 BP (Middle Holocene) Period of warm dry climate during which the cumulative effects of Holocene drought reach their climax; more drought tolerant species climax before 5500 BP; continued desiccation of lakes in the western Great Basin; Lake Tahoe and Pyramid Lake decline but are the only ones that do not dry up (ancient drowned forests at Tahoe date between 6300-4800 BP, and submerged stumps stand rooted

on the lake's floor up to 20 feet below its surface); many streams reduce to trickles, and the Truckee River may even cease to flow; Pyramid Lake may lie more than 210 feet below its current level; eolian erosion and depositional activity declines as playas become armored with silts and clays, and the amount of fresh, erodible sediments provided by tributary streams declines dramatically; at the heads of tributary streams slope erosion, due to much reduced vegetation cover and stream channel filling, is still very active; juniper-dominated semiarid woodland retreats upslope in Great Basin mountain ranges by as much as 1,000 to 2,000 feet; subalpine woodland disappears from some Great Basin ranges in which it had existed since the Pleistocene and survives in only the highest mountain ranges; desert shrub vegetation advances up the slopes surrounding the many valleys of the Great Basin; native peoples limit their activities on the floors of these dry basins, concentrating instead on the resources of Great Basin uplands and the mountain ranges and highlands surrounding the Great Basin; between 5600 and 5400 BP, a major regional episode of wetter climate, evidenced from the plateau of eastern Washington to the northern Mojave Desert, results in forests in Lake Tahoe drowning, sagebrush replacing greasewood communities, and springs being reactivated in the southern Great Basin and northern Mojave Desert; in Little Valley, downslope movement of white and red fir, together with greater abundance of riparian species, such as willow, birch, and alder, herald this event; renewed dry conditions (not approaching the conditions before 5500 BP) continue with additional brief episodes of moister climate until 4000 BP.

4000 BP Climates become cooler and moister, initiating the Neoglacial (Neopluvial) period, which lasts for the next 2,000 years; rebirth of Great Basin lakes, or at least of marshes, follows, as does the minor resurgence of glaciers in the Tahoe Sierra; Pyramid Lake rises well above its current level, indicating that the Truckee River is flowing again and receiving significant contribution from Lake Tahoe; greatest abundance of white and red fir in Little Valley marks this period; in the Great Basin to the north and east, major downslope expansion of juniper-dominated semiarid woodland and contracting of desert shrub communities characterize the next 2,000 years.

4000 to 2800 BP A marsh forms along the lower reaches of Taylor Creek, due to a rise in ground water levels from about 5000-4000 BP; an open water environment exists at Taylor Creek marsh around 2800 BP.

4000 to 1300 BP (Late Holocene) There is a significant shift from more xeric vegetation to the dominant conifer species that are present today; the record appears to be punctuated by alternating intervals of cool-moist and warm-dry periods.

2200 to 1600 BP A subsequent warm-dry interval persists; Pyramid Lake recedes below its current level, and Eagle Lake (Lassen County) falls after 2000 BP (Eagle Lake was well below its current level from at least 7000 to 5000 BP); many other marsh areas contract or disappear; semiarid woodland retreats in the western and northern Great Basin.

1600 to 1100 BP Warm conditions with slightly wetter, summer-shifted rainfall pattern results in major expansion of piñon pine into juniper-dominated semiarid woodland in the western Great Basin east of Lake Tahoe.

1300 BP to Historic Contact The period is marked by an overall xeric trend, punctuated by cool/moist cycles alternating with cycles of severe drought; tree-rings from the Sierra Nevada confirm that except for the "Little Ice Age" (and perhaps two other brief episodes), this period is characterized by climates drier than those of today.

AD 600 to 800 Continuing dry conditions are indicated by trees growing on Ralston Ridge Bog (south of Lake Tahoe) due to low water tables; submerged stumps at Rubicon Point, Lake Tahoe, date between AD 680 to 885.

AD 850 A brief wet interval is indicated by the presence of buried A-horizon soils in association with a sand lens near Taylor Creek, indicating a rise in the level of Lake Tahoe and deposition of lake deposits as sand.

AD 900 to 1050 A period of substantial drought is suggested by relict Jeffrey pine stumps, rooted in the Walker River stream bed, that date to AD 1030; submerged stumps in Walker Lake date to AD 970; submerged stump in Fallen Leaf Lake dates between AD 1050 and 1265.

AD 1260 to 1500 Another severe drought

occurs, as indicated by relict Jeffrey pine stumps, rooted in the Walker River streambed, that date to AD 1290; in the Truckee River watershed, the relationship between tree growth and stream flow indicates that intermittent drought conditions prevail around AD 1260; a dry period around AD 1281 is supported by submerged tree stumps, which indicates a substantial drop in Independence Lake (a Truckee River tributary).

AD 1500 During the last 500 years, a wet climate, punctuated by intermittent but substantial droughts, begins to dominate the region, with rising and lowering lake levels and advancing and retreating cirque glaciers.

AD 1430 to AD 1490 Drought is indicated by dozens of tree stumps submerged up to 30 feet below the present level of Donner Lake (also a Truckee River tributary), dating between AD 1433 and 1490.

AD 1579 to 1585 and AD 1630 Another warm period is documented by tree ring studies and Truckee River runoff.

Mid-1600s to Mid-1820s Generally cooler wetter conditions coincident with the European "Little Ice Age" event result in brief regrowth of Great Basin lakes and reexpansion of semiarid woodlands in the Great Basin and northern Mojave Desert; Tahoe's old growth forests develop during this time.

Mid-1700s to Mid-1800s The level of Lake Tahoe may have been occasionally below its rim; these episodes may be documented by a submerged stump in Tahoe offshore of the Upper Truckee River dating from about AD 1720 (230±50 BP uncalibrated), one in Emerald Bay dating to AD 1840 (110±60 BP uncalibrated), one from Moon Dune Beach at Tahoe Vista dating from AD 1802 (148.5±mod uncalibrated), and one from Cave Rock with a calibrated date of AD 1695-1725/1815-1920; two submerged stumps from Independence Lake date from AD 1780 (170±50 BP uncalibrated) and AD 1850 (100±mod uncalibrated), respectively; one stump from Donner Lake dates from AD 1800 (150±50 BP uncalibrated); given the problems of radiocarbon-dating materials less than 250 years old, these dates may also bracket the "Little Ice Age."

1875 to 1915 A period of greater precipitation is indicated by above-average flows of the Truckee River; northern Great Basin lakes reach high levels, matched only by the lake highs resulting from El Niños of the late 1979s and early 1980s.

1907 (July 14-18) Lake Tahoe attains its highest recorded lake surface level at 6,231.26 feet (11.00 feet mean sea level [MSL] above its lowest recorded surface level of 6,220.26 feet MSL, recorded on November 30, 1992).

1912 During an extreme drought, an attempt by the USRS and the TRGEC to dredge the Truckee River channel at Tahoe City and cut down its rim is blocked by lakeshore property owners through a court injunction.

1924 Drought drives downstream farmers to persuade Lake Tahoe property owners to allow the lake to be pumped when it falls below its natural rim.

1928 The Truckee River Basin experiences the beginning of a severe drought; lasting from 1928 through 1935, this drought would not be exceeded in severity until the 1987-1994 drought.

1950 A major winter flood dramatically increases flows into Lake Tahoe and the Truckee River.

1982 to 1986 A period of wet years results in an average annual snow water content of up to 200 percent of normal; 1983 becomes the standard high water year for virtually all waterways within the Lake Tahoe and Truckee River basins; this episode occurs throughout the northern Great Basin, as lakes reach their highest level since the mid-1870s.

1987 to 1994 An eight-year drought begins in the Truckee River drainage basin; although of the same duration as the 1928-1935 drought period, the 1987-1994 drought is far worse; the Lake Tahoe basin records an average annual snowpack water content down to a low of 29 percent of normal; Tahoe attains its lowest recorded lake surface elevation over its entire period of record (April 1900 to present); on November 30, 1992, Lake Tahoe reaches its record low at 6,220.27 feet MSL, 2.72 feet below its natural rim of 6,223 feet MSL (11 feet below its highest lake surface level of 6,231.26 feet MSL, recorded on July 14-18, 1907).

1991 Sustained drought subjects timber stands to severe insect attacks; by 1991 an estimated 300 million board feet of timber are dead or dying; salvage logging begins on the east, north, and southwest sides of the lake; thinning, prescribed burns, and mechanical brush treatments are implemented to reduce fuel loads and to restore forest health.

1995 A near-record water year of precipitation in the Lake Tahoe and Truckee River basins recharges ground water and replenishes nearly empty reservoirs; this trend of normal to above-normal precipitation continues to the present.

1996 The *Sierra Nevada Ecosystem Project* is released, a $6.3 million study and assessment commissioned by the US Congress and funded by the USFS; the 3,200-page study, written by 107 scientists, is intended as a tool for policy makers planning for the future of the Sierra Nevada; an important finding is that Sierran climate, which drives the biosystem as the source of much of California's and western Nevada's water, may be getting drier; century-long droughts that have occurred within the last 1,200 years may recur in the near future.

1997 (January 1) Lake Tahoe and the Truckee River Basin experience severe and extensive flooding that exceeds 100-year flood records.

Time Line of Transportation and Community Development

1844 (February 14) While conducting an expedition for the US Bureau of Topographical Engineers, John C. Fremont views Lake Tahoe from Red Lake Peak—the first Euro-American to do so.

1844 (May) Six members of the Stevens-Murphy-Townsend emigrant party become the first Euro-Americans to stand on the shores of Lake Tahoe; they leave the main party on the Truckee River and, instead, cross the Sierran divide above McKinney Creek.

1848 (January) The initial rush to the California gold fields bypasses the Lake Tahoe basin in search of easier routes that don't involve dual summit crossings.

1850s Georgetown-Lake Bigler Trail leads westward from McKinney Creek, through Rubicon Springs, and terminates at Georgetown.

1851 Tahoe's first Euro-American settler establishes a trading post at Lake Valley.

1851 Lake Tahoe receives its official name, Lake Bigler, in honor of California's governor, John Bigler. (The name Tahoe, a misnomer derived from the Washoe word *da'ow* and signifying "lake," does not become the official designation until 1945.)

1852 "Johnson's Cut-Off" is laid out, connecting Placerville and Carson Valley through Lake Valley via Echo Summit (Highway 50/Pioneer Trail).

1852 to 1854 Carson Emigrant Ridge Road connects with Johnson's Cut-Off, crossing over Spooner Summit (Highway 50).

1852 to 1855 Placer County Emigrant Road is established through Truckee River Canyon (Highway 89) and along Tahoe's north shore (Highway 28); road connects Auburn and Virginia City through Squaw Valley and Tahoe.

1855 G. H. Goddard and S. H. Marlette commence the California state boundary survey through the Tahoe basin.

1858 to 1859 Luther Pass (Highway 89) becomes the favored route through the Tahoe basin, bypassing lower Lake Valley.

1859 The discovery of silver near Virginia City causes a reverse migration from west to east; this time the Tahoe basin becomes a crossroads between California's Mother Lode and Nevada's Comstock Lode; several new routes are opened through the basin, the most popular of which are along Tahoe's south shore (Highway 50/Pioneer Trail).

1860s Glenbrook Bay becomes the east shore over-water terminus for the toll pack trail leading from Georgetown to McKinney Bay; from Glenbrook, travelers proceed eastward to Virginia City.

Early 1860s Settlements are established at Lake Valley, McKinney's, Tahoe City, Lake Forest, Agate Bay, Tahoe Vista, Kings Beach, Glenbrook, and Edgewood.

1860s Early resort era begins with resorts in Lake Valley, Tahoe City, Brockway, McKinneys, and Glenbrook; ranchers, hostlers, and commercial fishermen in Lake Valley profit from the lucrative

business of supplying travelers and the growing mining centers; up to 15 hostelries are established by 1865, supplying customers with locally grown hay, vegetables, dairy products, and fish.

1860 Tahoe Truckee Turnpike (Highway 89) opens through Truckee River Canyon.

1860 to 1861 The new Kingsbury-McDonald Grade (Highway 19/207) is developed over Echo Summit and Daggett Pass and siphons travel away from Luther Pass; it is designated as the Pony Express Trail.

1862 Rufus Walton Toll Road is opened from Glenbrook over Spooner Summit (Highway 50).

1863 The new Lake Bigler (Tahoe) Wagon Road channels the flow of travel over Echo Summit and through the Tahoe basin, away from Kingsbury Grade and over Spooner Summit.

1866 Over a period of three months, 6,667 pedestrians, 3,164 stage passengers, 5,000 pack animals, 2,564 teams, and 4,649 cattle travel the Lake Tahoe Wagon Road along Tahoe's south shore.

1869 The nation is joined by the first transcontinental railroad; connections to Tahoe's north shore by stage from Truckee promote tourism at an early date; lake front resorts soon flourish at Tahoe City, Glenbrook, and Tallac.

Truckee-Hot Springs Road (Highway 267) is constructed over Brockway Summit between Truckee and Brockway Springs.

1860s to 1910s Steamer traffic dominates travel in the Tahoe basin; roads are generally in poor condition and do not yet circumvent the lake.

1873 John LeConte conducts initial limnological studies on Lake Tahoe.

1870s A settlement is established at Carnelian Bay.

1880s Tourism flourishes with more resorts established in Lake Valley, Emerald Bay, Sugar Pine Point, Blackwood, and Tahoe City.

1883 The California Legislature creates the Lake Bigler (Tahoe) Forestry Commission, specifically to address the problems of overcutting, and plans for tourism; the commission unsuccessfully calls for creating a national park at Tahoe, to be formed by transferring state, federal, and private land to the state of California; objections stemmed from the fact that the land transfer would ultimately profit the Central Pacific Railroad.

1891 First continuous road is built over Mt. Rose Pass connecting Reno and Lake Tahoe ("The Road to Incline"/Highway27/431).

1898 The Lake Tahoe basin is stripped of marketable timber, and large-scale cutting ceases; logging railroads are salvaged, and capital and energy are funneled into a growing tourist industry.

1899 A 37,550-acre forest reserve is created, including Desolation Wilderness, Glen Alpine, and the lakeshore between Camp Richardson and Rubicon Bay; 13 acres at the former fish hatchery near Tahoe City are set aside to eventually become the site of California's first state park.

1900 A second effort to establish Lake Tahoe as a national park is blocked.

1901 Completion of the LTRTC railroad connecting Tahoe City with the Southern Pacific mainline at Truckee is a major boost for tourism; at Tahoe City, rail passengers are transferred to luxury steamers to lakewide destinations; Tahoe becomes the playground for the wealthy elite, and exclusive resorts are built or expanded near Tahoe City, Carnelian Bay, Brockway, Glenbrook, Tallac, and Emerald Bay.

1905 By this time ten communities with separate post office addresses have been established around Tahoe's lakeshore.

1907 With the creation of the national forest system, forest reserves are renamed national forests and the Tahoe basin is segmented under the jurisdictions of the Tahoe, the Toiyabe, and the Eldorado national forests; agency control dramatically changes land use patterns here, especially with regard to fire suppression, increased recreation, and the construction of summer homes.

1910s The first automobiles travel to the Lake Tahoe basin, ushering in a new era of tourism.

1911 The first USFS ranger station is established near Meyers; rangers are charged with preventing fires, enforcing fish and game regulations, administering timber sales, and experimenting with reforestation.

1912 A third attempt to designate the Tahoe

basin as a national park is defeated. Bliss, Yerington, and Mills estates, which once owned one-fifth of the land in the Tahoe basin, still retain 40,000 acres of cutover land and now offer it for subdividing.

1913 Distrusting government intentions, prominent Lake Tahoe property owners file articles of incorporation, forming LTAC, the first environmental group created specifically to preserve the lake's beauty by protecting its environment.

1914 Auto traffic to Tahoe increases after the main road through South Lake Tahoe (Highway 50/Pioneer Trail) and the road over Donner Summit (Highway 40/Int 80) are designated as part of the Lincoln Highway, the nation's first coast-to-coast highway.

1918 A fourth pursuit to assign national park status to the Tahoe basin is unsuccessful.

1920s Initial subdivisions prompt the development of independent utility companies to provide basic water and power utilities; early subdividing occurs in Lake Valley.

1925 The first auto loop road encircling the Lake Tahoe basin is completed.

1928 to 1935 The US Bureau of Public Roads expands and upgrades auto roads within the Tahoe basin and improves ingress and egress outside the basin; easy auto access encourages the development of tourist facilities geared to a wider public and spells the demise of the exclusive resorts; tourist visits are short and more frequent; accommodations in auto courts and campgrounds are on the rise.

1930s With a fledgling building boom, Tahoe boosters actively draw visitors and prospective residents, mainly by seeking the patronage of various transportation companies; a final proposal to establish Lake Tahoe as a national park is unsuccessful, given prior degradations by logging and over-commercialization; George Whittell acquires a continuous strip of property from the Bliss and Hobart estates that stretches from Crystal Bay south to Zephyr Cove; Federal and state agencies begin acquiring privately owned parcels and managing them for the public trust.

1931 Gaming becomes legal in Nevada, and a new growth industry takes off on the Nevada side of Lake Tahoe.

1935 An improved highway encircles Lake Tahoe; during the 1930s, the paving of highways 50, 89, 28, and 27 (now 431) opens up Lake Tahoe basin-wide.

1945 The name "Lake Tahoe" is officially designated.

1949 The Nevada and California legislatures pass laws prohibiting the discharge of wastes directly into Lake Tahoe or its tributary streams; on the California side, the Lahontan Regional Water Quality Control Board assumes regulatory responsibility.

1949 Ski lifts are operating at Granlibakken, and Meyers and Echo Summits.

1940s A renewed era of intense subdivision development begins after WWII; growing communities prompt the establishment of a number of independent utility companies to provide basic public infrastructure.

1950s By the 1950s building boom, discussions on water and sewage problems occupy more space in Tahoe's local newspapers; as development puts more pressure on the existing sewage disposal system, a temporary solution is found by spraying effluent directly onto the land; the gaming industry expands at Lake Tahoe.

1950 The Tahoe Realty Board is established to standardize building codes around the lake.

1955 The Joint California-Nevada Interstate Compact Commission is formed, working together to produce a draft interstate compact for consideration by each state's legislature in 1968.

1956 Heavenly Valley Ski Resort opens.

1958 A bill introduced in the state legislature to relocate the highway above Emerald Bay by constructing a bridge over the mouth of the bay is defeated by conservation interests.

1959 Limnological measurements on Lake Tahoe begin.

1960s Major subdivisions are developed, especially at Tahoe's south shore (Tahoe Paradise, Golden Bear, and Meadow Lakes), and summer homes are converted to permanent residences; between 1960 and 1980, housing in the Tahoe basin

increases from 500 to 19,000 homes, with many developments built on converted wetlands; planners talk in terms of a "saturation population," expected to occur in about 2010, when all useable land is occupied and no new growth can occur.

1960 The Squaw Valley Winter Olympics provoke growth in the Lake Tahoe basin and firmly establish Lake Tahoe as a year-round resort destination.

1962 Scientists, using an eight-inch secchi disc and a hydrophotometer, find that the disc is discernible in Lake Tahoe at a depth of 136 feet and light is detectable at 500 feet.

1963 The first significant, multidisciplinary scientific assessment of the entire Lake Tahoe basin ecosystem is completed by LTAC; the TRG publishes the first of many reports on lake limnology; air quality monitoring begins.

1964 Interstate 80 opens and facilitates year-round access to the Lake Tahoe basin.

1965 South Lake Tahoe incorporates as a city.

1967 Awaiting approval of TRPA, California creates the California Tahoe Regional Planning Agency (CTRPA) as a "watchdog" organization.

1968 Sewage is exported from the Lake Tahoe basin; by 1975 almost all wastewater is transported outside the basin; resolution of sewage problems allows for more land development.

1968 The Joint California-Nevada Interstate Compact Commission creates TRPA to oversee land-use planning and environmental issues within the Lake Tahoe basin.

1969 The Lake Tahoe Regional Planning Compact is adopted; under the compact, city, county, state, and federal governments collectively address land use planning, environmental regulation, and ecosystem restoration and monitoring.

1969 In a repeat test, the secchi disc is visible at 100 feet, a loss of 36 feet of visibility in seven years (equating to an annual four percent reduction in the clarity of the lake's waters); the National Environmental Protection Act (NEPA) is passed, establishing the United States Environmental Protection Agency (USEPA) and requiring that Environmental Assessments (Eas) and Environmental Impact Statements (EISs) be undertaken for major construction projects.

1970s New rates of sediment deposition into Lake Tahoe are found to increase four times over predisturbance rates; an era of systematic scientific research of the Lake Tahoe basin ecosystem begins; it is marked by collaboration among university, agency, and independent scientists that continues to the present day.

1970 49,000 subdivided lots and hundreds of miles of roads exist in the Tahoe basin; the last of the major subdivisions are developed at Incline Village and Glenbrook.

1972 The Clean Water Act is passed, based on the 1965 Water Quality Act.

1973 The Endangered Species Act (ESA) is passed, superseding and strengthening the Endangered Species Preservation Act of 1966 and the Endangered Species Conservation Act of 1969; the Lake Tahoe Basin Management Unit (LTBMU) is created to administer portions of three adjoining national forests in the Tahoe basin as a single entity.

1974 CTRPA proposes temporary construction restrictions on the California side of the lake until the completion of its master plan; building permits are drawn by lot by a blindfolded Catholic priest; in a storm of protest, hearings on building permits require monitoring by police.

1980s The acquisition of additional public lands and restoration of their natural environments becomes an important resource management strategy in the Tahoe basin; heightened research expands programs monitoring environmental conditions in the Lake Tahoe basin; a repeat test using the secchi is visible at 75 feet, a loss of 61 feet in about two decades.

1980 President Jimmy Carter creates the Lake Tahoe Federal Coordinating Council (LTFCC) to address environmental problems at the lake.

1981 After his landslide victory, President Reagan quickly rescinds the order creating the LTFCC.

1982 CTRPA is phased out upon the adoption of ordinances to revamp TRPA's governing body and to implement a new regional

plan with stronger environmental controls.

1982 TRPA establishes thresholds for the basin's natural resources and enacts a code of ordinance to regulate all land use activities here; thresholds are subject to periodic review.

1985 to 1987 Under TRPA leadership, the Consensus Building Workshop brings together stakeholders who have been battling over resource conservation/development issues for years; the workshop creates new options and produces innovative programs for managing lands in the Tahoe basin.

Early 1990s Tahoe Truckee Regional Economic Coalition (TTREC) is formed to monitor social and economic trends and to plan regionally for economic change.

1990 An exchange program between students and scientists working at Lake Tahoe and at Siberia's Lake Baikal (the largest and deepest freshwater lake in the world) is established; native peoples—the Washoe at Tahoe and the Buryat at Baikal—participate in the cultural exchange, with shared goals of reestablishing a presence on traditional lands.

1996 Public ownership stands at 85 percent of the 202,250 acre landbase, with 77 percent under federal jurisdiction; approximately 68 percent of the total land area is forested with dense, second-growth stands, generally lacking in diversity; up to 15 percent of the land is developed with residential/commercial buildings; 75 percent of marshes and 50 percent of meadows have been degraded; several plant and animal species have become endangered or extinct; the introduction of exotic or invader species has negatively affected surviving native communities; Lake Tahoe is the single most important recreation component of the Sierra Nevada economy; the Lake Tahoe basin registers over 52,600 residents and supports a $1 billion economy employing more than 20,000 people; an estimated 200,000 tourists visit on peak holidays, with visitor days estimated to exceed 23 million annually; the recreation industry includes over 30 ski areas, water- and land-based attractions, and a large gaming establishment; with a $1 billion recreation-based economy, the importance of maintaining a healthy natural environment is widely acknowledged; the *Sierra Nevada Ecosystem Project* (SNEP) is released—a study and assessment commissioned by the US Congress and funded ($6.3 million) by the USFS; the 3,200-page study, written by 107 scientists—to aid policy-makers planning for the future of the Sierra Nevada.

1997 (July) At the request of Nevada Senator Harry Reid in 1996, President Clinton convenes a federal conference on issues surrounding the environmental condition and degradation of Lake Tahoe; President Clinton praises the Washoe for their long stewardship in the Tahoe basin; the Washoe Tribe asks that all people who now share, live upon, or use their ancestral resources be responsible as guardians of these traditional lands, just as the Washoe have been for thousands of years.

1998 Federal funding is allocated for a multidisciplinary and interagency watershed assessment study entitled, *Institutional Assessment of the Lake Tahoe Basin*; the purpose of the assessment is to provide a means for achieving a desired future for the Lake Tahoe basin ecosystem by integrating available data regarding its physical, biological, and socio-cultural components.

Time Line of Human Land Use and Environmental Conditions in Lake Tahoe Basin

Logging

1859 to 1870s Limited logging of easily accessible stands in Lake Valley for local consumption.

1861 Small-scale lumbering and fluming operations begin at Glenbrook by Augustus Pray and the Lake Bigler Lumber Company; initial operation produces 10,000 board feet a day and shingles; Samuel Clemens (Mark Twain) stakes a timber claim nearby then watches as it goes up in smoke after his unattended campfire burns out of control.

1861 to 1873 Spooner Summit is worked by a number of small-scale logging and fluming enterprises; the most accessible stands are harvested during these early years due to limitations of log transport.

1860s to 1870s Small-scale independent cutting of easily attainable timber around Edgewood.

1863 to 1877 Small-scale cutting of easily accessible stands up Ward Canyon under wood contract to CTLFC.

1864 to 1878 Small-scale cutting of reachable timber by independent wood contractors around Agate Bay for local/regional consumption.

1867 to 1875 Independent cutting of accessible land around McKinney Bay and Sugar Pine Point.

1875 to Early 1880s Cutting around McKinney Bay and Sugar Pine Point by a number of wood cutters under contract to CTLFC.

1871 Establishment of saw mill near Daggett Pass.

1873 to 1897 With headquarters at Glenbrook, the CTLFC emerges as the chief lumber operator, monopolizing the Comstock trade with large timber holdings that reach basin-wide; as companion organizations, the CTLFC works closely together with the rather shadowy EDWLC in logging their lands and later in marketing and leasing their respective holdings; from 1873 until 1897, CTLFC operates a "super-system" of rafting operations, railroads, V-flumes, wagon and skid roads, wood camps, and saw mills; lumber is hauled to Spooner Summit by railroad and flumed down to storage yards near Carson City for transport by the VTRR; CTLFC eventually comes to control approximately one-fifth of the Tahoe basin's land area, including substantial stretches of lakefront; when operations cease in 1898, the CTLFC had cut 750 million board feet of lumber and 500,000 cords of wood in the Tahoe basin.

Mid- to Late 1870s Stands around White Hill (Spooner Summit) cutover by CTLFC.

1875 to 1885 M. C. Gardner railroad logging operations between Camp Richardson and Tahoe Mt. (east of Fallen Leaf Lake) under contract to CTLFC.

1877 Cutting under contract to CTLFC up Ward Creek Canyon.

1878 Initial cutting on Agate Bay by wood contractors for CTLFC.

1878 to 1884 Meeks Bay is hub of CTLFC west shore logging and rafting operations centered around Sugar Pine Point, Meeks Canyon, and Rubicon.

1878 to 1897 SNWLC, the second largest lumbering and fluming outfit in the Tahoe basin, commences operations in the northeastern quadrant of the basin; the SNWLC also does considerable cutting in the southeastern quadrant of the basin; in partnership with its land-holding subsidiary, NLC; SNWLC owns 55,000 acres in the basin, about 43,000 acres are logged in Washoe and Douglas counties, with the remaining 12,000 acres in Placer County being traded away to the TLC after SNWLC cutting ceases in the basin; the company operates a logging complex, which includes a narrow-gauge railroad, rafting on Lake Tahoe, an inclined tramway, V-flumes, wagon haul roads, wood camps, and a mill at Incline.

1880 Along Tahoe's east shore, 10 primary V-flumes are sending 33,300,000 board feet of timber annually to storage yards on the other side of the Carson Range; this major network is fed water and wood from many miles of secondary V-flumes, U-flumes and box flumes; lands owned by EDWLC in the vicinity of Kingsbury are cutover.

1881 Cutting around Agate Bay under contract to SNWLC; Tahoe Vista marine terminal for SNWLC.

Early 1880s Choicest and most easily accessible lumber is cut over around McKinney Bay and Sugar Pine Point.

1880s Cutting of accessible stands around Tahoe City.

Mid-1880s Stands along South Camp Peak (upper Logan House/Lincoln Creeks) are cutover by CTLFC; timber along Kingsbury Grade is cut under contract to SNWLC.

1884 Choicest and most easily accessible lumber is cut over between Meeks and Rubicon bays; Dollar Point is logged under contract to CTLFC.

1885 Stands in Slaughter House Canyon are cutover by CTLFC; cutting ends around Tahoe Mt.; Gardner goes bankrupt and salvages railroad to CTLFC.

1885 C. W. Chubbuck begins railroad logging operations up Cold Creek (Lake Valley) under contract to the CTLFC.

1886 Chubbuck goes bankrupt and sells railroad in Lake Valley to CTLFC, to be incorporated into the LVRR.

1887 to 1897 CTLFC conducts large-scale cutting in Lake Valley with their LVRR and LVF.

Late 1880s to 1890 Stands in lower reaches of Logan House Creek are cut over by CTLFC.

1890 Logging up Blackwood Canyon conducted under contract to CTLFC; red fir is harvested near Stanford Rock.

Ca. 1890 CTLFC acquires 8,000 acres around Daggett Pass from SNWLC/NLC; subsequent logging by CTLFC is probable.

1897 SNWLC/NLC ends logging operations in the Tahoe basin; CTLFC/EDWLC shuts down their Glenbrook mills and end cutting in the Tahoe basin.

1898 The Lake Tahoe basin is stripped of marketable timber, and large-scale cutting ceases; logging railroads are salvaged, and capital and energy are funneled into a growing tourist industry; approximately two-thirds of all marketable timber in the Tahoe basin has been harvested by this time, with 60 percent of the Lake Tahoe watershed clearcut, remaining land is largely alpine, barren, or inaccessible.

1903 to 1907 TLC builds logging railroad up Ward Canyon and intensively logs area.

1910s A resurgence of logging commences after construction of FPPC mill in 1901; fir stands, ignored during Comstock-era lumbering, are targeted, especially those along Tahoe's north and northwest shores.

1912 to 1914 FPPC logs fir stands on TLC land in Burton Creek watershed (north of Tahoe City).

1911 to 1958 C. G. Celio & Sons operate local lumber mill, with cutting around Meyers.

1920s to 1927 Small shingle mill is established on Griff Creek.

1927 to 1933 Small saw mill operates on Burton Creek, cutting 240 surrounding acres.

1946 Small-scale logging by Placerville Lumber Company occurs in upper Trout Creek.

1947 Fibreboard logs lands near the mouth of Watson Creek (Carnelian Bay).

1960s Logging continues in the Tahoe basin (especially on private lands on the north shore) but on much reduced scale.

1980s to 1990s Modern logging is limited to fuelwood and saw log sales aimed at fire and vegetation management along Tahoe's north and south shores; stands on east shore are not reentered until insect salvage operations in the mid-1990s.

1990s Sustained drought subjects timber stands to severe insect attacks; by 1991 an estimated 300 million board feet of timber are dead or dying; salvage logging begins on the east, north, and southwest sides of the lake; thinning, prescribed burns, and mechanical brush treatments are implemented to reduce fuel loads and to restore forest health.

Fishing

1854 Washoe spear and net hundreds of trout in Lake Valley and try to prevent Euro-Americans from fishing; several Washoe place names incorporate the words "trout" or "whitefish" or "fish", suggesting their abundance and cultural importance.

1859 onset of commercial fishing on Lake Tahoe when the "Fishery" is established near the mouth of the Upper Truckee River.

1862 William W. Lapham's "Fish Market Landing" is established at Stateline; Burke and Company use a half-mile seine to take tons of Tahoe trout daily from the area between Bijou and Round Hill.

1863 W.H. Brewer, member of the California State Geological Survey, is amazed at the 20-30 pound trout in Lake Tahoe; Tahoe's is characterized as a "piscatorial bonanza" and until the 1920s, the size and abundance of Tahoe trout and fantastic catch records are consistently reported.

1864 Attempt to halt the wholesale slaughter of fish with the enactment of a law forbidding "whites" to take fish between 10/15 and 4/1, with open season fishing confined to hook and line; Washoe are immune to state laws and continue to fish as "fronts" for a growing commercial industry.

1868 Pringle and Hurley establish "Lake Fishery" hatchery at Tahoe City to exploit Tahoe's Lahontan cutthroat trout.

late 1860s Legislation is enacted by the

Nevada Territorial Legislature in an effort to control over-fishing and the pollution and obstruction of streams.

1870s Twenty-five commercial operators fish Tahoe; tons of Tahoe trout are shipped east and west out of Truckee in iced railroad cars.

1870s Additional legislation is enacted to control over-fishing and the pollution or obstruction of streams from logging and fluming activities.

1880s Non-native brook trout are planted in Marlette Lake and fish are used to stock surrounding alpine lakes; trout in Marlette Lake become so plentiful that suckers are planted to eat the eastern brook's spawn, after which time the suckers have to be removed; lumber mill ponds are used, not only to store logs, but to raise trout to meet the demands of sportsmen and commercial suppliers' more earnest attempts are made to legislate over-fishing and the pollution or obstruction of streams from logging and fluming activities.

1880 70,000 pounds of Tahoe trout are shipped by railroad; wagon loads weighing from one to two thousand pounds each are marketed on the Comstock.

1887 First planting in the region occurs as Gilmore Lake is planted with game fish.

1887 Mackinaw trout are introduced into Lake Tahoe, with subsequent plantings in the later 1880s and 1890s; with the extinction of Tahoe's Lahontan cutthroat trout, the Mackinaw will become the most important sport fish

1889 further regulatory legislation is passed to protect the fishery by prohibiting sawdust dumping.

1891-1893 Non-native brook trout are planted in Lake Tahoe.

1895 Mackinaw fingerlings are introduced into lakes above Meeks Bay.

1896-1910 A commercial fishing outfit bases out of Carnelian Bay.

1900 Even after logging, Upper Truckee River abounds with whitefish and remains a popular Washoe fishing stream.

1904 Eighty commercial fishing boats are operating on Tahoe.

1917 The California legislature bans commercial fishing at Tahoe to protect the endangered Lahontan cutthroat trout.

1920s Mackinaw trout have migrated down from the lakes above Meeks Bay and are now established in Lake Tahoe.

1922-1928 The extinction of Lake Tahoe's Lahontan cutthroat trout takes place during this period—extinction is a result of decades of over-fishing, habitat pollution, obstruction of spawning runs, and introduction of non-native species.

1938-1944 During this time the Pyramid Lake Lahontan cutthroat trout also becomes extinct; both Tahoe and Pyramid Lake strains of trout have survived in these lakes for over 10,000 years; both have become extinct in a matter of decades.

1944 Over 14 million non-native fish are planted in the lake from 1944 to about 1960; Kokanee salmon are introduced to Lake Tahoe; the Heenan Lake strain of Lahontan cutthroat trout are introduced annually in Taylor Creek and the Upper Truckee River from 1956 through 1964.

Water Management

1865 Alexis von Schmidt initiates the first major controversy over Tahoe water with his plans to supply San Francisco by diverting water down the Truckee River near Squaw Valley and via tunnel through the divide above the North Fork of the American River.

1870 To further his water scheme, Alexis von Schmidt acquires land at the lake's outlet and constructs a small dam.

1871 von Schmidt's scheme fails, as legal suits over Lake Tahoe water rights are threatened.

1876 To meet the growing needs of the Comstock, the VGHWC draws water from Marlette Lake; this water is flumed through Tahoe's eastern divide via tunnel and piped down to Virginia City; predecessor to PG&E constructs a tunnel through Tahoe's western divide and diverts the waters of Echo Lake into the American River Basin.

1877 VGHWC raises the level of Marlette Reservoir to 37 feet, doubling its capacity to supply water to Virginia City.

Ca. 1877 Construction of the North Flume by the VGHWC augments water supply to Virginia

City; the flume taps Third Creek and all intervening drainages in Tahoe's northeast quadrant, south to a tunnel through Tahoe's eastern divide on Tunnel Creek; the flume is in year round operation until ca. 1950s.

1880 Francis G. Newlands targets Lake Tahoe as part of a network of proposed reservoirs in the Sierra Nevada to serve future development in Nevada.

1887 A third parallel water pipe taps the waters of Marlette Lake to serve growing municipal and mining water needs of the Comstock; Nevada and Lake Tahoe Water and Manufacturing Company unsuccessfully propose a four-mile water diversion tunnel through the Carson Range to divert Tahoe water into the Carson Valley.

1900 Californians renew interest in capturing Lake Tahoe as a water supply; plans are stopped, not only by the formidable engineering requirements, but by strong opposition from Nevadans.

1901 James E. Church begins studies and measurements of snowpack water content on Mt. Rose's summit, thereby pioneering the science of snow surveying.

1902 Congress commits to the construction of irrigation projects in the west with the passage of the National Reclamation Act and creation of the USRS (later renamed USBOR).

1902 USRS opens negotiations for the purchase of the Lake Tahoe Dam at Tahoe City from the DBLC; downstream power companies have previously entered into purchase negotiations with the DBLC; TRGEC (predecessor to SPPC) buys the Lake Tahoe Dam including 54 acres of land surrounding the outlet and negotiates rates with four industrial consumers of water power downstream.

1907 (July 14-18) Lake Tahoe attains its highest recorded lake surface level at 6231.26 feet (11.00 feet MSL above its lowest recorded surface level of 6220.26 feet MSL, recorded on November 30, 1992).

1909 Tahoe lakeshore property owners oppose another unsuccessful tunnel scheme plans to take water eastward from Lake Tahoe and store it in a large reservoir to be constructed at Washoe Lake; flows would be diverted down Steamboat Creek (a tributary of the Truckee River) and water would be available to farmers in the lower Carson River Basin.

1912 during an extreme drought, an attempt by the USRS and the TRGEC to dredge the Truckee River channel at Tahoe City and cut down its rim is blocked by lakeshore property owners through a court injunction.

1913 The USRS and TRGEC replace the old rock-filled timber crib dam at Tahoe City (originally constructed by the DLBC in 1870) with a concrete slab and buttress structure containing 17 vertical gates; the new dam is located 400 feet downstream from the lake's natural rim.

1915 USRS assumes full control of the Lake Tahoe Dam, along with 14 acres of adjoining property at the outlet; all water rights, not appropriated by downstream power companies (up to the top four feet), are allocated to the federal government.

1919 The Truckee-Carson Irrigation Project is officially renamed the Newlands (Irrigation) Project, in honor of Nevada Senator Francis G. Newlands.

1924 Drought drives downstream farmers to persuade Lake Tahoe property owners to allow the lake to be pumped when it falls below its natural rim.

1928 The Truckee River Basin experiences the beginning of a severe drought; lasting from 1928 through 1935, this drought would not be exceeded in severity until the 1987-1994 drought.

1930 Drought-stricken downstream water interests start digging a diversion trench at Tahoe's rim (with plans to dynamite the dam itself) but are stopped by a court injunction obtained by Lake Tahoe property owners.

1935 The Truckee River Agreement for the conservation and control of the Truckee River drainage basin establishes conditions under which water can be taken from Lake Tahoe when it falls below its natural rim; water is to be stored in the top 6.1 feet (established at between 6223.0 to 6229.1 feet MSL), thereby creating a storage capacity of approximately 744,600 acre-feet.

1950s The North Flume, in operation on Tahoe's northeast shore since the 1870s, is abandoned; deep erosion scars created by flume

wash-outs are still clearly visible on Incline Mountain.

1954 The U.S. Army Corps of Engineers makes stream improvements on the Truckee River, enlarging the channel from the Lake Tahoe Dam downstream.

1959 Radiocarbon is used to measure algal primary productivity in Lake Tahoe and other aquatic ecosystems.

1964 Algal bioassay experiments are used to evaluate effect of nutrient pollution on Lake Tahoe.

1967 Warnings about accelerated eutrophication as the "Bad News from Lake Tahoe" written by Charles Goldman for the non-technical public in the publication, *Cry California*.

1968 A formal compact between Nevada and California guaranteed more than two-thirds of Tahoe's surplus water for large-scale development at the lake, with Nevada gaining surplus water for irrigation from the Truckee, Carson and Walker rivers; the compact ignored the rights of Pyramid Lake Paiute and threatened the ecological health of Pyramid Lake.

1969 Review of limnological and primary productivity studies at Lake Tahoe.

1970 Beginning of extensive series of studies on the distribution, production and ecology of crayfish in Lake Tahoe.

1971 Signing of the California-Nevada Interstate Compact allocates Lake Tahoe's waters and apportions Truckee River water between the two states; role of trace nutrients (e.g., iron) in limiting primary productivity are studied

1972 Ecophysiology of bacterial populations in Lake Tahoe stimulated by siltation; surface sediments on the bottom of the lake are characterized; deep living phytoplankton populations in the lake are first studied; the concept of the lake microcosm, an ecosystem out of balance, continues to be presented.

1973 First detailed investigation of optical properties and color of Lake Tahoe; report of lake mounds in Tahoe; remote sensing of sediment plumes from the Upper Truckee River; first linkage to saving Lake Tahoe and Lake Baikal; association between bacteria, fungi, the decomposition of organic matter and nutrient recycling in large, deep lakes is demonstrated.

1974 Publication of "Eutrophication of Lake Tahoe Emphasizing Water Quality" provides early example of applied and integrated limnological research.

1975 Primary productivity of Lake Tahoe's nearshore regions examined; public education regarding the danger signs for Tahoe's future as the decline in air and water quality continues; use of lake nitrate concentration as an indicator of deep mixing is first reported; the effects of kokanee salmon on stream ecology are considered; sewage effluent spraying near a south shore tributary are found in discharge flow to Lake Tahoe; long-term changes in the primary productivity of Lake Tahoe are brought to light; the first evidence for a significant change in Lake Tahoe's zooplankton structure following the introduction of the opossum shrimp, *Mysis relicta* is found.

1976 The influence of sediment inflow on phytoplankton primary productivity is observed; nitrogen fixation associated with terrestrial vegetation in Ward Valley is measured; nitrogen uptake and release in the Lake Tahoe basin forested watershed is studied.

1977 Tritium is used as a tracer to study lake mixing.

1978 Study of nutrient limitation using natural phytoplankton populations; trophic status and nutrient loading for Lake Tahoe is reviewed; the impact of kokanee and opossum shrimp introductions of Lake Tahoe biological ecology is assessed; an extensive series of projects on zooplankton ecology are initiated.

1979 Water and nutrient transport via groundwater from Ward Valley into Lake Tahoe are assessed; energy and water budgets for Lake Tahoe are developed; monograph is published on nutrient transport in surface runoff from the Ward Creek watershed.

1980 Detailed studies of attached algal growth along the shoreline of Lake Tahoe begin; evidence is found for algal heterotrophy and ecological implications for deep living phytoplankton; first LTIMP report is published.

1981 Chemical allelopathy is found in aquatic systems; two decades of change in Lake Tahoe are reviewed.

1982 Environmental factors affecting Lake

Tahoe zooplankton are studies; the importance of deep mixing to the nutrient budget of Lake Tahoe's surface waters is realized.

1983 Factors regulating stream water chemistry in subalpine environments are assessed, as are the role of deep mixing in internal nutrient loading and algal growth, the importance of atmospheric deposition in nutrient loading to lakes, and the role of benthic nitrogen fixation in Lake Tahoe.

1984 Recent sedimentation is associated with the fertility of Lake Tahoe; initial paleolimnological studies begin; zooplankter *Daphnia* returns to Lake Tahoe; the ecology of deep chlorophyll and patterns of precipitation, climate and primary productivity over decadal time scales are considered.

1985 Investigations of *Mysis* and zooplankton ecology and attached algal growth and distribution continue; long-term data sets are used in limnology.

1986 The first five years of LTIMP sampling and Lake Tahoe's response to long-term nutrient loading are reviewed.

1987 The dynamics of the deep chlorophyll layer in Lake Tahoe are studied; the urbanization of Lake Tahoe basin becomes a microcosm for the study of environmental change with continuing development.

1988 Food resources and zooplankton populations in Lake Tahoe are studied, along with the integrated analysis of the onset of cultural eutrophication on Lake Tahoe.

1989 The relationship between land-use and tributary water quality is assessed, as is the importance of meteorological forcing in explaining interannual fluctuations in primary production; studies of the Lake Tahoe fish community structure begins.

1990 Changes in phytoplankton community structure are recognized; deep mixing and annual productivity and forest fires, atmospheric deposition and primary productivity are related; the importance of long-term research in ecological management is emphasized.

1991 Increased precipitation acidity at Tahoe is detected; the 25-year history of mysids and lake trout of Lake Tahoe is reviewed; the ecology of the littoral zone fish community is studied.

1992 Studies concern the sources of variability in the primary productivity record at Lake Tahoe, the surface runoff water quality and the effects of BMPs, the use of wetlands for water treatment, and lake trout spawning in Tahoe.

1993 Nitrate transport is found in Tahoe tributaries; long-term change is documented in algal nutrient bioassay experiments; the linkage between the conservation of Lake Tahoe and Baikal is revisited.

1994 Long-term atmospheric deposition data is analyzed in relation to Tahoe's nutrient budget; the timing, distribution and abundance of kokanee spawning in a Lake Tahoe tributary is studied; the effects of shoreline structures are assessed in relation to the summer habitat use by littoral-zone fishes in Lake Tahoe; trophic interactions and population dynamics of lake trout and kokanee salmon are studied.

1995 Long-term changes in Lake Tahoe nutrient chemistry are analyzed.

1996 Spawning of shorezone fisheries and water quality impacts of marina dredging are investigated; the concept of a lake clarity model is introduced.

1997 Nutrient limitation becomes a determinant of watershed management strategy; phosphorous loading to Lake Tahoe from tributary inflow using LTIMP data base is analyzed and biologically available phosphorus is investigated.

1998 Water quality, watercraft use and ecotoxicology issues are integrated; a whole-lake nutrient budget with inputs and losses is developed; paleolimnological study of Lake Tahoe emphasizes land disturbance, changes in sedimentation and recovery.

1998 Bottom of Lake Tahoe is mapped by USGS (excluding the nearshore zone).

1999 Historical water clarity data from 1967-1996 are analyzed.

Grazing

Mid-1850s to 1860s Markets created by teamsters traveling through Lake Valley prompt the development of seasonal farming and ranching; meadowlands are quickly preempted (usually in units of 160 to 320 acres).

1860s During this early period most dairying and ranching co-occurs with budding

settlements in Lake Valley, Tahoe City, Kings Beach, Glenbrook, and Edgewood.

1860s to 1870s Sheep bands are moved from western foothills into the high Sierra over Tahoe's western divide into Glen Alpine, Meeks, McKinneys, and Blackwood creeks watersheds and over Tahoe's northern divide into the Tahoe City, Burton and Griff creeks watersheds.

1870s At least 13 commercial dairies are in operation, producing butter and milk for both local consumption and export; during the early Comstock era, commercial hay production reaches over 800 tons annually.

1900s to 1930s With the demise of logging, cut-over lands along Tahoe's south, north and east shores are sold to ranchers for grazing; lake lands generally support cattle; high meadows are used for sheep; bands are large, 1000 at a minimum, and most herds number an average of 1000 to 1500 ewes; the earliest recorded aspen carvings documenting Basque shepherds in the Tahoe basin date from 1899; most aspen art dates during the 1920s-1930s and into the 1950s, indicating grazing activities to be most intense during this period.

1900 Sudworth observes that sheep grazing occurs basin wide, with some areas denuded of grass and shrubs.

1930s Grazing in the Tahoe basin is restricted to allotments assigned to individual permittees in an effort to control overuse by regulating the timing and location of herds.

Time Line of Human Land Use and Environmental Conditions, Upper Truckee River/Trout/Saxon/Heavenly Valley Creeks Watersheds (Lake Valley) T12N/R18E

Paleoenvironmental Sites

Pollen Records: Osgood Swamp (Adam 1964a, 1964b, 1965a, 1965b, 1967, 1973, 1974); Meyers Grade Marsh and Grass Lake (Dorland 1980); Ralston Ridge (Sercelj and Adam 1975)

Recorded Archaeological Sites

63 prehistoric sites: Upper Truckee River = 46; Trout Creek = 12 ; Saxon Creek = 4; Heavenly Valley Creek = 1

70 historic sites; one railroad logging system totaling about 13 miles of grade and 16 miles of wagon haul roads and a two-mile V-flume; many miles of transportation routes

Native American Use

da'ow ("the lake")—Washoe place name for Lake Tahoe

mes a—Washoe place name for Lake Valley

Washoe camp one mile north of Meyers along the Upper Truckee River; minnows and suckers are caught here and bears are a problem; bedrock mortars in the vicinity.

Washoe camp is on west side of Upper Truckee River, west of Big Meadows; many fish traps are in the area.

gobiba—Washoe place name for Fountain Place (below Freel Peak); area is along prehistoric trail between Woodfords and Tahoe, up Willow Creek Canyon and down to Sierra House on Trout Creek.

mesuk wa't'a—Washoe place name for outlet of Echo Lake.

ImgiwO'tha (*Imgi* "cutthroat trout" *wO'tha* "river")—Washoe name for camp 200 yards east of Upper Truckee River and one mile from the lake.

mesuk malam—Washoe place name for Upper Truckee/Trout Creek delta (swamp).

t'sigohu w'at'a—name for Washoe camp on Trout Creek tributary near Sierra House (Cold Creek).

MathOcahuwO'tha (*mathOcauwa'* "white fish" *wO'tha* "river")—name for fall camp on Trout Creek to catch whitefish and collect ripening berries.

dew'ltelgking ("sound made pestles pounding in mortars")—name for Washoe encampment east of Highway 50 on Trout Creek (on the old Johnson Ranch).

The James, a Washoe family, live on Trout Creek; Ben James works for Tallac Resort as a caretaker and backcountry horse guide and tends dairy and beef cattle around Taylor Creek.

In the Washoe Claims Case, Washoe consultants rank the Upper Truckee drainage, inclusive of Washoe Meadows (golf course) and the Meyers vicinity, as the number one resource area; this is entirely consistent with other Washoe testimony. This and the Taylor Creek drainage and

extensive wetland and meadow system at the south shore are acknowledged by all sources as particularly valued resource areas, as major fisheries, and as an extensive array of plant resources. Richard Barrington, a prominent Washoe witness for assessing resources within the aboriginal territory for the Washoe Land Claim, states in 1963 that the south shore was particularly noted for "wild potatoes" and "onions" (George Wright Papers), a position reiterated by recent testimony.

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks the Upper Truckee River as the most valued fishery in the Tahoe basin, with Trout Creek being sixth (Bender 1963 in George Wright papers).

1854 Washoe spear and net hundreds of trout in Lake Valley and try to prevent Euro-Americans from fishing.

1901 Washoe camp in Lower Lake Valley; Washoe camp behind Rowland's Lake House near the Lake House Road (photograph).

Ca. 1900s Historic Washoe camp east of Bijou (photograph).

Early 1910s Lewis Fillmore, a Washoe, is employed by Knox Johnson as caretaker at Sierra House; One Wolf, also a Washoe, works at Sierra House as a handyman and woodcutter.

Early 20th Century Washoe fish abundant whitefish populations in Trout Creek; even after logging, Upper Truckee River abounds with whitefish and remains a popular Washoe fishing stream.

1940 With the growing populations in Lake Valley, Washoe discontinue using Trout Creek area altogether.

Prehistory and Washoe History

10,000 to 7000 BP (Early Holocene) Climates warm and dry rapidly, causing glaciers to melt and Lake Lahontan to shrink; oldest human occupation of Tahoe region dates from 8000 to 9000 BP, with the initial influx of people soon after glacial retreat; sparse Pre-Archaic and Early Archaic populations engage in a foraging economy based on high residential mobility and large game hunting.

7000 to 4000 BP (Mid-Holocene) Much warmer and dryer period; desiccation of many lakes in the western Great Basin; Lake Tahoe and Pyramid Lake decline but are the only ones that do not dry up; ancient drowned forests at Tahoe date from between 6300 and 4800 BP, and submerged stumps stand rooted on the lake's floor up to 20 feet below its surface; Tahoe waters also conceal submerged archaeological features and inundate prehistoric living sites; prehistoric populations increasingly exert their influence in altering the landscape and affecting fauna and flora through a gradual decrease in overall mobility, greater land use diversity, a broadened diet, and intensified use of plant resources.

4000 to 1300 BP (Late Holocene) Pollen data indicate a shift from more xeric vegetation to the dominant conifer species that are present today; the record appears to be punctuated by alternating intervals of cool-moist and warm-dry periods; intensive Middle Archaic use of the Tahoe Sierra begins during this period, as mixed-mode foragers-collectors venture into the highlands on seasonal gathering, fishing, and hunting forays.

1300 BP to Historic Contact The period is marked by an overall xeric trend, punctuated by cool-moist periods alternating with periods of severe drought; such extreme climatic fluctuations may have allowed for year-round residence in the Tahoe highlands at some times and prohibited even seasonal occupation at other times; prehistoric populations continue to rise, as reflected in more intensive use of all parts of the Tahoe environment; this time is equated with the Late Archaic prehistoric period and the ethnographic Washoe; Lake Tahoe assumes the physical center of Washoe territory and the spiritual center of the Washoe world.

1848 Even after Euro-American "encroachment" (the legal term the federal government used to describe the process by which the Washoe gradually lost their territory since ca. 1848), the Washoe continue to trek to the lake to harvest plant resources, fish, and later work as domestic laborers and game guides for resorts.

1877 Washoe leaders make formal protest to government officials (including the President of the United States), complaining of the destruction of

their lands, for which title has never been extinguished by treaty; futile petitions, demands, and trips to Washington continued to the present.

1887 After passage of the General Allotment Act of 1887, unclaimed 160-acre plots are granted to individual Washoe; the Washoe petition lands around Lake Tahoe, but none are granted.

1917 The federal government purchases small tracks of land for the Washoe near Reno and Carson City, upon which many Washoe are obliged to settle; this, along with the active abolishment of certain Washoe land use traditions by Indian agents, further discourage Washoe presence in the Tahoe basin.

1945 The name "Tahoe," a popular historic misnomer derived from the Washoe word *da'ow* and signifying "lake," becomes the official designation.

1950s The 1950s mark a period of focused protest by the Washoe, who register their objections to the nontraditional usage of spiritual locales and the despoliation of ancestral resources within the Tahoe basin; modern laws and intolerance by Tahoe residents drastically limit Washoe access to the basin; nevertheless, Tahoe remains a compelling element in Washoe consciousness, and they continued to visit the lake where possible.

1951 The Washoe Tribe initiates a land claims case for compensation of lost homelands in and around the Tahoe basin.

1970 The land claims case initiated by the Washoe Tribe in 1951 is settled, awarding them $5 million of the $42.3 million requested as compensation for their lost homeland, amounting to 10,000 square miles and including Lake Tahoe at its center.

1990 An exchange program between students and scientists working at Lake Tahoe and at Siberia's Lake Baikal (the largest and deepest freshwater lake in the world) is established; native peoples—the Washoe at Tahoe and the Buryat at Baikal—participate in the cultural exchange, with shared goals of reestablishing a presence on traditional lands.

1994 The Washoe Tribal Council develops a comprehensive land use plan that includes goals of reestablishing a presence within the Lake Tahoe basin and revitalizing Washoe heritage and cultural knowledge, including the harvest and care of traditional plant resources and the protection of traditional properties within the cultural landscape.

1997 (July) At the request of Nevada Senator Harry Reid in 1996, President Clinton convenes a federal conference on issues surrounding the environmental condition and degradation of Lake Tahoe; members of the Washoe Tribe are represented on a presidential panel at this environmental summit; President Clinton praises the Washoe for their long stewardship in the Tahoe basin; in turn, the Washoe Tribe asks that all people who now share, live upon, or use their ancestral resources in the coming decades be responsible guardians of these traditional lands, just as the Washoe have been for thousands of years.

1997 In the wake of Clinton's visit to Lake Tahoe, a landmark agreement is signed between the Washoe Tribe and the USFS to return the use of more than 400 acres of land within the Tahoe basin to the tribe under a special use permit; Clinton is the sixth president since 1877 that the Washoe have petitioned to return their lands for traditional use; the Washoe aim to actively demonstrate their philosophy on resource stewardship and land restoration at Lake Tahoe; these reacquired areas will be used to reinstate ancestral land management practices and to return Indian people to their ancient homeland for cultural renewal.

Transportation and Community Development

1848 John Calhoun "Cock-Eye" Johnson opens route over Echo Summit and through lower Lake Valley (Highway 50/Pioneer Trail/Highway 19/207).

1851 Martin Smith is first Euro-American settler in Lake Valley.

1852 Emigrants camp in Lake Valley.

1854 Asa Hershel Hawley homesteads 160 acres in Lake Valley and pioneers new route into upper Lake Valley.

Luther's Pass is surveyed and Hawley's Grade is improved, syphoning traffic into Upper Lake Valley (Highway 89).

1859 Yank's Station is established; other

way stations are soon built along the new road through lower Lake Valley (Highway 50/Pioneer Trail).

1860 Pony Express route is designated through Lake Valley over Echo Summit and Daggett Pass (Highway 50/Pioneer Trail/Highway 19/207); this route is heavily used by passenger and freight wagon traffic en route to the Comstock during the early 1860s.

1861 Post office is established in Lake Valley.

1863 The new Lake Bigler (Tahoe) Wagon Road channels the flow of travel over Echo Pass and through the Tahoe basin, away from Kingsbury Grade and over Spooner Summit (Highway 50); this route is heavily used by passenger and freight wagon traffic en route to the Comstock during the early 1870s.

1898 A fire starts near Meyers in September and sweeps up the mountains to the east.

1903 A fire southeast of Bijou burns for more than three weeks.

1923 to 1924 To provide basic water and power utilities for growing communities, Tahoe Electric Power Company appropriates surplus waters on Cold Creek and at Star Lake.

1924 Frank Globin's Al Tahoe Hotel and Water Company develop three settling ponds on Cold Creek.

1952 to 1956 Al Tahoe Hotel and Water Company builds Lake Christopher as a reservoir and stocks it with fish.

1930s Meyers, Al Tahoe, and Bijou subdivisions are thriving.

1936 CTLFC/EDWFC trade away 8,000 acres to Eldorado National Forest.

1940s Highway 50 over Echo Summit and Highway 89 from Truckee to Tahoe City are improved all-weather roads with year-round maintenance.

1945 Aram Harootunian offers 670 lots at Al Tahoe.

1950s Expanded gaming industry at the lake.

1956 Heavenly Valley Ski Resort opens.

1960 Squaw Valley Winter Olympics.

1960s New subdivision developments (Tahoe Paradise, Golden Bear, and Meadow Lakes).

Logging

1859 to 1870s Small-scale logging to supply lumber for local settlers and way stations.

1859 Pixley's Mill on Heavenly Valley Creek (T12N/R18E/S3).

1860 Woodburn's Mill on Trout Creek (T12N/R18E/S15), with a daily output of between 6,000 and 10,000 board feet.

1873 Woodburn acquires 560-acre timber tract around his mill (T12N/R18E/S15).

1874 CTLFC/EDWFC begin acquiring timber tracts in Lake Valley.

1877 EDWFC is assessed on 8360 acres in T12N/R18E.

Early 1880s CTLFC owns 5960 acres in T12N/R18E.

1883 to 1895 CTLFC acquires 3800 acres in T12N/R18E.

1884 G. W. Chubbuck acquires 1,200 acres of timber land near Bijou and logs land for EDWFC.

1885 Chubbuck constructs a four-mile logging railroad from the lake up Cold Creek (financed by CTLFC and later incorporated into LVRR).

1886 Initial operations on CTLFC's LVRR.

1887 CTLFC commences logging with LVRR; key archaeological features of the railroad logging system recorded within T12N/R18E include a 13-mile railroad fed by 16 miles of wagon haul roads and one two-mile V-flume, along with at least 28 railroad/wood camps; historic roads have since eroded into trenches up to six feet deep.

1888 Woodburn owns 2,200 acres surrounding his mill in T12N/R18E/S15.

1888 Peak year for CTLFC saw log/cordwood production in Lake Valley, with a total of 1,027,753 board feet (BF).

First year for production figures for LVRR at 159,000 BF (15 percent of over one million BF total lumber shipped by CTLFC); LVF constructed by CTLFC up Cold Creek; first year for production figures for LVF at 180,000 BF (18 percent of total BF of lumber shipped by CTLFC).

1888 and 1895 Woodburn sells 2,200 acres to CTLFC.

1889 126,000 BF production for LVRR operation (14 percent of CTLFC total BF lumber shipped); 80,000 BF production for LVF operation (nine percent of total lumber shipped by CTLFC).

1890 184,000 BF production for LVRR (44 percent of total lumber shipped by CTLFC); 53,000 BF production for LVF (13 percent of total lumber shipped by CTLFC).

CTLFC assessed on 4680 acres in T12N/R18E.

1889 to 1891 Years of most intensive timber harvest in Lake Valley.

1893 Major LVRR expansion in T12N/R18E.

EDWFC assessed on 9100 acres in T12N/R18E.

1897 T12N/R18E (and Lake Valley in general) completely cutover.

1898 LVRR torn up and recycled as tourist railroad between Truckee and Tahoe City (LTRTCRR).

1911 C. G. Celio & Sons operate local lumber mill at Meyers and conduct small-scale logging.

1912 CTLFC taxed on 5,040 acres in T12N/R18E.

1915 to 1917 Celio cuts 500,000 feet annually.

1946 Small-scale logging by Placerville Lumber Company in upper Trout Creek.

1958 Celio ceases lumbering operations.

1955 to 1970s Timber stands along Trout Creek, upper Saxon Creek, and around Meyers are reentered; logging occurs on a fairly small scale.

1980s to 1990s Modern logging limited to fuelwood and saw log sales aimed at fire and vegetation management; (A comparison of modern log scaling records in T12N/R18E and those from 1887 indicate that the 1887 forest was once composed of Jeffrey pine/sugar pine/cedar; the forest is now dominated by Jeffrey pine/lodgepole pine/white fir/cedar. Historic log diameters, once up to 52 inches, are now about 30 inches, with average diameters of historic stands being 26.4 inches and modern stands 14 to 16 inches.)

Fishing

1859 Commercial fishing on Lake Tahoe dates to 1859, when the fishery is established near the mouth of the Upper Truckee River.

Ranching/Grazing

Mid-1850s to 1860s Markets created by teamsters traveling through Lake Valley prompt the development of seasonal farming and ranching; meadowlands are quickly preempted (usually in units of 160 to 320 acres).

1862 In the summer and fall of 1862, 400 tons of hay are cut in Lake Valley's meadowland.

1870 The "California Products of Agriculture" census shows that 228 tons of hay have been baled in the Lake Valley Township.

1875 C. F. McGlashan notes in his "Resources and Wonders of Tahoe" that Lake Valley is still mainly a "hay and dairy producing center, dotted with fertile ranches" and that Lake Valley ranchers contribute most of the 800 tons of hay cut along Tahoe's shoreline in 1875.

1880 A period correspondent reports that "the valley affords pasturage for 1800 cows."

1880s to 1890s Bartons graze dairy cattle on Barton Meadows (along the east of the Upper Truckee River near the lakeshore).

1900 Harry O. Comstock and Melville Lawrence graze cattle on Robert Woodburn's cutover timber holdings along Trout Creek.

1908 Chris and Knox Johnson run cattle on large tracts in Lake Valley; Johnsons own about 1,200 acres around Bijou Meadows (entailing an area from the radio towers near the South Tahoe Public Utilities District emergency water retention basin, down to Bijou); they lease other lands within a radius of Bijou and Lake Christopher and Fountain Place and Meyers.

1908 to 1950s Johnsons, Lake Valley's pioneer irrigators, develop a ditch system and a series of small dams on Trout, Cold, and Heavenly Valley creeks and water Bijou and Trout meadows during the summer; ditches loose about 50 percent of their water through the porous granitic soils.

Late 1910s to 1930s CTLFC sells 4,940 acres of cutover land to local ranchers for grazing.

1912 EDWFC leases 2,446 acres to Comstock and Lawrence for grazing.

1914 Some of Comstock and Lawrence's lands are acquired by rancher, John C. Scott.

1915 to 1916 Dresslers first use High Meadows as summer sheep grazing range; herds are driven up from Carson Valley via Highway 19/207, Highway 50, Pioneer Trail, and USFS 21N21 and driven back via Mott Canyon; Dresslers have no herdsman, so sheep wander onto adjoining grazing lands; subsequent owners of this land, the Trimmers, hold tighter controls on their herds.

1919 Scott acquires additional grazing land from the CTLFC in 1919; Scott also purchases Hiram Barton's holdings.

1922 and 1926 Bartons acquire grazing land from the CTLFC.

1922 Chris Johnson owns 2,470 acres of land; Knox Johnson's holdings total 1,167 acres.

1928 John E. Dunlap operates a diary ranch on a 1,600-acre tract of land purchased from the CTLFC on the west side of the Upper Truckee River floodplain in what is now Gardner (Tahoe) Mountain, Tahoe Island Park, Tahoe Keys, and Tamarack Subdivision.

1929 to 1933 Johnsons acquire additional grazing lands from the CTLFC; they lease other grazing lands from the CTLFC, which are later exchanged to Eldorado National Forest.

Time Line of Human Use and Environmental Conditions, Emerald Bay/Cascade and Fallen Leaf Lakes/Taylor Creeks Watersheds

Recorded Archaeological Sites

33 prehistoric sites: Emerald Bay = 1; Tallac Creek = 2; Taylor Creek = 30

30 historic sites; one railroad logging system, with six to 10 miles of grade and associated wagon haul roads and skids; a few miles of transportation routes

Native American Use

Washoe camp across the highway from Camp Richardson; the area contains a Washoe burial ground and bedrock mortars; camp abandoned ca 1940.

Washoe camp (bedrock mortars) on the beach at Tallac.

daugacacuwO'tha ("clear water river")—name for Washoe camp along Taylor Creek for spring/summer trout fishing and the collection of birds eggs in Taylor Creek Marsh.

Washoe camp (bedrock mortar) on west side of mid reaches of Taylor Creek.

dawgasa siw da'ow—Washoe place name for Fallen Leaf Lake.

debelelelek ("reddened or smeared red")—Washoe place name for "Little" Tallac Creek (where spiritual being was killed).

dEyEli'bukhwOnhw—Washoe fishing site at the mouth of Cascade Creek.

salita s ("sunshine coming in")—Washoe place name for Emerald Bay.

hoga da'ow—Washoe place name for Cascade Lake.

hoga or *dahoga ma'lam wa't'a*—Washoe place name for Cascade Creek.

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks Taylor Creek as the third most valued fishery in the Tahoe basin (Bender 1963 in George Wright papers).

The Taylor Creek drainage and extensive wetland and meadow system at the south shore are acknowledged by all sources as particularly valued resource areas and as major fisheries and for an extensive array of plant resources. Richard Barrington, a prominent Washoe witness for assessing resources within the aboriginal territory for the Washoe Land Claim, states in 1963 that the south shore was particularly noted for "wild potatoes" and "onions" (George Wright Papers), a position reiterated by recent testimony.

Transportation and Community Development

(Access to the area is primarily by boat until the completion of a road encircling the lake in 1925.)

1880s Emerald Bay is daily excursion spot for tourists.

1884 to 1947 Emerald Bay Resort (small-scale) developed.

1928 Mrs. L. J. Knight builds Vikingsholm.

1880 "Glen Alpine Tonic Water" commercially bottled and distributed statewide.

Logging

1872 M. C. Gardner acquires large timber holdings between Camp Richardson and Tahoe Mt.

1875 Gardner contracts to provide 60 million feet of logs to CTLFC and constructs a railroad.

1883 Gardner expands his logging railroad from six to 10 miles.

1885 Cutting ends around Tahoe Mt.; Gardner goes bankrupt and sells abandoned railroad to CTLFC as salvage.

Fishing

1887 Gilmore Lake is planted with game fish by Nathan Gilmore (first planting in the region).

1890s Tallac Fish Hatchery established at Baldwin Beach (mouth of Taylor Creek).

Grazing

1860s to 1870s Nathan B. Gilmore drives sheep from Placerville to summer pasturage at Glen Alpine.

Time Line of Human Land Use and Environmental Conditions, Meeks Creek Watershed/Meeks and Rubicon Bays

Recorded Archaeological Sites

6 prehistoric sites: Meeks Bay = 3; Rubicon Bay = 3

4 historic sites; no linear features

Native American Use

mugaulu'wO'tha—name for Washoe fish camp on Lonely Gulch; trout runs are brief and Washoe protect themselves and their catch from bears.

ma'yalawO'tha—name for Washoe midsummer camp on Meeks Creek below Highway 89 bridge to catch fish and gather berries and seeds; Meeks Creek known as a mineral springs; Washoe move their summer camps from Meeks Creek to McKinney Creek early 1900s.

wO'thanamIna—name for Washoe camp in Rubicon Bay (Paradise Flat).

ta gi—Washoe place name for Rubicon Creek.

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks Meeks Creek as the eighth most valued fishery in the Tahoe basin (Bender 1963 in George Wright papers).

Transportation and Community Development

(Access to the area is primarily by boat; access by road is limited until the completion of a road encircling the lake in 1925.)

1919 G. V. Kehlet develops Meeks Bay as a campground resort.

Logging

1878 Meeks Bay is the hub of CTLFC west shore logging and rafting operations centered around Sugar Pine Point, Meeks Canyon, and Rubicon Bay.

1884 The choicest and most easily accessible lumber is cutover.

Grazing

1862 Meeks and Company cut 25 tons of wild hay.

1878 G. T. and J. A. Murphy graze milk cows on the meadow.

1884 to 1919 Murphy Brothers expand their grazing operations and acquire 640 acres of cutover land from CTLFC and run dairy and beef cattle in Meeks Meadow for the next 35 years.

Time Line of Human Land Use and Environmental Conditions McKinney Creek Watershed (Homewood/Chambers/Sugar Pine PT)

Recorded Archaeological Sites

2 prehistoric sites: McKinney Creek = 1; Sugar Pine Point = 1

Native American Use

malka—Washoe place name for Homewood Canyon.

duku dawata ("loud creek, river")—Washoe place name for Madden Creek.

Washoe camp at Rubicon (mineral) Springs during their acorn trek westward.

dukhmI'ImwO'tha—name for Washoe fish camp on General Creek.

cu'wE'thUkhwO'tha (*cu'wE'thUkh* [service berry] *wO'tha* "river")—camp on McKinney Creek for fishing and collecting medicinal plants.

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks McKinney Creek as the seventh most valued fishery in the Tahoe basin, with General Creek at Sugar Pine Point being the ninth place holder (Bender 1963 in George Wright papers).

Transportation and Community Development

(Access to the area is primarily by boat; road access is limited until the completion of a road encircling the lake in 1925.)

1850s Georgetown-Lake Bigler Trail up McKinney Creek to Rubicon Springs and over divide to Georgetown.

1862 J. McKinney first settles here.

1860s McKinney's is the terminus of the trail from Georgetown, California; from here, travelers cross Lake Tahoe to Glenbrook Bay and proceed east to Virginia City.

1863 McKinney's Hunters Retreat is established, along with vegetable garden and dairy.

1887 Bellevue Hotel is built at Sugar Pine Point.

1894 Moana Villa Hotel is constructed at Homewood.

1910s Hotel Homewood is built at Homewood.

Logging

1867 to 1877 Agustus Colwell preempts 900 acres of timberland fronting on McKinney Bay (McKinney Creek south to Sugar Pine Point) and builds steam-powered saw mill; he leaves shoreline timber, instead cutting the southwest slopes of McKinney Creek Canyon, then east over the mountains toward Meeks Bay.

1875 to 1877 Colwell contracts for CTLFC on McKinney Creek and engages in small-scale cutting of most easily accessible timber stands.

1878 Nat Stein, Michele Spooner, and George W. Wiggins log Sugar Pine Point (probably under contract to CTLFC).

Early 1880s CTLFC booms 60,000 feet of sugar pine each week from Sugar Pine Point area.

1881 CTLFC plans to set up "Chinese Wood-Choppers" at Sugar Pine Point.

Grazing

1862 Burton and Company cut 75 tons of wild hay from a narrow strip flanking McKinney Creek.

Time Line of Human Land Use and Environmental Conditions, Blackwood Creek Watershed

Recorded Archaeological Sites

1 prehistoric site; (multiple bedrock mortar sites west of Barker Pass)

2 historic sites; no linear features

Native American Use

dawma lim ti yel ("large confluence")—Washoe place name for Blackwood Creek; Washoe camp is on the south side of a small hill north of Blackwood Creek; Washoe trap ground squirrels and marmots, gather berries and wild rhubarb, and fish; major trail up Blackwood Canyon to Georgetown.

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks Blackwood Creek as the second most valued fishery in the Tahoe basin (Bender 1963 in George Wright papers).

1860s H. C. Blackwood shoots a Washoe for setting a fish trap on creek.

Transportation and Community Development

(Access to the area is primarily by boat; road access is limited until the completion of a road encircling the lake in 1925.)

1880 McConnels run small resort ("Idlewild").

Logging

1880 Yerington et al. (i.e., CTLFC) purchase land at mouth of Blackwood Creek.

1890 Logger Winnie Smith runs two-mile long log chute up to Stanford Rock to harvest red fir

stand; logs are rafted to CTLFC's Glenbrook Mill.

Grazing

1863 H. C. Blackwood runs stock in the meadow.

1860s W. S. Cothrin pastures sheep in the back country.

1873 George Conners runs a sheep camp in the upper reaches of Blackwood Creek.

Time Line of Human Land Use and Environmental Conditions, Ward Creek Watershed

Recorded Archaeological Sites

12 prehistoric sites

4 historic sites; one four-mile railroad logging grade

Native American Use

daugaica—name for Washoe camp in the upper reaches of Ward Creek; "a few acorn trees grew here"; Washoe fish camp at the outlet of Ward Creek; bedrock mortar located farther upstream.

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks Ward Creek as the fourth most valued fishery in the Tahoe basin (Bender 1963 in George Wright papers).

Transportation and Community Development

(Access to the area is primarily by boat; road access is limited until the completion of a road encircling the lake in 1925.)

1961 Small-scale home site development in association with Alpine Meadows Ski Area.

Logging

1863-1870s Augustus and Rube Saxton Mill at mouth of canyon; small-scale cutting is all the way to Twin Peaks.

1877 Todman cuts on small-scale under contract for CTLFC.

1877 Giant forest fire destroys choice timber near the mill.

1903 to 1907 TLC builds logging railroad up Ward Canyon and more intensively logs area.

Grazing

1910 to 1940 watershed is grazed.

1920s to 1930s Most intense period of grazing in the headwaters.

Time Line of Human Land Use and Environmental Conditions Truckee River (Tahoe City)

Recorded Archaeological Sites

2 prehistoric sites

1 historic site

Native American Use

daubayOdu'E' ("running over")—Washoe camp on the hill overlooking the outlet; they fish and collect grasshoppers and swallow eggs at nearby Swallow's Cave.

Transportation and Community Development

1852 to 1855 Placer County Emigrant Road is established through the Truckee River Canyon and along Tahoe's north shore (Highway 89/Highway 28).

1860 Tahoe Truckee Toll Road is constructed through Truckee River Canyon (Highway 89).

1861 First log cabin built.

1863 Tahoe City townsite laid out.

1868 Tahoe City becomes official townsite and resort community.

1880s Tourism flourishes and resorts expand.

1901 Construction of LTRTCRR connecting Truckee and Tahoe City.

1901 to 1964 Tahoe Tavern operates as a major tourist landmark.

1924 Bittencourt Subdivision built.

1946 Fairway Subdivision built.

1947 Bunker Subdivision built.

1952 Lake Terrace Subdivision built.

Logging

1880 Tahoe City is a "medium large" logging camp.

1882 Logging contractor, Nat Stein, relocates his logging camp to Tahoe City.

Ca 1880s Davis and Notewares shingle mill is established.

1900 to 1909 TLC logs its lands, which are now accessible by the LTRTCRR.

1912 to 1914 FPPC contracts to log fir on 2,120 acres in Placer County belonging to the TLC (north of Tahoe City and belonging to the TLC).

Fishing

1868 Pringle and Hurley establish Lake Fishery hatchery at Tahoe City; they experiment with the introduction of nonnative species.

Grazing

1862 Wild timothy hay is harvested from meadows surrounding Tahoe City

Time Line of Human Land Use and Environmental Conditions, Burton Creek Watershed (Lake Forest)

Recorded Archaeological Sites

4 pre historic sites

2 historic sites within the watershed; few miles of transportation routes

Native American Use

wO'thanamIn—Washoe camp at mouth of Burton Creek where whitefish are taken and grasshoppers and tree-dwelling worms are collected in nearby meadows; the whitefish run here is earlier than on Trout Creek.

diphEhkwO'tha (*diphEkh* "white paint" *wO'tha* "river")—Washoe camp near the mouth of Burton Creek where they obtain fish, berries, and sunflower seeds.

Transportation and Community Development

1852 to 1855 Placer County Emigrant Road is established along Tahoe's north shore (Highway 28).

1859 Initial settlement and early tourist center at Burton's Island Farm (Lake Forest); vegetables are cultivated and timothy hay is harvested.

1863 35 tons of timothy hay are harvested at Burton Creek Meadows.

1930s Commercial development of Lake Forest.

Logging

1912 to 1914 FPPC contracts to log fir on 2,120 acres in Placer County belonging to the TLC; (A field inventory sample of historic cut stumps on a 10-acre plot within a 100 percent fir stand in the upper reaches of Burton Creek disclosed 17.4 stumps/acre with a 35-inch average diameter and a maximum diameter of 55 inches.)

1927 to 1933 R. H. Watson operates small sawmill on Burton Creek at half a million board feet annually; Watson cut second growth stands on 240 surrounding acres.

1992 USFS Twin Crags timber sale.

Grazing

1880s to 1910 Dairy operations in Antone Meadows.

Time Line of Human Land Use and Environmental Conditions Watson Creek Watershed (Carnelian Bay)

Recorded Archaeological Sites

29 prehistoric sites: National Register Prehistoric Watson Creek Basalt Quarry District = 28; Carnelian Canyon Creek = 1

15 historic sites; several miles of transportation routes

Native American Use

masundauwO'tha (*masun* "slow" *wO'tha* "river")—Washoe camp on Watson Creek, up from the lake; groups might spend a whole summer to fish, hunt ground squirrels and marmots, and gather several kinds of seeds, mushrooms, locusts, and berries.

Transportation and Community Development

1852 to 1855 Placer County Emigrant Road established along Tahoe's north shore (Highway 28).

1873 Dr. Bourne's Hygienic Health Resort established.

1876 Settlement established at Carnelian Bay.

1880s James Cleland acquires Dr. Bourne's resort (71 acres in T16N/R17E/S22) and grows vegetables and bales timothy hay on meadowlands bordering Carnelian Canyon Creek.

1910 First subdivision established.

Logging

1874 CTLFC begins acquiring timber tracks.

1884 A. W. Pray, R. Saxton and J. Lubeck log Dollar Point (probably under contract to CTLFC).

1947 Fibreboard Products Inc. log T16N/R17E/S17,20,W_21.

1989 USFS Watson timber sale.

Fishing

1896 to 1910 Flick Brothers acquire Carnelian Bay land fronting the water and fish commercially.

Time Line of Human Land Use and Environmental Conditions, Griff Creek Watershed (Tahoe Vista/Kings Beach/Brockway)

Recorded Archaeological Sites

9 prehistoric sites within watershed: Griff Creek = 6; Tahoe Vista = 2; Brockway = 1

9 historic sites; several miles of transportation and logging roads

Native American Use

gumlE'phEl wO'tha—Washoe camp on Griff Creek; Washoe prohibited from placing fish traps.

lo om ("hot springs")—Washoe place name for Brockway Springs.

Transportation and Community Development

1852 to 1855 Placer County Emigrant Road (Highway 28) along north shore.

1869 Truckee-Hot Springs Road (Highway 267) between Truckee and Brockway.

Agate Bay

Early 1860s Temporary settlement to supply trout and wild hay to mining camps in Martis Valley.

1881 H. E. Casey (and others) logging under contract to CTLFC and SNWLC.

Tahoe Vista

1865 Pine Grove Station established by a wood contractor.

1880s Marine camp for saw log shipments to SNWLC at Sand Harbor; cordwood camp and shingle mill locale.

1911 Casino/hotel established.

1914 First subdivision built.

Kings Beach

1864 Wiggins Station established by wood contractor as a logging camp and small mill community.

1925 Begin era of subdivisions.

Brockway

1869 Brockway Hot Springs Resort.

1920s Casino/club/golf course added to resort; subdividing begins.

Crystal Bay

1927 Subdivision/casino development.

1960s The casino "Sinatra Years" and a boost to local economy.

Logging

Ca. 1864 Davis and Scott Shingle Mill near SR 28/Highway 267 intersection.

1864 to 1872 George W. Wiggins Shingle Mill established (with Nat Stein) near SR 28/Highway 267 intersection.

1865 D. W. Wright cordwood camp at Tahoe Vista.

1872 John Griffins Saw Mill at Kings Beach.

1878 Initial cutting by wood contractors for CTLFC.

1880s Steam-powered shingle mill at Tahoe Vista; Tahoe Vista marine terminal for saw logs cut on Martis Peak under contract with SNWLC.

1881 H. E. Casey saw log and cordwood contract with SNWLC; logs rafted from Agate Bay to Sand Harbor.

(A field inventory sample of historic cut stumps from three 10- to 15-acre plots in Tahoe Vista disclosed average stump diameters of 38.5, 33, and 32.1 inches, maximum stump diameters of 66, 66, and 46 inches, average stump densities of 7.9, 5.6 and 2.5 per acre and a species composition of pine [76 percent, 76 percent and 72 percent), cedar (four

percent, 24 percent and 14 percent) and fir (four percent, zero percent and 14 percent], respectively.)

1920s to 1927 Roy Andrews cedar shake/shingle saw mill on East Branch Griff Creek; ice harvested on log ponds; mill is also a front for illegal boot-leg operations.

1960s Logging by Fibreboard Corp in Martis Peak/Brockway area.

1992 USFS Brockway timber sale.

Ranching/Grazing

1860s to 1930 Local dairy business flourishes on large scale in the upper reaches of Griff Creek.

1862 William Wallace and Lambo Company harvest 25 tons of wild hay near SR 28/Highway 267 intersection; water is diverted from Griff Creek for irrigation.

Time Line of Human Land Use and Environmental Conditions, First/Second/Third/Incline/Mill Creeks Watersheds T16N/R18E

Recorded Archaeological Sites

41 prehistoric sites: First Creek = 2; Second Creek = 1; Third/Incline Creeks = 39

41 historic sites; five-mile logging railroad and many miles of associated wagon haul roads and flumes, including the eight-mile long North Flume

Native American Use

ma'goiyatwO'tha—Washoe camp near mouth of Incline Creek for collecting berries.

wa aba am ("plunging into water")—Washoe place name for Third Creek.

Recent interviews have provided information about the value of Third Creek to families from the Reno area and is ranked fifth out of ten streams by Washoe. Third Creek once watered an extensive wet meadowland, similar to south shore (Bender 1963 in George Wright Papers).

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks Incline/Third Creek as the fifth most valued fishery in the Tahoe basin (Bender 1963 in George Wright papers).

(Given the late period subdivision development, Washoe traditionalists continue to harvest plants around Incline Village up until the last several decades.)

Transportation and Community Development

1852 to 1855 Placer County Emigrant Road (SR 28) along north shore.

1891 First continuous road over Mt. Rose Pass connecting Reno area and Lake Tahoe ("The Road to Incline"/SR 27/SR 431).

1929 Highway 28 route between Spooner Summit and Incline is graded.

1930s George Whittell acquires a continuous strip of property from the Bliss and Hobart estates that stretches from Crystal Bay south to Zephyr Cove.

1932 Grading of SR 27 between Incline and Mt. Rose Pass.

1950 to 1960 Construction of SR 431 (replacing SR 27).

1959 9,000 acres of the Whittell estate are sold to Crystal Bay Development Company as Incline Village.

1968 Crystal Bay Development sells Incline Village to Boise Cascade Corporation.

1973 After limited logging, Boise Cascade lands are acquired by Incline Village General Improvement District for subsequent development.

Logging

1876-1898 Overall large-scale cutting, with intensive cutting lasting half that long.

1878 Initial cutting by SNWLC probably commences about one mile north of Crystal Bay.

1879 to 1894 SNWLC Incline Mill operates at 75,000 feet a day.

1880 SNWLC builds a 4,000-foot tramway at its Incline mill; at the top, wood is dumped into a V-flume (built originally by the VGHWC) and carried through a tunnel down to Washoe Valley to a storage yard served by the VTRR; a steamer rafts logs from timber holdings in Tahoe's southeast shore to Sand Harbor, where logs are loaded onto a logging railroad bound for the mill.

1881 to 1890 Most intense period of timber harvest and engineering for water supply and wood transport.

1889 SNWLC initial cut is 8 million feet of lumber and 50,000 cords of fuel wood.

1881 to 1885 SNWLC peak cordwood production in Washoe County.

1887 Incline Mill produces a peak cut of 12 million feet of lumber.

1883 43,000 acres of SNWLC land in the Tahoe basin are stripped of trees.

1890 to 1891 SNWLC peak operations close down.

1894 Last major logging season for SNWLC.

Late 1960s to Early 1970s Limited logging around Incline by Boise Cascade.

(A field inventory sample of historic cut stumps from a 60-acre plot on Third Creek disclosed 0.7 stumps/acre of fir and pine, with an average diameter of 33 inches; a 60-acre sample along First Creek produced 1.4 stumps/acre of mostly pine, with an average diameter of 27 inches; maximum stump diameters in both samples are 56 inches.)

Grazing

1910s to 1950s With demise of logging, cutover lands are converted to grazing.

Water Management

1875 VGHWC raises Marlette Dam to 37 feet, forming a lake 1 3/4 miles long by 3/4 mile wide, containing 2,000 million gallons of water and doubling its capacity to supply water to Virginia City.

1877 In partnership with the SNWLC, the VGHWC constructs a 4.38-mile box flume northward from Marlette Lake Dam to the West Portal of the tunnel into the Carson Range divide; water supplies Virginia City.

Ca. 1877 Construction of the North Flume by the VGHWC to supply water to Virginia City; flume tapped waters of Third Creek and all intervening drainages south to the tunnel on Tunnel Creek; flume was in year-round operation until ca. 1950s.

1939 VGHWC deeds five inches of water from the North Flume to Norman Biltz at Incline Lake.

1944 Major washout of the diversion works along the North Flume.

1950s North Flume is abandoned.

1959 Curtis-Wright Co. raises the Marlette dam to 52 feet, increasing the lake's storage capacity to 3.4 billion gallons (10,400 acre feet of water).

Time Line of Human Land Use and Environmental Conditions, Marlette and Spooner Lakes/Glenbrook, Logan House, and Lincoln Creeks Watersheds

Paleoenvironmental Sites

Pollen Record: Little Valley (Wigand and Rhode, in progress)

Recorded Archaeological Sites

32 prehistoric sites: Marlette = 14; Secret Harbor = 2; Skunk Harbor = 1; N. Canyon = 1; Spooner Meadows = 11; Glenbrook Creek = 2; Cave Rock = 1

92 historic sites center around a nine-mile logging railroad and comprise more than 60 miles of wagon haul roads and skids, over 20 miles of flumes and associated reservoirs, about 75 wood camps, and several saw mills; many miles of emigrant and freight toll roads

Native American Use

dawmaladup solno ("fog on top")—Washoe place name for Spooner Summit.

damalili da aw—Washoe place name for Marlette Lake, on old trail crosses over the mountains from Little Valley to Incline.

Washoe camp is at Sand Harbor.

phagathsami—Washoe fishing camp is on Marlette Creek.

dawma lim demse fil—Washoe place name for Secret Harbor Creek.

daumaladuphwO'tha—main Washoe camp at Glenbrook; from here they walk up to Slaughterhouse Creek to fish and down toward South Point to gather berries; Washoe live here even after Euro-Americans settle.

suina—Washoe camp on south side of Glenbrook Creek.

dE'Ekwadapoc ("standing gray rock")—Cave Rock is a Washoe cultural landmark that is

respected, feared, and avoided by most Washoe, except spiritual practioners.

Washoe fish camp on unnamed creek draining into Zephyr Cove.

Out of a list of the 10 most desirable watersheds in descending order of resource value, Washoe testimony from the Washoe Land Claims Case ranks Glenbrook Creek as the tenth most valued fishery in the Tahoe basin (Bender 1963 in George Wright papers).

Transportation and Community Development

1852 to 1854 Carson Emigrant Ridge Road over Spooner Summit (Highway 50).

1860 A. W. Pray et al. settles on Glenbrook Bay.

1861 Community at Glenbrook Bay is established at Walton's Landing; it is considered the east shore over-water terminus for the toll pack trail leading from Georgetown, California, to Upson Bay (McKinney's) on Tahoe; travelers proceed eastward to Virginia City.

1862 Rufus Walton Toll Road from Glenbrook over Spooner Summit (Highway 50).

1863 Lake Bigler (Tahoe) Toll Road channels flow of travel out of Tahoe basin over Spooner Summit (Highway 50); hotel/way station established along Lake Tahoe Wagon Road at Zephyr Cove (Highway 50); Michele Spooner and Company establish Spooner Station at Spooner Summit (Highway 50/Highway 28 intersection).

1865 Rilla Ranch occupies present day Marlette Lake.

1866 Glen Brook House is constructed, and the enduring role of Glenbrook as a hostelry and tourist resort begins; Telegraph office is established at Glenbrook.

1860s to 1870s Period of most intensive use of travel corridor by freight and stage wagons (Highway 50).

1914 to 1915 Route over Spooner Summit is designated as the Lincoln Highway (the nation's first transcontinental highway); entrance of automobile era.

1925 Lincoln Highway is incorporated into Highway 50.

1929 Highway 28 route between Spooner Summit and Incline is graded.

Late 1930s White Hill Ski Area (Spooner Summit) offers a T-bar lift; the ski area's life is short-lived by a lack of snow and the opening of Heavenly Valley Ski Area in 1956.

1930s George Whittell acquires a continuous strip of property (45,000 acres) from the Bliss and Hobart estates that stretches from Crystal Bay south to Zephyr Cove.

1976 Glenbrook Inn closes.

Late 1970s Bliss family sells Glenbrook property for the private Glenbrook subdivision.

Logging

1861 Small-scale lumbering and fluming operations begin at Glenbrook by Agustus W. Pray and the Lake Bigler Lumber Company; initial operation produce 10,000 board feet a day and shingles; Samuel Clemens (Mark Twain) stakes a timber claim nearby then watches as it goes up in smoke after his unattended campfire goes out of control.

1861 to 1873 Timbered lands west of Spooner Summit are worked by a number of small-scale logging and fluming enterprises.

1863 Spooner and Carl operate shingle mill between Spooner Summit and Glenbrook.

1866 Pray et al. incorporate as the Lake Tahoe & Empire Flume Company and build a 14-mile flume.

John and Thomas Elliot construct a sawmill near Spooner's Summit.

1868 Summit Fluming Company is incorporated by the Elliot Brothers et al.

1868 to 1873 CTLFC begins acquisition from small-scale independent operators of timber ranches and fluming companies on Tahoe's east central shore, acquiring 50,000 acres of timberland by 1873.

Late 1860s The Summit Fluming Company constructs first dam to form Marlette Lake; (the original Marlette Basin was a meadow).

Ca. 1868 to 1873 Wetlands in Spooner Meadow are dammed to form Spooner Lake, with accompanying ditch diversions into and away from the reservoir.

1870 Oliver Lockie and Company acquire a 400-acre timber ranch at Spooner Summit; they establish cordwood and saw log camps and run

shingle mill and saw mill; A. W. Pray logs Zephyr Cove and rafts sawlogs to his Glenbrook mill.

1871 Marlette Lake covers 500-600 acres.

1873 CTLFC commences large-scale cutting; large wood receiving and sending lumber yard is established at Spooner Summit at the head of the Clear Creek Flume, which floats lumber and cordwood down to storage yards on the VTRR spur near Carson City; CTLFC raises dam at Marlette Lake to 24 feet

Ca. 1873 CTLFC constructs South Wood Camp to Spooner Summit V-Flume; CTLFC expands old Summit Flume to now run 6.4 miles from South Camp Peak to the receiving ponds at Summit Summit; several splash ponds, dams, and holding ponds are constructed along the route; fluming operations are facilitated by a network of access roads and the establishment of a main wood camp near the beginning of the South Wood Camp V-Flume; wood camp is closed in 1894; CTLFC constructs Marlette Lake to Spooner Summit V-Flume; CTLFC expands flume (originally build in 1870 by the Summit Fluming Company between Marlette Lake and Spooner Summit) to now run 8.6 miles; flume is used to augment water supplies on Spooner Summit, float cordwood, and supply water to the flume complex within Secret Harbor Creek drainage; CTLFC constructs North Canyon to Spooner Summit/Station U-Flume; originally constructed in 1863 to supply water to the Spooner and Carl Shingle Mill, CTLFC expands this flume into a system of four parallel flumes about 40 to 50 vertical feet apart in the vicinity of Spooner Summit' CTLFC constructs Summit Ponds, three small reservoirs at Spooner Summit, to collect surplus water from converging flumes and augment the flow in the Clear Creek Flume; CTLFC constructs the Secret Harbor Creek V-Flume, a flume complex of six cordwood V-flumes, water-carrying U-flumes, and ditches that tap Secret Harbor Creek.

1876 G. W. Chubbuck subcontracts to supply cordwood from Zephyr Cove to Pray; Largest CTLFC cut at Glenbrook mills is recorded in this year.

1877 Year of CTLFC's peak harvest for east shore operations.

1879 CTLFC cutting around Spooner Summit is phased out; one of the first telephone systems in the west is installed between Glenbrook and Carson City.

Mid- to Late 1870s Estimated dates of logging from dendrochronological sampling of remnant historic cut stumps and green trees disclose that Spooner Summit (White Hill) and the upper reaches of Glenbrook Creek and Montreal Canyon Creek (T14N/R18E/S13) are cut by the mid- to late 1870s.

Mid-1880s Estimated dates of logging from dendrochronological sampling of remnant historic cut stumps and green trees disclose that most stands on South Camp Peak and the upper reaches of Logan House, North Logan House, and Lincoln creeks are logged in the mid-1880s.

1885 Estimated dates of logging from dendrochronological sampling of remnant historic cut stumps and green trees disclose that Slaughter House Canyon is logged ca. 1885.

Late 1880s to 1890 Estimated dates of logging from dendrochronological sampling of remnant historic cut stumps and green trees disclose that stands along the lower reaches of Logan House Creek are logged in the late 1880s and in 1890.

1890s CTLFC acquires Zephyr Cove from Hobart Estate (SNWLC).

1892 CTLFC abandons North Wood Camp.

1894 CTLFC abandons South Wood Camp.

1897 CTLFC shuts down Glenbrook mills.

1950s Isolated pockets of timber are cut southwest of Marlette Lake.

Fishing

1880s Nonnative trout are planted in Marlette Lake, and fish are used to stock surrounding alpine lakes; trout in Marlette Lake become so plentiful that suckers are planted to eat the eastern brook's spawn, after which time the suckers have to be removed.

Ranching/Grazing

1860 A. W. Pray et al. harvest wild hay and plant grain and vegetables in Glenbrook meadow with a yield of 60 bushels of wheat and four tons of timothy hay per acre; the native hay crop is so profuse that a horse-drawn reaper is needed to harvest it.

1900s to 1930s The earliest recorded aspen carvings documenting Basque shepherds in the Tahoe basin date from 1899 and are found in Secret Harbor drainage; most aspen art dates during the 1920s to 1930s and into the 1950s, indicating grazing activities on the east shore to be most intense during this period.

Time Line of Human Land Use and Environmental Conditions, McFaul/Burke/Edgewood Creeks Watersheds (Kingsbury)

Recorded Archaeological Sites

12 prehistoric sites: Marla Bay = 1; Elk Point = 1; Burke Creek = 2; Edgewood Creek = 8

33 historic sites; many miles of log haul/skid roads

Native American Use

atabi samat ("fish swimming through, fish passage")—Washoe place name for McFaul Creek.

lamwO'tha (*lam*, [bedrock] mortar; *wO'tha*, river)—Washoe camp near Edgewood Creek; noted for fishing and [service] berries, two kinds of roots and a grass seed.

Washoe camp near Burke Creek (contains a bedrock mortar).

Washoe camp (with bedrock mortar) on the lakeshore west of Stateline.

Transportation and Community Development

1860 Friday's Station established as Pony Express stop.

1860 to 1861 Pony Express route up Kingsbury Grade (Highway 207).

1922 Resort established at Marla Bay.

1931 Legalization of gaming in Nevada.

1938 Zephyr Cove becomes part of southern extent of George Whittell extensive east shore holdings.

1940s to 1950s Increase in gaming houses/hotels/restaurants around Stateline.

1956 Heavenly Ski Resort opens; expansion occurs after the 1960 Winter Olympics at Squaw Valley.

1959 Kingsbury Grade (Highway19/207) is paved over Daggett Pass.

Logging

1860s to Early 1870s Establishment of small, independent timber ranches and wood lots around Edgewood.

1870s EDWFC initiates large land acquisitions around Daggett Pass (including the Summit Mill).

1871 Establishment of steam-powered sawmill up the canyon toward Daggett Pass.

1872 to 1879 SNWLC/NLC purchase about 8,000 acres, with the intent of large-scale logging in 1880; CTLFC acquires this land in 1890.

1880 EDWFC lands are cutover by 1880.

1884 McFaul cuts cordwood around Edgewood.

1889 Under contract with the SNWLC, G. N. Folsom cuts 520-acre timber track between the foot of Kingsbury Grade to Daggett Pass; saw logs are rafted to Sand Harbor; a shingle mill is constructed up the canyon; Folsom bases his operations out of the logging settlement of Hobart (near Round Hill).

1890 CTLFC acquires all of SNWLC/NLC 8,000 acres (subsequent logging by CTLFC is probable).

1893 Folsom increases his timber holdings to 610 acres; lumbering activity at Hobart is at its peak.

1896 Folsom's southeast shore operations are reduced to cordwood cutting.

1897 Cutting ceases in the area.

1939 EDWFC lands are purchased for back taxes and sold to the Clover Valley Lumber Company in 1940; the company conveys the land to George Whittell in 1941.

1949 to 1954 Timber pockets north of Kingsbury Grade are logged by Placerville Lumber Company.

Fishing

1862 William W. Lapham's "Fish Market Landing" is established at Stateline; Burke and Company use a half-mile seine to take tons of Tahoe trout daily from the area between Bijou and Round Hill.

Ranching/Grazing

1860s to 1890s Meadows between Edgewood and Zephyr Cover are grazed.

1864 Timothy hay is harvested at Marla Bay.

1876 G. W. Chubbuck cuts timothy grass at Zephyr Cove.

1884 McFaul pastures dairy cows.

1898 Robert L. Bence leases meadowlands in Folsom's former holdings and runs dairy cattle. Meadows are purchased by Park family (Park Cattle Company) and grazed until recent decades.

Mid-1900s Chris Rabe purchases meadows and farms/ranches the area.

Ca. 1960s Meadows are still used as cattle range.

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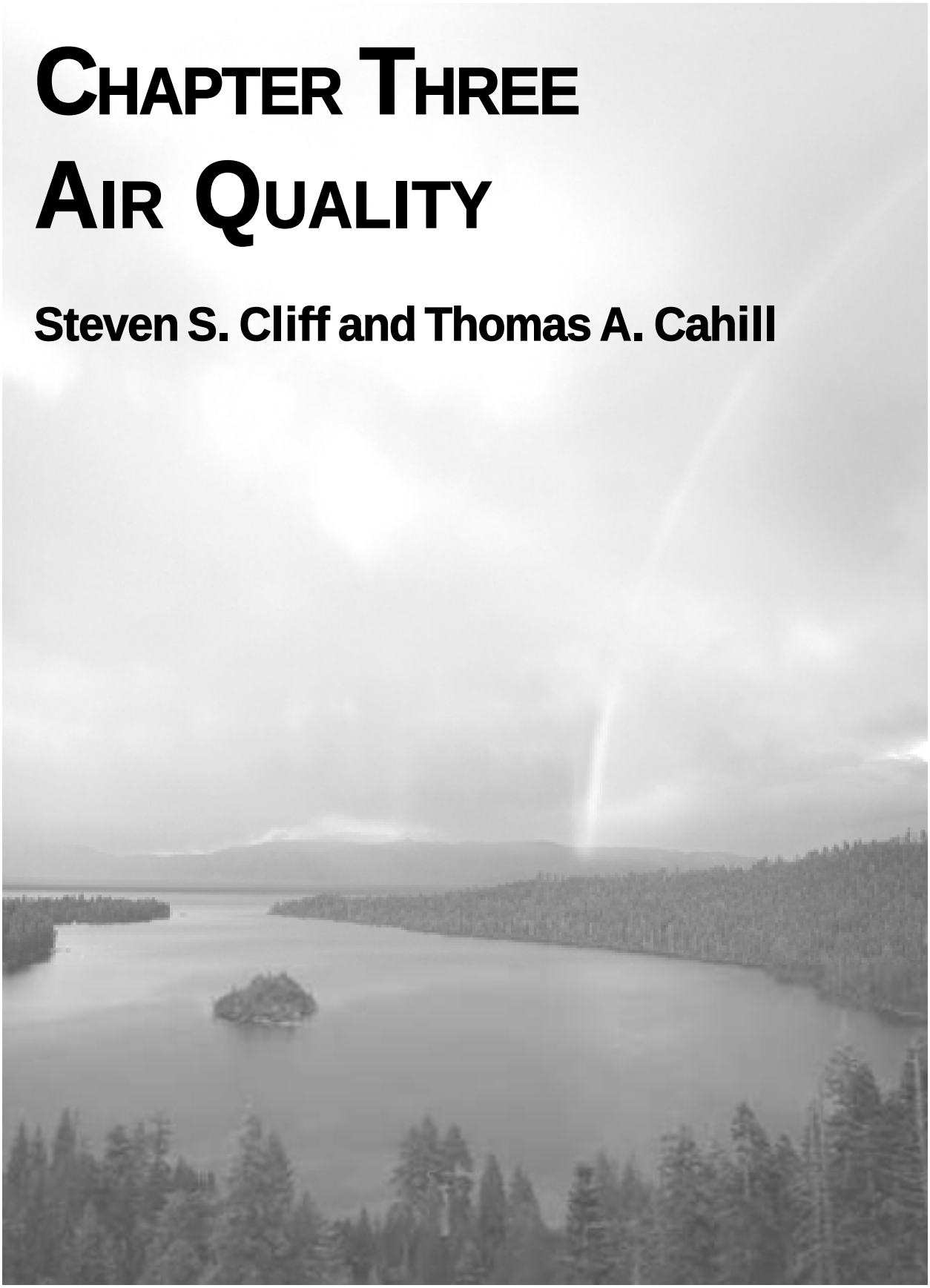
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CHAPTER THREE
AIR QUALITY

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CHAPTER THREE

AIR QUALITY

Steven S. Cliff and Thomas A. Cahill

Introduction

Lake Tahoe resides in a high elevation basin separated from the Sacramento Valley by the dominant Sierra Nevada divide along the Crystal Range. Lower ridges of the Carson Range to the east separate the lake from the Great Basin. These physical attributes define atmospheric processes in the Tahoe basin as much as define hydrological processes. The presence of the cold lake at the bottom of the Tahoe basin determines an atmospheric regime that, in the absence of strong synoptic weather systems, develops very strong, shallow subsidence and radiation inversions at all times throughout the year. In addition, the rapid radiation cooling at night generates gentle but predictable downslope winds each night, moving from the ridgetops down over the developed areas at the edge of the lake and out over the lake itself. Local pollutants within this basin are trapped by inversions, which occur almost nightly in the summer and between storms during the winter, greatly limiting the volume of air into which they can be mixed. This condition then allows pollutants to build up to elevated concentrations. Downslope winds each night move local pollutants from developed areas around the periphery of the lake out over the lake, increasing the opportunity for these pollutants to deposit into the lake itself. This meteorological regime of weak or calm winds and a strong inversion is the most common atmospheric pattern at all times of the year (Cahill et al. 1989, 1997).

The location of Lake Tahoe directly to the east of the crest of the Sierra Nevada Mountains creates the second most common meteorological regime, that of transport from the Sacramento Valley into the Lake Tahoe basin by mountain upslope winds. This pattern develops when the western slopes of the Sierra Nevada are heated, causing the air to rise in a chimney effect and move upslope to the Sierra crest and over into the basin. The strength of this pattern depends on the amount of heating, thus is strongest in summer, beginning in April and essentially ceasing in late October (Cahill et al. 1997). This upslope transport pattern is strengthened and becomes even more frequent by the alignment of the Sierra Nevada range across the prevailing westerlies common at this latitude, which combine with the terrain winds to force air up and over the Sierra Nevada from upwind sources in the Sacramento Valley.

Other meteorological regimes at Lake Tahoe are defined by strong synoptic patterns that overcome the dominant terrain-defined meteorological regimes of local inversions, nighttime downslope winds, and valley transport. These include winter storm regimes that bring almost all the precipitation received by the basin, mostly in the form of snow. Winter storms have strong vertical mixing, diluting local and upwind pollutants to low levels while bringing in air from the very clean North Pacific sector, accounting for the fact that snowfall within the basin has a relatively low concentration of anthropogenic pollutants, such as nitrates and sulfates (Laird et al. 1986; Cahill et al. 1997). Another important pattern is associated with the basin and range lows that during the summer circulate moisture in from the east, often forming thunderstorms along the Sierra crest. In addition, strong high pressure patterns north and northwest of Lake Tahoe can bring strong dry winds across the basin at almost any time of the year.

Each of these meteorological regimes has a potential for concentrating anthropogenic pollutants within the basin. The inversion-based basin trapping collects local sources, such as vehicular, urban, and forest burning emissions. Furthermore, these inversions, even if weak, limit the air into which

pollutants can be mixed, thereby raising them to significant levels. Transport of pollutants from the Sacramento Valley increases concentrations of both ozone and fine particulates, such as sulfates, nitrates, and smoke, from industrial, urban, vehicular, agricultural, and forest sources in western slopes of the Sierra Nevada, Sacramento Valley, and the San Francisco Bay Area. In the winter, the basin is decoupled from the Sacramento Valley but participates in the synoptic winter storms, generally from the North Pacific, which bring most of the precipitation into the watershed in the form of snow but along generally clean transport trajectories. The basin and range lows bring in air from a very clean sector of the arid west as do the Northwest highs with their strong dry winds (Malm et al. 1994).

Historical Conditions

Natural lightning fires and fires set by the Washoe people produced smoke in the Lake Tahoe basin in historic times. The analyses of Tahoe basin fire return frequency of the Sierra Nevada Ecosystem Project (Cahill 1996) indicate a fire return frequency of roughly 30 $\pm$ 10 years, resulting in roughly three percent of the basin being burned each year; less frequently on the western side, more frequently on the eastern side. This results in fires covering on the average approximately 25 acres per day every day during a fire period from May through October. However, this is also the time of the year that strong upslope mountain winds clean out the basin each afternoon, so that the smoke was not carried over day to day.

Even in the absence of smoke from fires, some haze would have been present, as the sun volatilizes light-scattering terpene aerosols from the forest during the summer. The logging associated with the Comstock Era also undoubtedly resulted in smoke from fires and steam engines (Elliott-Fisk et al. 1997). However, other than wood smoke and natural aerosols, there was little to affect air quality in the basin until the urbanization of the last forty to fifty years.

In the 1960s, human population levels increased and more people began to live in the Lake Tahoe basin year-round. Single-family housing units in particular rose from only a few thousand in 1950 to many tens of thousands today, each requiring soil disturbance for construction, support services, and road access, wood for fireplaces, and all the necessities of habitation. Urbanization and the various and widespread basin recreational opportunities generated substantial vehicular traffic. Human occupants of the surrounding mountain landscapes and those of the basin led to inputs from wood-fueled stoves, dust, and other particulates from upwind and in-basin areas. As early as 1963, a team of expert scientists studying the water resource problems of Lake Tahoe for the Lake Tahoe Area Council (LTAC) said that atmospheric deposition of the algal nutrients phosphorus and nitrogen should be considered a major component of the lake's nutrient budget (McGauhey et al. 1963).

In 1972, a spot check of carbon monoxide and fine particulate (i.e., automotive) lead showed high values in the city of South Lake Tahoe. In response, a study was undertaken in the summer of 1973 by the California Air Resources Board (CARB) at 10 sites around the lake and nearby (CARB 1974). The results confirmed the earlier study, showing levels that reached or surpassed those seen in many cities for primary automotive pollutants (Cahill et al. 1995). This study resulted in the Lake Tahoe basin being designated as a separate air basin by both California and Nevada, with very stringent standards on carbon monoxide (because of the high elevation) and on visibility (because of the scenery). Regular monitoring of pollutants commenced at South Lake Tahoe in 1976, along with studies by the UC Davis Air Quality Group (AQG) in (Cahill et al. 1977). The AQG studies and work by the CARB clarified the nature of the inversions and basin transport. The AQG performed the first analysis of the fraction of pollutants transported into the basin (ozone, sulfates) versus local anthropogenic sources (carbon monoxide, nitrogen dioxide, lead, most coarse particles) and natural sources (half of the methane, other hydrocarbons). With the CARB monitoring, these studies documented dramatic levels of pollutants that occurred in winter under strong

inversions at both the southern and northern ends of the lake.

In 1978, the US Environmental Protection Agency (EPA) designated portions of the Lake Tahoe air basin as a nonattainment area for carbon monoxide. Meanwhile, residential development added many new homes during the 1970s. The popularity of wood heaters, coupled with the availability of inexpensive firewood, increased wood smoke emissions dramatically during cold weather months. In 1979, scientists from EPA's Las Vegas laboratory conducted sophisticated measurements of visual range in the Lake Tahoe basin and established a baseline condition that still is used today. As the concern for environmental quality, clean air, and clean water grew both nationally and in the Lake Tahoe basin, many pointed to the automobile as the source of the Lake Tahoe basin's air quality concerns. References to smog at Lake Tahoe caused by high levels of traffic inside and outside the basin were common in the literature of the time, and automobiles and wood smoke continue to dominate air quality concerns (Elliott-Fisk et al. 1997).

In the late 1980s analysis of particles in the air improved dramatically after TRPA installed two state-of-the-art particulate samplers, identical to those used in the IMPROVE network of EPA and the National Park Service, under contract with AQG. Optical equipment (cameras and devices that measure light scattering and absorption) at the particulate sampling stations gave scientists the ability to look simultaneously at particulate matter and its impact on visual range. Based on CARB sampling (CARB 1974) and Rice's studies (1988, 1990), sites were chosen at D. L. Bliss State Park near Emerald bay to represent materials coming across the mountains from the Sacramento Valley and at South Lake Tahoe, to represent local in-basin sources. As with the earlier studies, the Bliss site represents the average pollutant levels present across the entire air basin, on which are superimposed the local pollutant sources from urbanized areas around the lake, especially at the northern and southern ends. When the two concentrations are the same, then pollutants can assume to be transported from outside the basin. This situation is the case for fine sulfates. The difference between the Bliss data and the South Lake Tahoe data then represents local contributions to pollution.

While great progress was made with analysis of particles in the atmosphere and their effect on visibility, relatively little progress was made on understanding gaseous pollutants, other than trend data at the sole CARB monitoring site in South Lake Tahoe. Thus, most of the data on gasses around Lake Tahoe must be derived from the summer 1973 CARB studies scaled to trend data from South Lake Tahoe. Nevertheless, these trend data have proven very important in resolving questions of atmospheric inputs to degrading lake clarity, in that they show a steady decline in ambient nitrogenous gasses NO, NO_2, and NO_x.

Current Status of and Trends in Air Quality at Lake Tahoe

The current status of air quality at Lake Tahoe is, by most urban standards, very good to excellent. Few if any violations of state and federal air quality standards for gasses and particles have occurred in many years (Section 3.7.3). The problem with this is that Lake Tahoe is a unique and scenic location with a nutrient-sensitive lake that makes up much of the high elevation basin, which is not a typical urban condition. For this reason, Lake Tahoe was made into its own air basin by California and Nevada in the 1970s and was provided with air quality standards better suited to this unique site. These new standards included a reduction in the California CO standard from 9 parts per million (ppm) to 6 ppm, in recognition of the increased importance of CO to human respiration at high altitude. New standards also included increasing the California visibility standard from 10 miles (16 km) to 30 miles (48 km). The visibility standard then was matched by Nevada. Additional basin-specific standards were enacted in response to the 1981 EPA basin carrying capacity analysis, including CO reductions and visibility thresholds.

Gaseous pollutant data from Lake Tahoe are largely derived from the CARB summer 1973 profiles and the CARB monitoring site, 1977 to the present, in South Lake Tahoe (SLT). The pollutants

for which data are available include carbon monoxide (CO), which is a primary pollutant derived from vehicular and combustion sources (two SLT sites), nitric oxide (NO), which is a primary pollutant derived from vehicular and combustion sources, nitrogen dioxide (NO_2), which is NO modified by atmospheric oxidation, and oxides of nitrogen (NO_x), which include both NO and NO_2, hydrocarbons, methane (CH_4), derived from natural and combustion sources, nonmethane hydrocarbons (NMHC) from both natural and automotive sources (CH_4 and NMHC available from the 1973 study only), ozone (O_3) which is a secondary product of NMHC, NO_x, and sunlight, and sulfur dioxide (SO_2), a primary combustion product (for which some data exist from 1977 on). The analyses of University of California Davis (CARB 1979-1994) and all subsequent work indicate that all of these pollutants are overwhelming anthropogenic and local in origin, with the exceptions of methane (which is half natural, half local anthropogenic) and ozone (which is > 90 percent transported from anthropogenic upwind sources).

All of these pollutants are presently well below state, federal, and basin air quality standards, and all except ozone continue to decrease based on improved fuels and vehicular engines (CARB 1999). The steady increase in ozone at Lake Tahoe from 1977 to the present is unique in all of California. For all other urban sites with 20 years of data, ozone has declined. The result is that ozone is rising to levels close to the state and the proposed new federal standard, which is presently on hold due to court rulings. It is also close to levels at which chronic ozone damage to vegetation could become more serious than the present light to moderate injury levels (Cahill et al. 1997).

Ozone concentrations are highest during the summer, when sunlight drives the chemical processes that create ozone from airborne hydrocarbons and oxides of nitrogen. Two factors puzzled scientists. First, the Lake Tahoe basin's highest ozone concentrations were observed in the late afternoon, early evening, and at night, but not closer to solar noon when one would expect them. Second, despite a decrease in emissions of oxides of nitrogen in the basin (again, a result of the cleaner vehicles), ozone concentrations did not decrease. These two factors led air pollution experts to suggest that ozone was, in fact, being transported into the basin from upwind areas (Cahill et al. 1977). Although the basin generated its share of biogenic and anthropogenic ozone precursors, the resulting ozone was probably appearing somewhere downwind in Nevada.

The particulate pollutants for which data exist were derived from the CARB study of 1973, UCD/CARB studies in 1977 and 1979, data from the CARB South Lake Tahoe site 1977 to the present, and the intensive TRPA particulate monitoring at SLT and Bliss State Park (BLIS), 1988 to the present. The latter two together are designated TRPA. Data exist for several pollutants, including total suspended particulate (TSP) mass of particles below 30 micrometers diameter (from 1973 CARB and SLT 1977 to 1987), inhalable particulate matter (PM_{10}) mass (from 1977 to the present, SLT and 1988 to the present, TRPA), and fine particulate ($PM_{2.5}$) mass (from UCD/CARB 1977 and 1979 and 1988 to the present, TRPA). The mass is made up of the following major constituents (roughly in order of importance):

Organics	OC	Organic carbon (1988 to the present, TRPA);
Sulfates	SO_4	Sulfates, generally ammonium sulfate (UCD/CARB 1977, 1979; 1988 to the present, TRPA);
Soil	Soil	Crustal soil-derived particles, especially coarse modes (UCD/CARB 1977, 1979; 1988 to the present, TRPA)
Nitrates	NO_3	Nitrates, generally ammonium nitrate, (1988 to the present, TRPA). Note: also gaseous nitric acid under certain conditions (unmeasured).

The mass includes minor and trace constituents useful in identifying sources. While there are scores for these, the most important include the following:

Lead	Pb	Primary automotive emission (1973 CARB; UCD/CARB 1977, 1979; CARB SLT 1977 to the present; TRPA, 1988 to the present);
Biomass smoke	Knon	Tracer of wood and grass smoke, derived from fine potassium (UCD/CARB 1977, 1979; TRPA, 1988 to the present);
Zinc	Zn	Urban effluent from combustion (UCD/CARB 1977, 1979; TRPA, 1988 to the present);
Selenium	Se	Selenium from industrial combustion of sulfur containing fuels (coal, oil) (TRPA, 1988 to the present).

By 1994, TRPA air monitoring had clearly defined the ratio of local-to-transported particulate matter and had coupled it closely to visibility degradation (Molenar et al. 1994). In the summer, roughly half of the $PM_{2.5}$ particles are of local origin, and half are transported from upwind sources on the western slopes of the Sierra Nevada, the Sacramento Valley, and the San Francisco Bay Area. In the winter, most of the particulate pollutants are local.

Effects of Air Pollutants at Lake Tahoe

The uniqueness of Lake Tahoe naturally leads to complexity in air quality concerns relative to typical urban air basins. These complexities often allow one to lose sight of the sweeping general concepts into which the detailed concerns are imbedded.

Air quality is adequate when it does not materially degrade the Lake Tahoe ecosystem, including its human component. Thus, what may be considered good air quality in many monitored locations may be disastrous at Lake Tahoe. To aid in maintaining perspective, air quality questions can be summarized as follows:

- Does air quality limit how far one can see through the air?
- Does air quality limit how deep can one see into the lake?
- Is air quality adequate to protect the forest?
- Is air quality adequate to protect human health?

Each of these questions is designed to address a particular set of ecological and societal values of Lake Tahoe, and the loss of which would degrade the entire system. To see this, consider the hypothetical consequences if the answers to the above questions turn out to be affirmative:

- If visibility is poor, one of the world's great scenes is degraded, and tourists go elsewhere.
- If the lake is cloudy and mats of algae float on it, the ecosystem is degraded and tourism suffers.
- If the forests are devastated by ozone damage and they are full of dying trees, the scene is degraded and the chance for catastrophic fires increases.
- If people who come to Lake Tahoe suffer from carbon monoxide or ozone and high fine particle impacts that make breathing difficult, visitors will stop coming, and local residents will suffer.

Visibility

Visibility reduction is dominated by fine particulate mass. In 1991, TRPA reported that the five major constituents of visibility-reducing aerosols in the basin were, in order of their mass, organic carbon, water (bound to particles, especially sulfates and nitrates), soil, ammonium sulfate, and ammonium nitrate. The air samplers collected small concentrations of industrial metals, which are indicators of industrial sources that are not present in the basin (TRPA 1991). The findings were expanded and published (Molenar et al. 1994) and showed that for both regional (lakewide) and subregional (South Lake Tahoe), the visibility has steadily degraded.

The regional visibility is dominated by transport from upwind sources, especially organic matter (smoke), sulfates, and nitrates. The largest

concentrations of these components occur in the summer, when long-range transport conditions are most likely. Ammonium sulfate is an industrial emission pollutant, with only minor sources (diesel, fuel oil combustion) in the Lake Tahoe basin. Ammonium nitrate (mostly from automobiles, generally upwind of the basin in summer and local in winter) represents only six percent of the fine particulate mass. From these measurements, scientists have been able to draw two conclusions: long-range transport of pollutants from distant urban and industrial sources is definitely occurring, and automobile exhaust is only a small contributor to haze and diminished visual range in the basin.

The local visibility degradation is dominated by wood smoke, with nitrates and fine soil particles contributing especially in winter. These local urban plumes appear to extend a few miles over the lake, carried on the weak downslope winds each night.

Contribution of Airborne Pollutants to the Decline in Lake Clarity

In the 1980s, those working to understand water quality trends in Lake Tahoe took a renewed interest in airborne algal nutrients (especially phosphorus and nitrogen). Since the 1963 LTAC study (McGauhey et al. 1963), airborne nitrogen and phosphorus compounds have been recognized as significant components of Lake Tahoe's nutrient budget. Studies of deposition elsewhere in the country (e.g., the Great Lakes) gave added impetus to this idea, as did the nation's interest in acid rain and deposition of nitric and sulfuric acids. Airborne substances undoubtedly play a role in Lake Tahoe's water quality dynamics, but what role exactly is unclear at this time.

In 1981 and 1982, the staff and consultants working on TRPA's threshold standards contacted air quality experts throughout the country and asked what loading rate, in kilograms per hectare per year, of nitric acid one might expect to see in the Sierra Nevada. Based on the responses, they estimated an annual dissolved inorganic nitrogen (DIN) load to the surface of Lake Tahoe on the same order of magnitude as the loads coming from surface streams and ground water inputs. This conclusion, even without monitoring data to confirm it, influenced the development of TRPA's threshold standards and subsequent regional plan. It caused TRPA to look beyond erosion and runoff control as methods to control cultural eutrophication and to shed light on the sources, distribution, and impacts of airborne pollutants.

In the years following TRPAs nutrient budget study, both water quality and air quality specialists attempted to measure or model nitrogen and phosphorus inputs to Lake Tahoe, with variable and sometimes contradictory results. In 1985, a vital record of nitrate and phosphorus deposition was initiated by the Tahoe Research Group at two sites in the Ward Valley and throughout the basin, including the lake itself (Jassby et al. 1994). However, because deposition is literally a molecular-level phenomenon, monitoring it directly is difficult. Spatial variation in meteorology within the basin, especially over the lake itself, complicates attempts to measure dry-weather and wet-weather deposition.

In 1990 expert testimony in the case of Kelly v. TRPA, summarized what was known about the atmospheric deposition of nutrients to Lake Tahoe. This testimony proposed that the decline in the lake's water quality was not primarily due to atmospheric inputs, because the dominant nitrogenous species over the lake, NO_2, had been declining for 20 years as the lake got worse (Section 3.7.4, 1d). Particulate nitrogen from upwind areas appeared to be less important. With abundant nitrogen in the system from various ecosystem sources, phosphorus is now the limiting influence on aquatic productivity (see Chapter 4). Soils, especially disturbed soils (e.g., along road cuts), appear to be the largest source of phosphorous, with smoke from wood stoves, agricultural burning, and other combustion potentially being important sources of phosphorus.

Impacts of Air Pollutants on Forest and Human Health

The major documented impact of air pollution of the Sierra Nevada forest is ozone on Jeffery pines (Cahill et al. 1996b). Data from this phenomenon were used to develop a threshold ozone concentration below which damage to the Jeffery pine was minimal. This threshold was based

on concentration multiplied by hours above 0.09 ppm. This level of O_3 is rarely reached at Lake Tahoe presently but will be routinely violated in 10 years if present trends continue.

Surveys of ozone injury to forests in the Lake Tahoe basin (Pedersen 1989) showed only light to moderate impacts, but the characteristic ozone mottle was and is clearly evident, especially on high foliage in the tallest trees. Ozone damage ages the trees, reducing productivity through premature aging of the pine needles, reducing sap flow, and making the tree vulnerable to drought, insect attack, and other stress factors.

The primary impact of Lake Tahoe air pollutants on human health used to be the relatively high carbon monoxide levels of the 1970s. Carbon monoxide concentrations have since been greatly reduced. At present, the high $PM_{2.5}$ levels in the winter in urbanized areas is the major concern. However, a recent study for the American Lung Association (Cahill et al. 1998) showed low impacts on cardio-pulmonary and stroke markers at Lake Tahoe. This same study showed a statistical association with particulate pollutants and ischemic heart disease in other sites in California.

Link Between Science and Policy for the Benefit of Lake and Watershed Management

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

Indeed, serious concerns regarding ecological condition and long-term environmental protection underscore the need to provide the highest quality science to aid in problem resolution at Lake Tahoe. Ecosystem health, sustainable environment, and watershed management are interrelated and are part of the growing view that the fabric of the natural landscape is a complex weave of interacting influences, including physical, chemical, and biological factors. Time after time, valid scientific data, with unbiased interpretation, have provided decision-makers in the Tahoe basin with valuable information and insight. For this reason the Lake Tahoe Watershed Assessment is important to provide a sound scientific foundation to inform the ongoing policy and management dialogue.

A critical component for long-term planning at Lake Tahoe is an air quality model based on the terrain and meteorological setting, local and regional pollutant sources, and the removal mechanisms of deposition and transport out of the basin. This model is important because data on air quality are deficient due to limited measurements in space, time, and component, with large areas of the basin totally unrepresented by data of any sort at any time. Through a heuristic model, these limited measurements can be combined with other data (such as traffic volume changes over time, upwind source profiles, urban patterns of growth, and parallel data from similar sites) to provide a comprehensive model for the basin. Though limited in overall predictive ability owing to the limited data set, this heuristic modeling approach maximizes the ability to predict pollutants, hence to evaluate changes made in human use patterns. Without such a comprehensive model, management actions designed to improve one condition (e.g., forest health by prescribed fires) could degrade another condition (e.g., visibility or human health). This is especially true for the lake's assimilative capacity to receive nutrients and pollutants. The importance of an understanding of air quality with respect to lake clarity lies in the lake's very slow response to the changes in atmospheric and aquatic inputs, which is quite unlike air quality itself. By knowing the causes and effects of air pollutants in the basin, management agencies will be better able to plan strategies in a more quantitative and therefore effective manner. Based on previous and ongoing

research and monitoring, inclusive predictive models for air quality are being developed for the first time in this report.

Watershed Assessment Focus

The unique conditions at Lake Tahoe can make actions that are seemingly harmless elsewhere quite harmful at Lake Tahoe. Lake Tahoe lies in a high altitude basin ringed by large mountains and is downwind of the rapidly developing San Francisco Bay Area and the Sacramento region. The basin contains a very large, cold lake in a small watershed, giving a refill time of roughly 700 years, thus a long memory for insult. The mountainous topography and developmental priorities have put almost all roads and houses close to the water's edge. As a consequence, each night a weak downslope wind pushes air pollutants out over the lake and traps them under a strong and shallow inversion. Thus, these pollutants degrade visibility and are deposited into the lake, enhancing algal growth and loss of lake clarity. The pollutants persist over the lake until they are removed by strong winds in summer, at roughly 11 AM each morning; at other times of the year air pollutants may accumulate in the basin for several days.

All of these factors place severe constraints on acceptable levels of air pollutant emissions. These emission constraints are often unpopular, thus require the very best scientific support to ensure their necessity and efficacy in protecting Lake Tahoe. With this solid scientific foundation, the public will accept constraints as necessary. This is especially true for those actions that protect lake clarity, as the lake recovers slowly from insult. Pollutants deposited into the lake today may have an impact even decades from now. Compare this with visibility degradation, which could be completely cured in days if local and upwind sources are curtailed. Forest health problems are resolved in a time frame somewhere between that of the lake response and visibility, while human health concerns have both a short-term immediate component (carbon monoxide induced shortness of breath) and long-term (loss of lung function and heart problems) effect. This watershed/airshed assessment must then address five critical issues as follows:

- Issue 1. The need to gather discontinuous air quality data at Lake Tahoe into a consistent form through the development of a heuristic model.
- Issue 2. The need to determine and quantify pollution sources by location and type (natural and anthropogenic, local and transported) that result in air pollution at Lake Tahoe.
- Issue 3. The need to determine the effects of air pollution levels, including regulatory and human health impacts, and welfare issues, including visibility, lake clarity, and forest health.
- Issue 4. The need to assess the relative impacts of air pollution sources in the Lake Tahoe basin welfare.
- Issue 5: The need to establish the means by which emissions can be reduced to levels necessary to avoid deleterious effects.

The discussion of these key issues and questions serves a number of important purposes. First, it allows scientists to conduct a comprehensive review of past atmospheric studies in the Lake Tahoe basin. Second, it provides agency and university scientists, policy-makers, interested organizations, and the concerned public with an invaluable document that serves to consolidate our knowledge about the Lake Tahoe basin. Third, the format of the Lake Tahoe Watershed Assessment, based on issues and questions, provides a framework for future research and monitoring. Although the scope of this document may leave out critical components in its assessment of the Lake Tahoe basin, the issue and question format facilitates the focus of the discussion. Fourth, the contributors to this section of the document also have had the opportunity to conduct a number of new analyses. For example, the first winter-time particulate sampling specifically designed to answer questions regarding atmospheric inputs of nutrients to the lake from local air pollution sources has been conducted. Fifth, the efforts of many university and agency scientists are being combined into focused research areas with specific goals to meet agency, public, and academic needs. Finally, the assessment process has

allowed atmospheric scientists to begin the important discussion of air pollution sources and impacts on lake clarity, forest health, and human health in a much more integrative fashion.

The first issue addressed in this chapter, the need for a comprehensive model, is then used to address issues two through four in an integrative manner heretofore lacking in any Lake Tahoe basin report. Because of the previous absence of a predictive model, the generation of a new comprehensive Lake Tahoe Airshed Model (LTAM) will constitute the major portion of this chapter's content, followed by shorter (even terse) application to specific issues. However, on the basis of our collective experience and from extensive conversations with environmental scientists at Lake Tahoe, it is clear that future research and monitoring must address the key data gaps that limit the predictive ability of the model under changing human use patterns. This approach is critical to the future of restoration efforts within the basin.

The Lake Tahoe basin is a small but complicated airshed with both upwind and local sources of pollutants. Because of this complexity, it is highly unlikely that any single mitigation project will have a significant affect on all of the air pollution impacts to the Lake Tahoe basin. A comprehensive approach to science and management based firmly on information contained in this assessment therefore is needed. Furthermore, technical products, such as the LTAM, which will give management agencies in the Lake Tahoe basin a basis for achieving air quality adequate to protect the diverse components of the Lake Tahoe air and watershed, are imperative.

At the completion of the Lake Tahoe Watershed Assessment project a number of significant findings have resulted. First, a comprehensive discussion of air quality in the basin has been undertaken. This discussion elucidates the need for comprehensive focused study of the impact of the atmosphere on the Lake Tahoe ecosystem. Second, air quality data from disparate sources have been collected into a single heuristic tool, the LTAM. A large-scale effort to gather long-term research and monitoring air quality data at Lake Tahoe reveals a significant gap in understanding of the link between air quality and lake clarity. For instance, no published study reports measurements of atmospheric phosphorous to match the deposition study results of Jassby et al. (1994). However, loss of visibility and forest damage from atmospheric pollution is well documented (Molenar et al. 1994; Pedersen 1989). Third, using the predictive ability of the LTAM, prescribed and wildfire scenarios have been evaluated. Finally, a prediction of historical air quality in the Lake Tahoe basin is derived from the LTAM. It appears that historically, wildfires in the basin were small and well ventilated, resulting in local visibility of approximately 20 miles (32 km) and regional visibility of greater than 60 miles (96 km). These visibility predictions are well within the current TRPA standards.

Issue 1: The Need to Collect Discontinuous Air Quality Data at Lake Tahoe into a Consistent Form through the Development of a Heuristic Model

With contributions from Tony VanCuren and Thomas M. Cahill

The uniqueness of the Lake Tahoe basin airshed makes air quality models developed for general airsheds ineffective. The nexus among lake clarity, forest health, visibility, and human health make modeling of this ecosystem particularly challenging. Due to limited knowledge of variable parameters, such as source strength, meteorology, deposition, and often composition, model development is made more formidable. Despite these substantial obstacles, a model that is specific to the Lake Tahoe basin was developed as part of this watershed assessment. This model will continue to be developed as data become available. Furthermore, this airshed model is expected to be integrated with other models developed for the basin.

What is the model that was developed specifically for the Lake Tahoe basin, and what are the sources and reliability of data used for its development?

Information on the air quality at Lake Tahoe is qualitatively available from the mid-19th century, from comments by such visitors as Mark

Twain (1872), and from photographs from the 19th and early 20th centuries, but detailed information dates only from the mid-1970s. Even now, quantitative long-term data are available at only limited sites and times. Air quality data since the 1970s are available from a variety of sources, but no continuous record exists for all air pollutant data.

In designating Lake Tahoe as an air basin, the CARB appreciated the fact that terrain plays a major role in air quality at Lake Tahoe. The tall mountains, cold lake, and terrain that forces roads and development close to the lakeshore all make spatial gradients very important at Lake Tahoe. A number of important processes dominate the sources and transport of pollutants in the basin. Upwind transport, local sources, forest deposition, lake deposition, and transport out of the basin are all major dynamical factors at Lake Tahoe. An overview of the important atmospheric processes are shown in figures 3-1 and 3-2.

For several decades, a limited number of air quality studies in the Lake Tahoe basin have been conducted. The CARB, the California Department of Transportation (CalTrans), UCD, and the Nevada Department of Environmental Protection (NDEP) all have collected and reported data on air quality in the basin. Unfortunately, monitoring stations at Lake Tahoe have been moved or closed over this period, making direct comparison of these data difficult. For instance, CalTrans conducted an extensive traffic study of the California portion of the basin in 1974; data from an equally extensive air quality study were collected a year before. Due to the discontinuity of these data, direct comparison of transportation-related air pollutants is unavailable for the Tahoe basin. Furthermore, because a substantial portion of the sites used to collect air data from the 1973 CARB study (Figure 3-3) have been closed, researchers are unable to compare contemporary traffic data with air quality throughout the basin.

Although a continuous record of air quality data is missing for the Lake Tahoe basin, there are valuable data from a number of sources. Aerosol concentration and composition data are available from a study by CARB/UCD in 1977 and 1979 and from ongoing TRPA/Air Resource Specialists (ARS)/UCD collaboration from 1989 to the present. Gaseous data are available from the 1973 CARB study, NDEP monitoring at Incline (limited data only), and continuous sampling by the CARB at two sites in South Lake Tahoe for approximately 10 years. As of this writing the CARB is planning to close one South Lake Tahoe site and add sites at Cave Rock, Incline Village, a west shore site (probably near Tahoma), and Echo Summit. As part of this monitoring site extension, the South Lake Tahoe site at Sandy Way will be upgraded with a full complement of air quality data. TRPA maintains aerosol sites for monitoring of visibility at South Lake Tahoe and D. L. Bliss State Park. Currently, the Interagency Monitoring for Protected Visual Environments (IMPROVE) program plans to take over the Bliss site for monitoring the Desolation Wilderness as a Class 1 visual area.

Air quality is important to the scenic beauty of Lake Tahoe and its environment. Visibility, biotic integrity, and lake clarity are all highly valued in the basin. Air quality is partially implicated in reducing lake clarity, damaging forests, and in contributing to visibility concerns. The complexity of these problems and limitations in data and theory limit the ability of researchers and managers to gauge present conditions at unmeasured sites and to extrapolate the impacts of future regulatory actions. Therefore, it is important to accurately gauge the level of confidence we have in both measurements and theory, as applied to Lake Tahoe (Table 3-1).

The Lake Tahoe Airshed Model

To address both the gaps in ambient data and the unique qualities in the basin, we developed a model specific to the Lake Tahoe air basin. The USFS LTAM is an Eulerian array of 1248-2.56 km^2 (1 mi^2) cells across the basin encoded on a Microsoft Excel spreadsheet. The domain is 72 km (45 miles) north to south (Truckee to Echo Summit) and 42 km (26 miles) west to east (Ward Peak to Spooner Summit) (Figure 3-4). All but the most southern end of the watershed is taken into account by the model. The LTAM is semiempirical in design and incorporates all available air quality measurements at

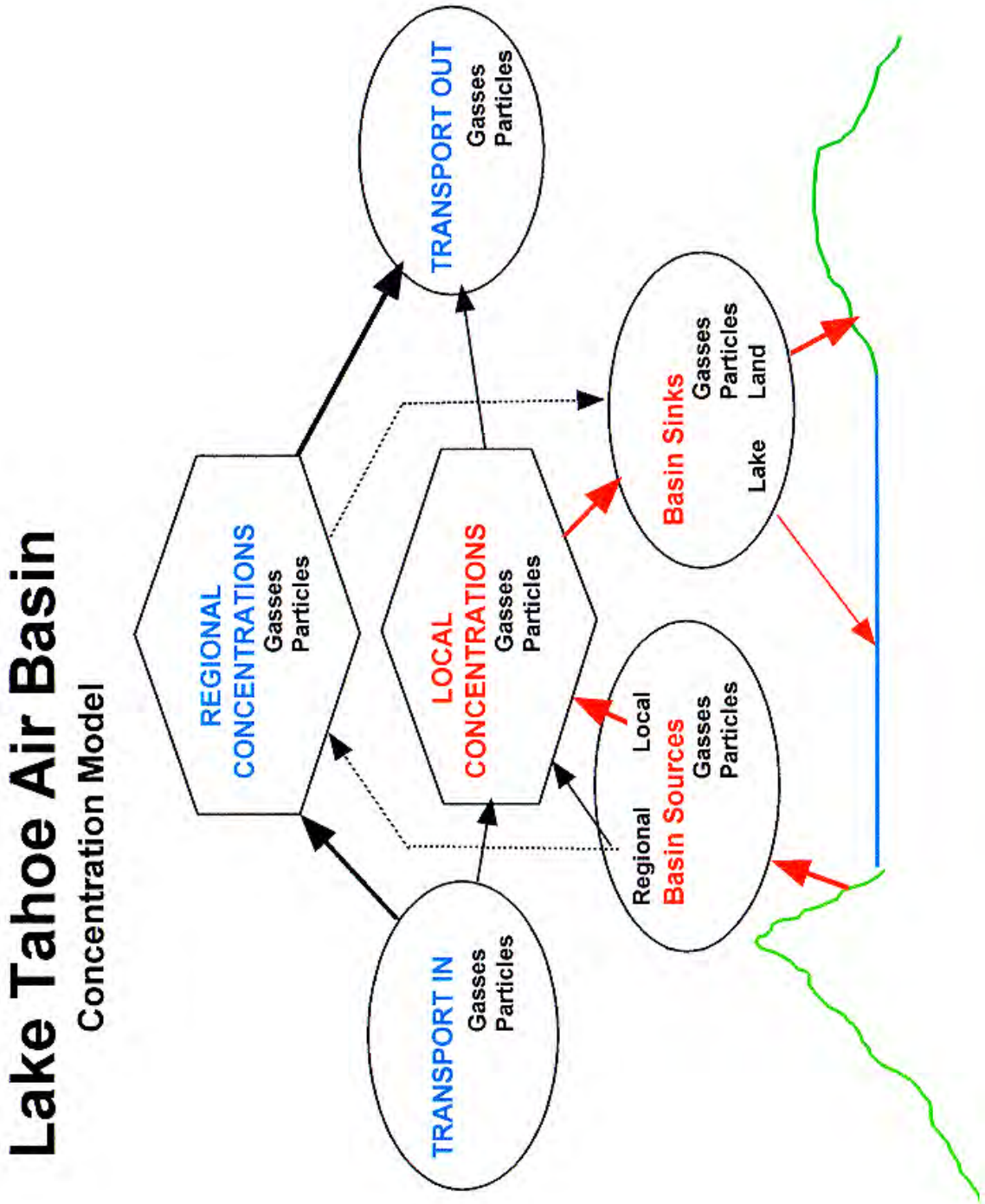


Figure 3-1—Schematic air model for the Lake Tahoe basin, based on concentration of pollutants.

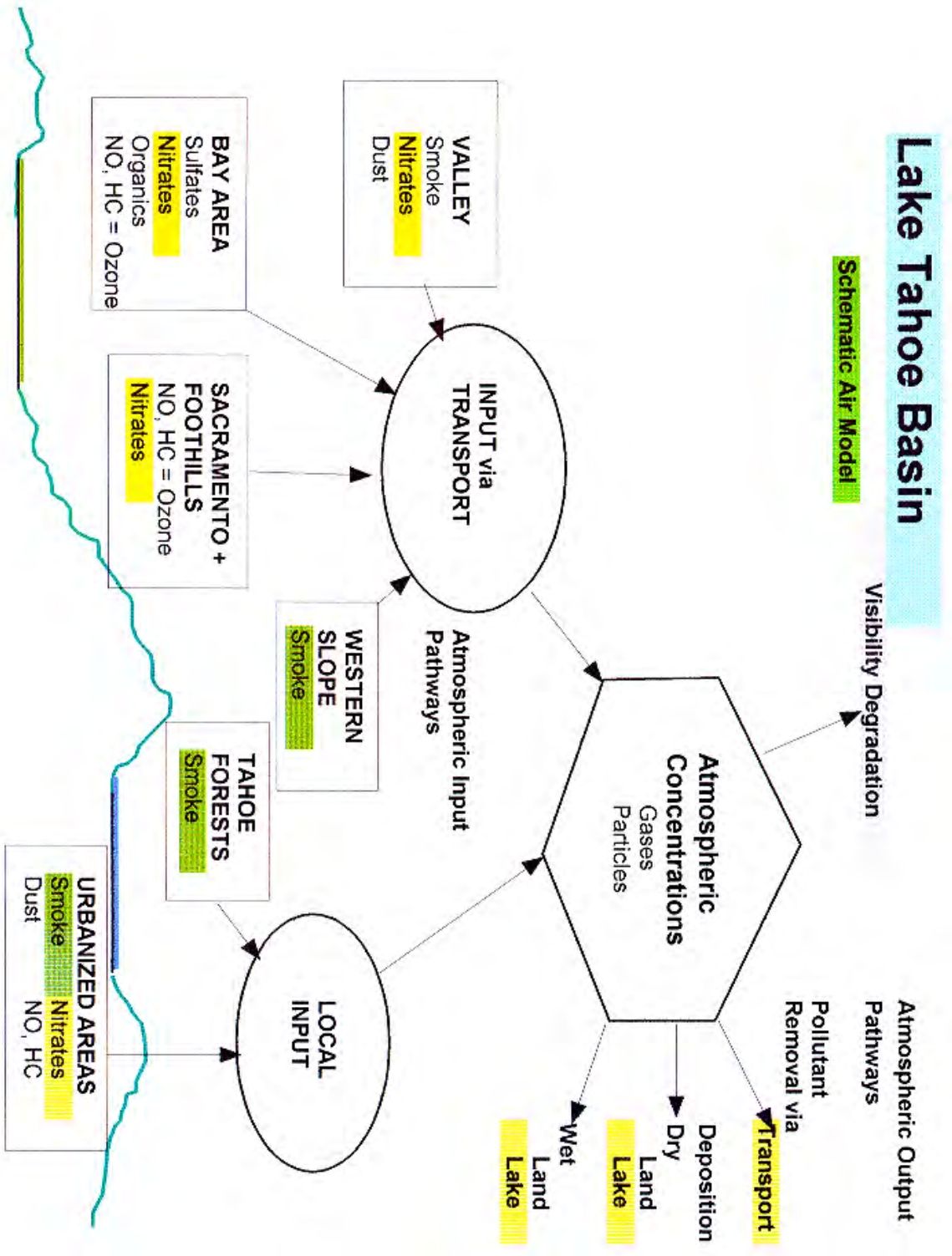


Figure 3-2—Schematic air model (including processes and pollutants) for the Lake Tahoe air basin.

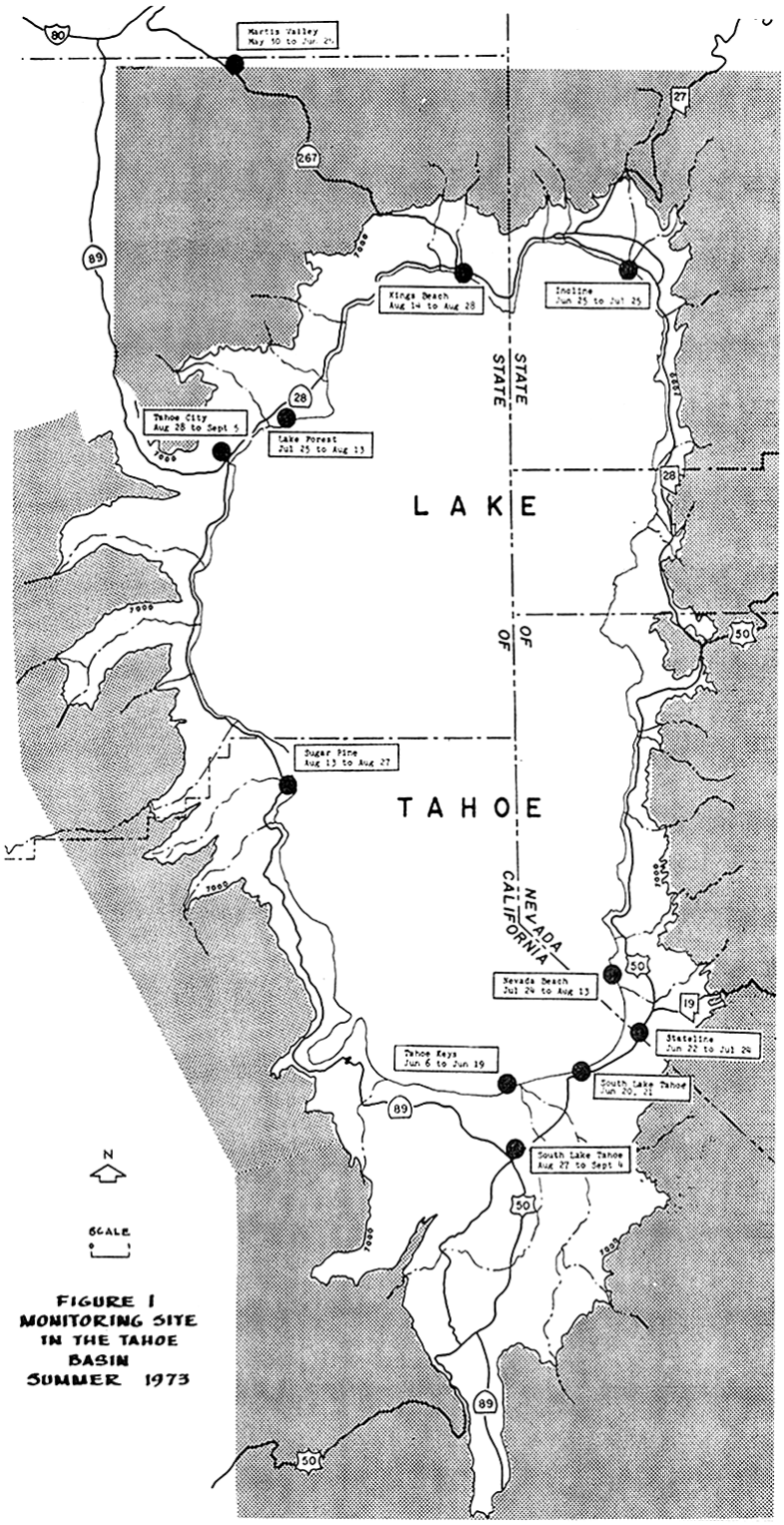


Figure 3-3—Locations of sampling stations used in the 1973 ARB air quality study in the Lake Tahoe basin.



Figure 3-4—Area covered by the Lake Tahoe Airshed Model (LTAM). West to east is modeled from approximately Ward Peak to Spooner Summit and north to south from Donner Lake to Echo Summit. There are 1,248 individual cells that are used for calculating pollutant concentration for this portion of the watershed. This is the underlying map used to display pollutant concentration output from the LTAM results.

Table 3-1—Description of the level of understanding of atmospheric parameters at Lake Tahoe (LT). The five parameters are broken down by scientific knowledge as high, limited, or seriously deficient.

Parameter	High	Limited	Seriously Deficient
Meteorology	SLT	West, NW shores, upwind derived	East, NE shores, ridges
Sources	Upwind (Central Valley, Bay Area)	Local urban, transportation	Area sources, fires (wild/prescribed)
Concentrations and composition			
Gasses	SLT	Rest of LT area	
Particles	SLT	West shore	NW, NE, East
Processes			
Transport	SLT	Rest of LT area	
Deposition		Coarse particles Gasses	Fine particles
Effects	Visibility loss Ozone tree damage	Human health	Lake nutrient effects

Lake Tahoe, 1967 to the present, plus aspects of meteorological and aerometric theory. Free variables, such as traffic flow, acres of forest burned, and population density, are assumed to be linear with pollutant emissions. This model is a heuristic tool used to gather the disparate sources of air quality data at Lake Tahoe into a consistent framework.

The LTAM is a component of the overall Lake Tahoe basin watershed models designed to provide information on the role of the atmosphere in the health and welfare concerns of the Lake Tahoe basin. The construction of this model has two major immediate goals: to identify the relative fraction of in-basin and out-of-basin, natural and anthropogenic components of the atmosphere of the Lake Tahoe basin and to evaluate the effects of atmospheric pollutants in the Lake Tahoe air basin on lake clarity, visibility, human health, and forest health.

The LTAM is designed to be complex enough to include all major components, accurate enough to represent important physical, chemical, and biological processes, and simple enough to allow calculation of results that can be verified by ambient data. In this effort, emission estimates valid in other parts of the state and nation, even if available, may not be relevant to the unique conditions of the Lake Tahoe area. Whenever possible we have used measured values in the basin to establish source emission relationships.

Meteorology

The key parameters that relate to impacts of atmospheric pollutants are source and sink (deposition) strength and meteorology. The meteorological conditions in the LTAM are broken up into summer day, summer night, and winter (nonstorm) conditions. May and early June are considered in the summertime regime. For late September through late October, a combination of the summer day and night and winter meteorological regimes is used. Data on wind speed and direction at the north end of Lake Tahoe are taken from the record at the US Coast Guard pier in Tahoe City. Data at the southern end of the lake are from TRPA data. Mid-lake meteorology is derived from personal observations, enhanced by theoretical interpretation of nighttime downslope patterns seen at the south end of the lake.

Meteorology and topography dominate dispersion downwind from a source. Lateral dispersion in urban settings are calculated from the measured US Hwy. 50 transects (CARB/UCD 1979), while lake transport is estimated from the same parameters modified by the relative z_o obstruction ratio (trees versus a flat lake), giving an estimated one-fifth decrease per grid dimension of 2.56 km^2. This is confirmed by photographs taken in

early winter mornings, showing the South Lake Tahoe haze extending two to five miles over the lake.

Topography is important for the effects it has on the Lake Tahoe basin, especially the development of persistent inversions that trap local pollutants close to the ground. Night winds are assumed to follow topography, moving from the highest points, the watershed boundary, downslope to the lowest elevation, the lake surface. Thus every evening, air is moved from land to water and is trapped close to the water surface. This process tends to maximize deposition to the lake surface, although data confirming this conclusion are lacking.

The model handles meteorology by defining average conditions for seasons and then coding the wind field into each cell by performing an upwind-downwind average along the most prevalent wind direction. For example, the summer day model calculation for west shore meteorology is an average of the three upwind (more west) cells. Further averaging of the meteorological output takes place for summer night and wintertime conditions to approximate the effects of the observed inversions that develop within the basin.

Summer conditions in the basin begin to appear in late May and June and persist into early October. They are characterized by strong differences between day and night, with major transport into and out of the basin during most days. Winter conditions (late October to February) are defined as having no extra-basin transport and persistent inversions. In the spring, strong winds transport fine soil dust both within and from outside of the basin. The choice of these periods was based on the spotty long-term record of meteorology in the Lake Tahoe air basin—primarily the 1967 US Coast Guard station at Tahoe City—to which we added measurements from the South Lake Tahoe CARB site, from the airport (daytime only), and from research studies, especially the 1979 UCD/CARB study, and local personal observations.

For summer daytime winds, the model uses a nominally west to east wind by default, with equal averaging of the three upwind cells (NW, W, SW) to mimic lateral dispersion. Along the northwest (NW) shoreline beyond Tahoe City, the weighting is changed to give a mostly southwest (SW) wind, based on good local data, while the same SW wind is used on the SW lake shore near Tahoe Keys. For nighttime winds, the CARB/UCD 1979 study and South Lake Tahoe data indicate weak terrain winds flowing from high elevations to low elevations at all points. Again, averaging is used to mimic lateral dispersion. For summer nights, the daytime concentrations are retained as pollutants fill the basin and have long enough residence times not to decrease greatly over night. Winter (stagnation) meteorology is very much like summer night, but transported particles are set to zero in the model, and greater cell averaging is used to approximate the effects of the stagnant inversion.

By the time pollutants have traveled to the Lake Tahoe basin, they have become relatively uniform both in the direction of transport (i.e. fall off < 1%/cell) and at right angles to transport (Figure 3-5, ozone and sulfates). Therefore, the LTAM adds this as a source to each cell as would be seen in total background, i.e., no local source, conditions.

For air pollutant emissions from fire, the prescribed fire ambient air data of Cahill (1996), especially from Yosemite National Park, are used. However, these fires are divided into two factors: PF1, in which there is no lofting of smoke (h) ($0 < h < 0.1$ km), and PF2, in which lofting of smoke (h) to greater altitudes ($0.1 < h < 0.5$ km), as observed in prescribed fires with high fuel loading and/or drier conditions (Cathedral burn, October 1998, SNEP Three Rivers, 1995). In these cases, observed ambient concentrations are used rather than mass emission estimates. Fires then are added to the model using one of the following possible settings:

- Prescribed Fire Type 1 (PF1)—the 1992 Turtleback Dome (Yosemite National Park) prescribed fire, monthly average values (Cahill 1996).
- Prescribed Fire Type 2 (PF2)—the 1994 Three Rivers prescribed fire, an example of a large fire.
- Wildfire (WF)—the results the of 1992 Cleveland wildfire at the maximum

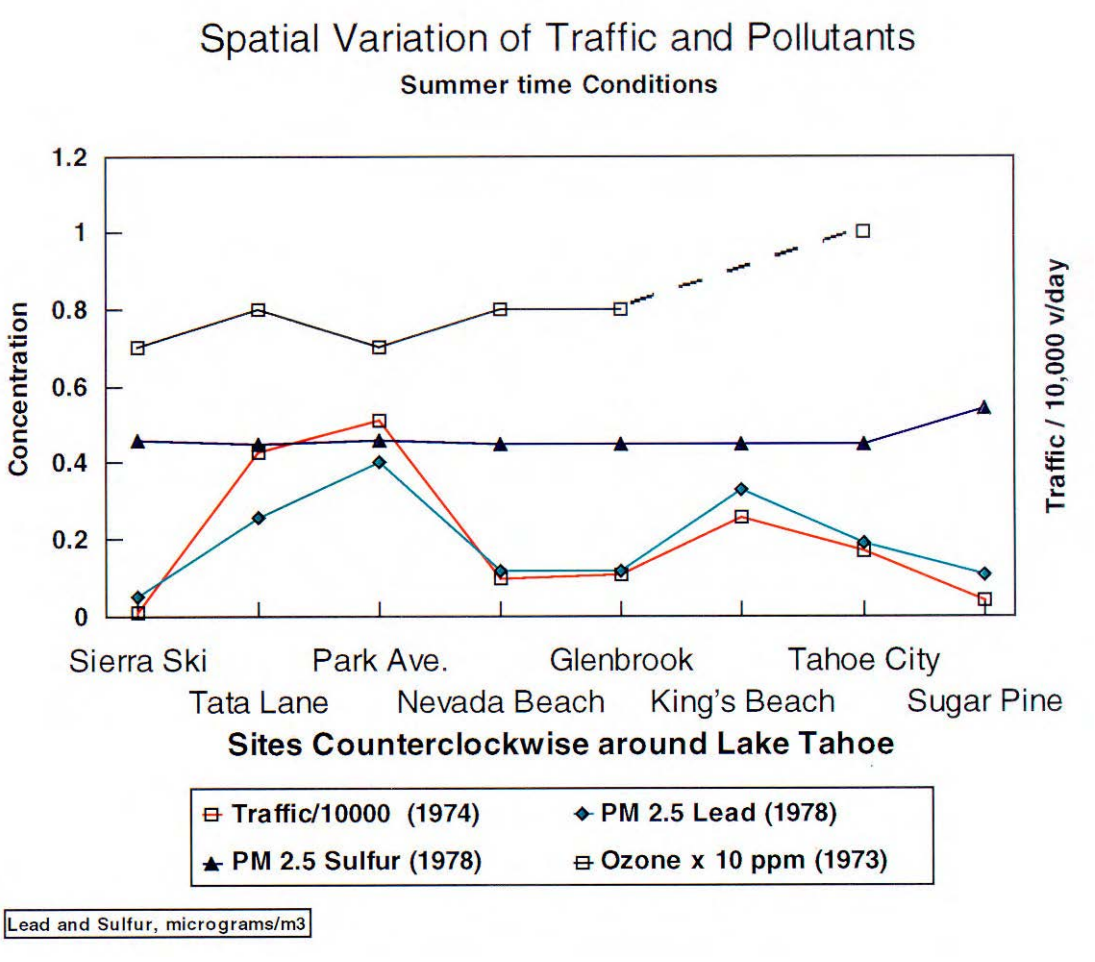


Figure 3-5—Concentration of pollutant and traffic counts for summer conditions at sites around Lake Tahoe.

impact site (Truckee), with chemical composition derived from samples taken at TRPA's D. L. Bliss site.

Model Calculation

Modeling is accomplished by a three-cell average centered on the mean wind direction. This gives a representation of the geographic variability of the wind direction. As sources are encountered, the values are added. Mixing of air from adjacent cells is modeled by mathematical averaging of the meteorological output. This approximates transport of pollutants and mixing within the inversion for the summer night and winter meteorological parameters. Because the winter inversion is so strong and prevalent for a number of days between storms, a greater degree of averaging is performed for the winter calculation.

The falloff of particles downwind of a local line or area source is logarithmic, based on the observed fall off of fine particles at South Lake Tahoe (CARB/UCD 1979). In the prescribed PF1 case, the high correlation between NO_x and lead in the CARB/UCD data allowed adding a generic fine-particle falloff setting to these values. Falloff over the lake, however, should be less rapid due to the much lower surface roughness parameter (z_o) over the water. In the total absence of these data, this parameter is a magnitude of three to five times less than in forest conditions. The values are expressed as the fraction of a pollutant transported into the adjacent downwind cell. Thus, we can use the values

from Table 3-2 for the decrease (D) of pollutants downwind of a source, based on fine particle transport measurements and theory.

Pollutants emitted near ground level, and especially in inversions at night and winter, have been shown to be local in character. While particle removal may play a role, the wind sheer generated in the transition between a forest canopy and the cleaner, faster moving air above it is probably the major factor. Evidence of this was seen in particulate measurements upwind and downwind of Highway 50, in which lead levels (presumably derived from local tailpipe emissions) fell rapidly versus distance, while sulfur levels (presumed to come from long-range transport into the basin) actually rose slightly at the ground level sites, indicating downward mixing of upper level air (CARB/UCD 1979; Figure 3-6).

Upwind pollutant emissions in the basin are derived from the efficient transport between the Sacramento Valley and Lake Tahoe that exists for the summer, typically beginning in April and ending in late October. Sulfate concentrations, which are derived almost entirely from Bay Area refineries and thus represents transported fine particles into the basin, are indicative of this transport effect. The regionality of the transport effect can be further seen in data from Seqouia, Yosemite, and Lassen national parks (Figure 3-7). This effect was investigated through the paired TRPA air sampling sites at D. L. Bliss State Park at Emerald Bay, which represents transported air, and at South Lake Tahoe, which represents both transported and local pollutants (Figure 3-8). An analysis of the annual behavior of transported and local particles (figures 3-8, 3-9, and 3-10) allows upwind sources versus local sources to be estimated (Figure 3-11). A similar analysis of gaseous pollutant data from the 1973 CARB study indicates that NO_x, CO, hydrocarbons, and lead are mostly locally derived and that O_3 is transported (Figure 3-12). These analyses identify very different transport regimes, gasses versus particles, summer versus winter. The model's complexity can be reduced to simplifying observations: all primary gasses (CO, NO, NO_2, NO_x, NMHC, SO_2) are local methane is half natural, half anthropogenic, all secondary gasses (O_3) are transported from upwind sources TSP (0 to roughly 30 microns diameter) is mostly local, and PM_{10} is largely local, $PM_{2.5}$ is entirely local (winter), half local, half transported (summer).

Because sources (sulfates, nitrates, smoke, soil) are far away, the lateral dispersion of wind during transport predicts a uniform distribution of pollutants across the Lake Tahoe air basin. This is in fact observed. The correlation among local traffic, lead, sulfate, and ozone (Figure 3-5), and between soils and road salt (Figure 3-13) indicates that a uniform distribution of transported pollutants exists in the basin and that local sources are quite variable depending on

Table 3-2—LTAM input for decrease in pollutant concentration through dispersion and mixing or loss by deposition per cell (1.6 km) dimension. This describes prescribed fires, wildfires, and long-range transport from upwind. Both forested and over-water areas are given as used in the model. The value D is the relative concentration change per cell in the LTAM. Bold-faced type indicates well-known values as described in text below.

		D_{summer}	D_{winter}
Sacramento Valley source, > 0.95, based on sulfate values measured across the lake		**1.0**	0.9
Pollutant falloff for forested areas:			
PF1	Local source, below tree canopy	**0.40**	**0.15**
Other	Local source, below tree canopy	**0.40**	**0.15**
PF2	Local source, just above tree canopy est. from interpolation between PF1 and WF	0.7	0.6
WF	Local Source, far above tree canopy est. from smoke plumes, and	0.96	0.8
Pollutant falloff for over-lake area:			
PF1, PF2, and WF and other local source est. from night time SLT haze		0.9	0.8

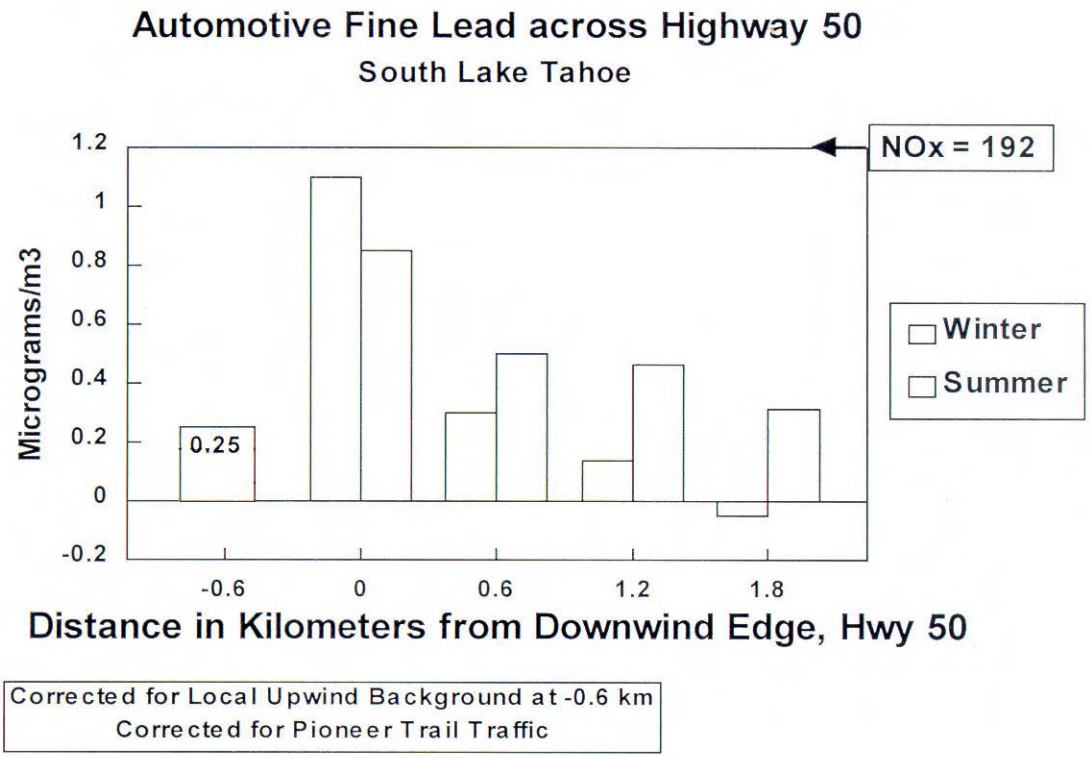


Figure 3-6—Concentration decrease of particulate lead with distance from highway source. This decrease is used to calculate the falloff parameter for PF1 in the LTAM.

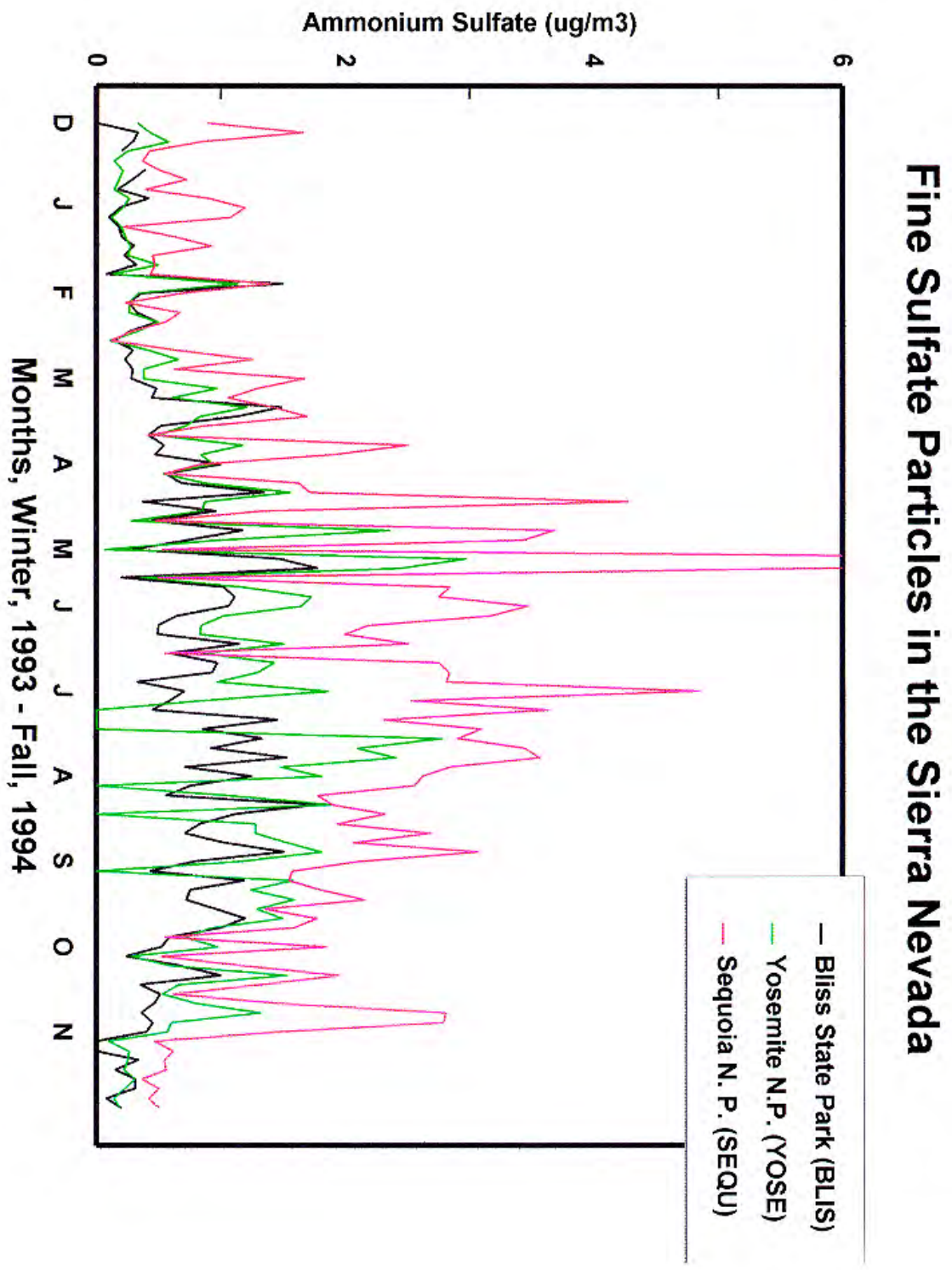


Figure 3-7—Concentration of ammonium sulfate versus time at Sequoia and Yosemite National Park and D. L. Bliss State Park. Note correlation for all three sites.

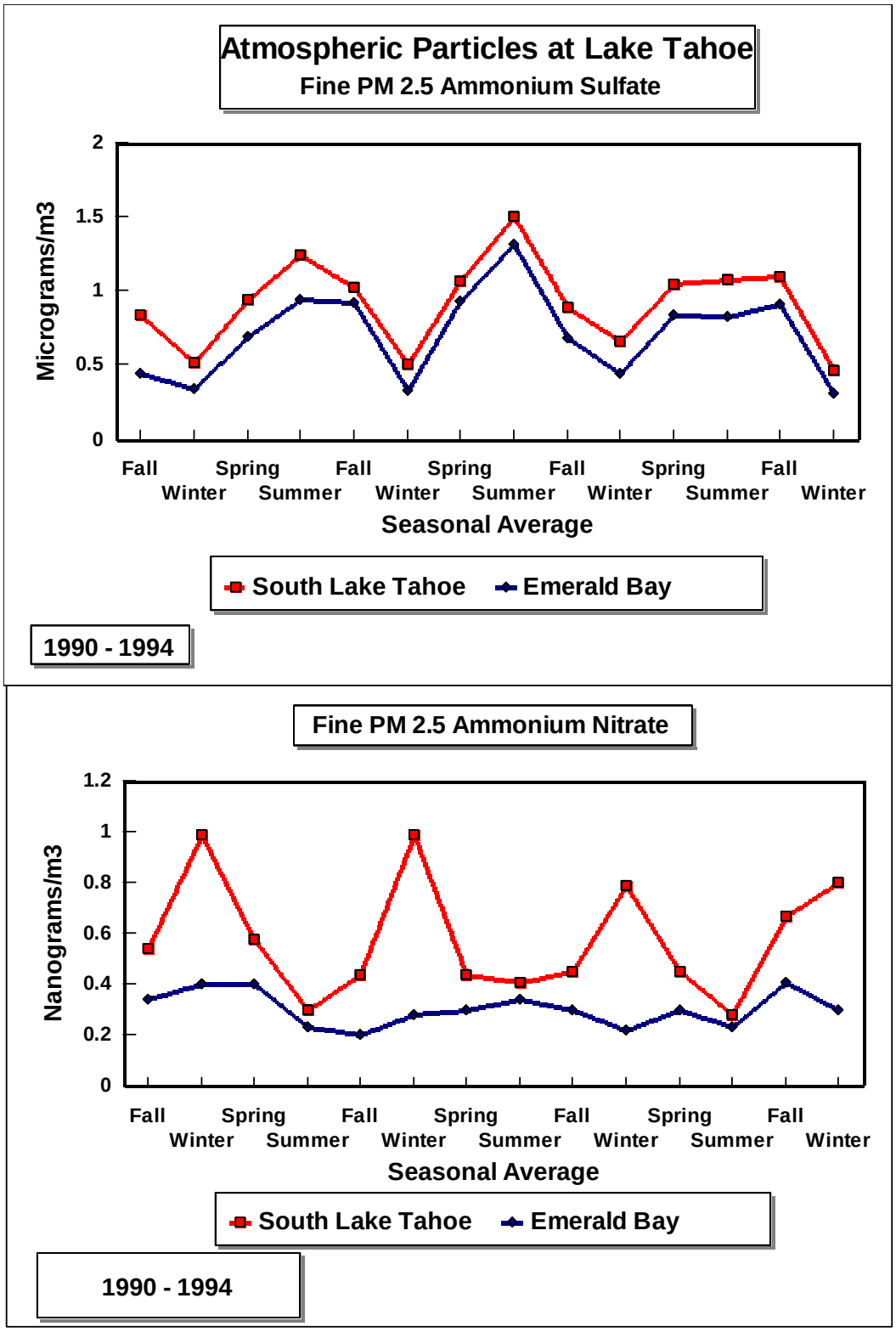


Figure 3-8—Seasonal concentration of $PM_{2.5}$ ammonium sulfate and nitrate at South Lake Tahoe and D. L. Bliss State Park from 1990 through 1994.

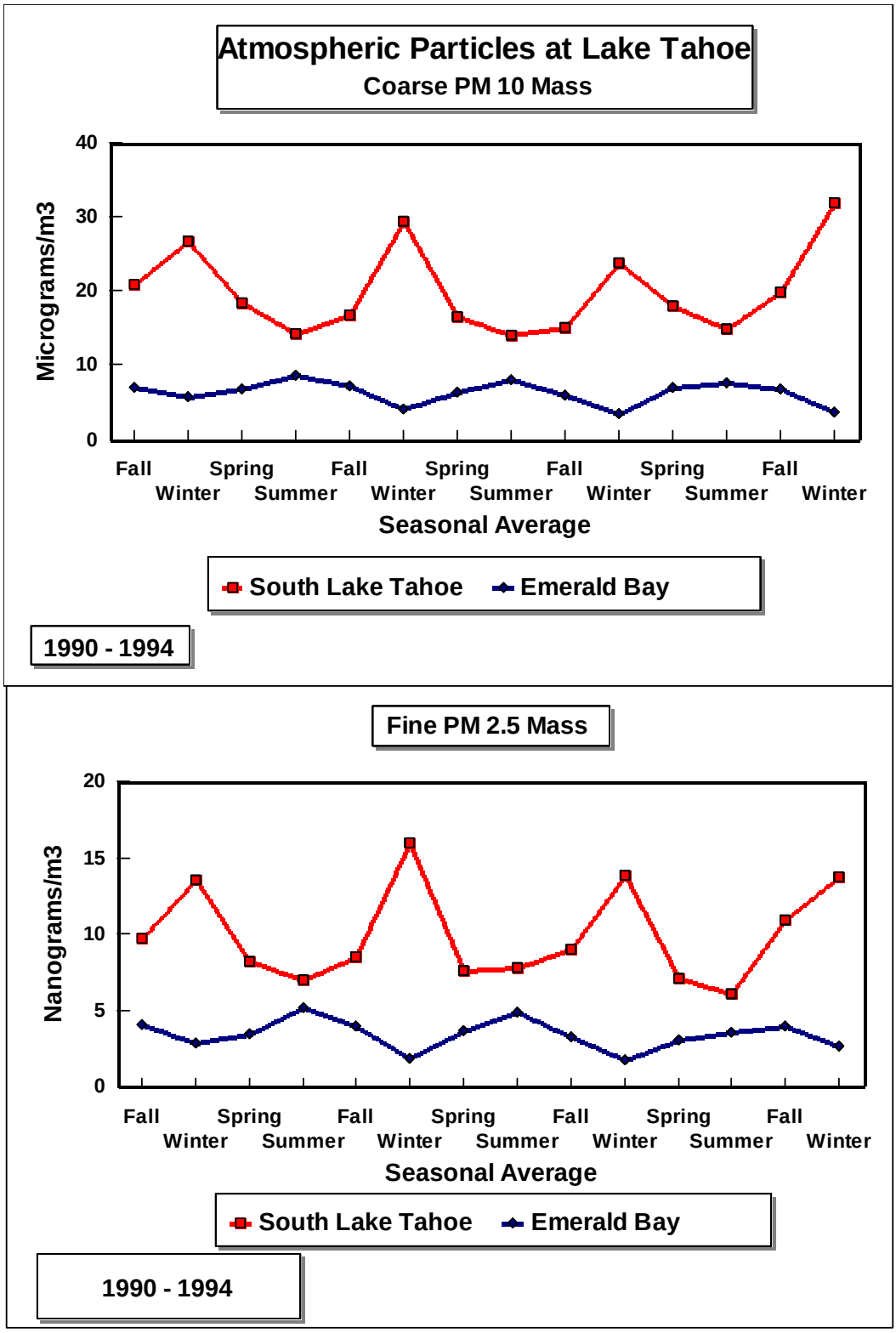


Figure 3-9—Temporal concentration of PM_{10} and $PM_{2.5}$ at South Lake Tahoe and D. L. Bliss State Park for summer and winter from 1990 through 1994.

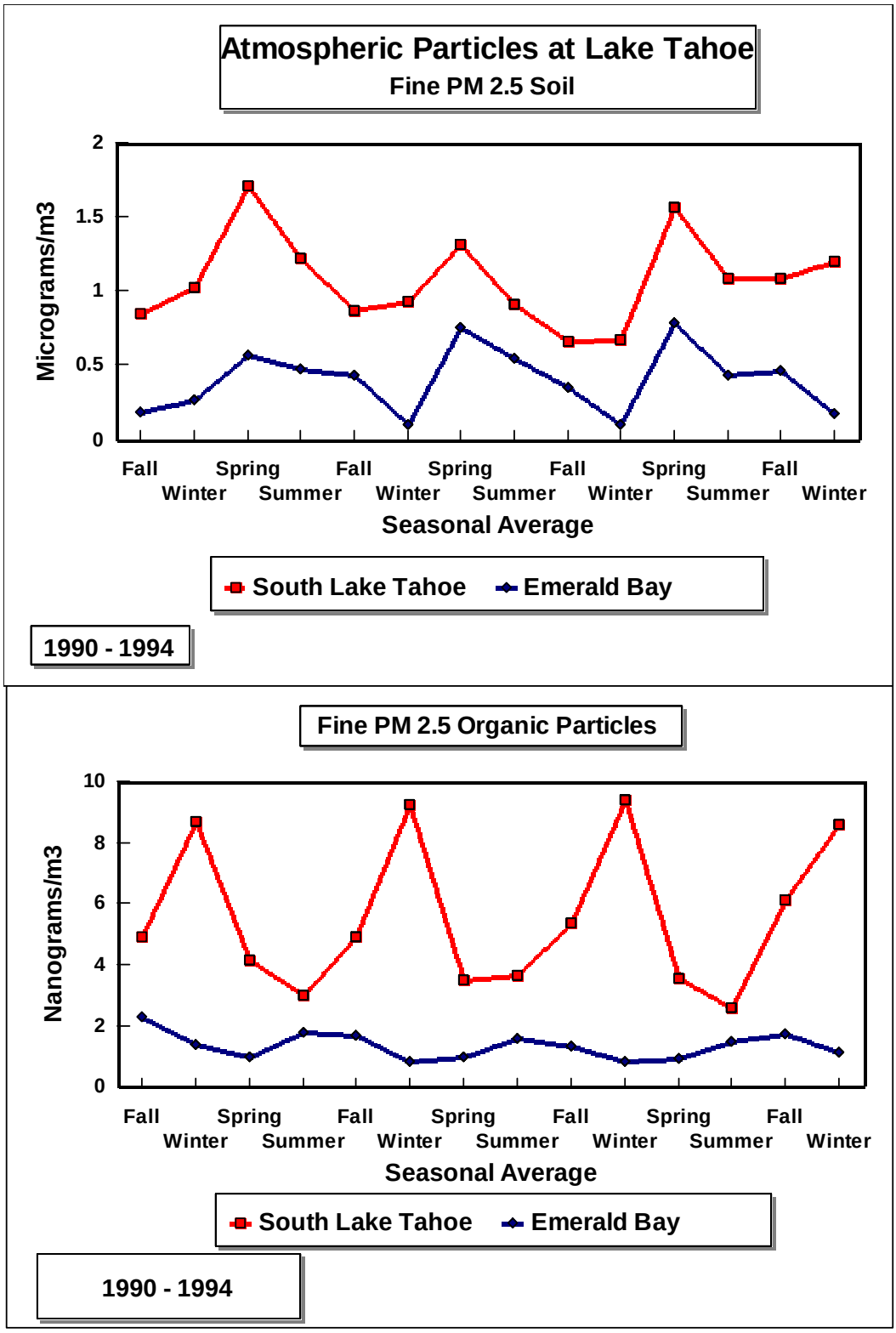


Figure 3-10—Seasonal concentration of $PM_{2.5}$ soil and organic aerosols at South Lake Tahoe and D. L. Bliss State Park from 1990 through 1994.

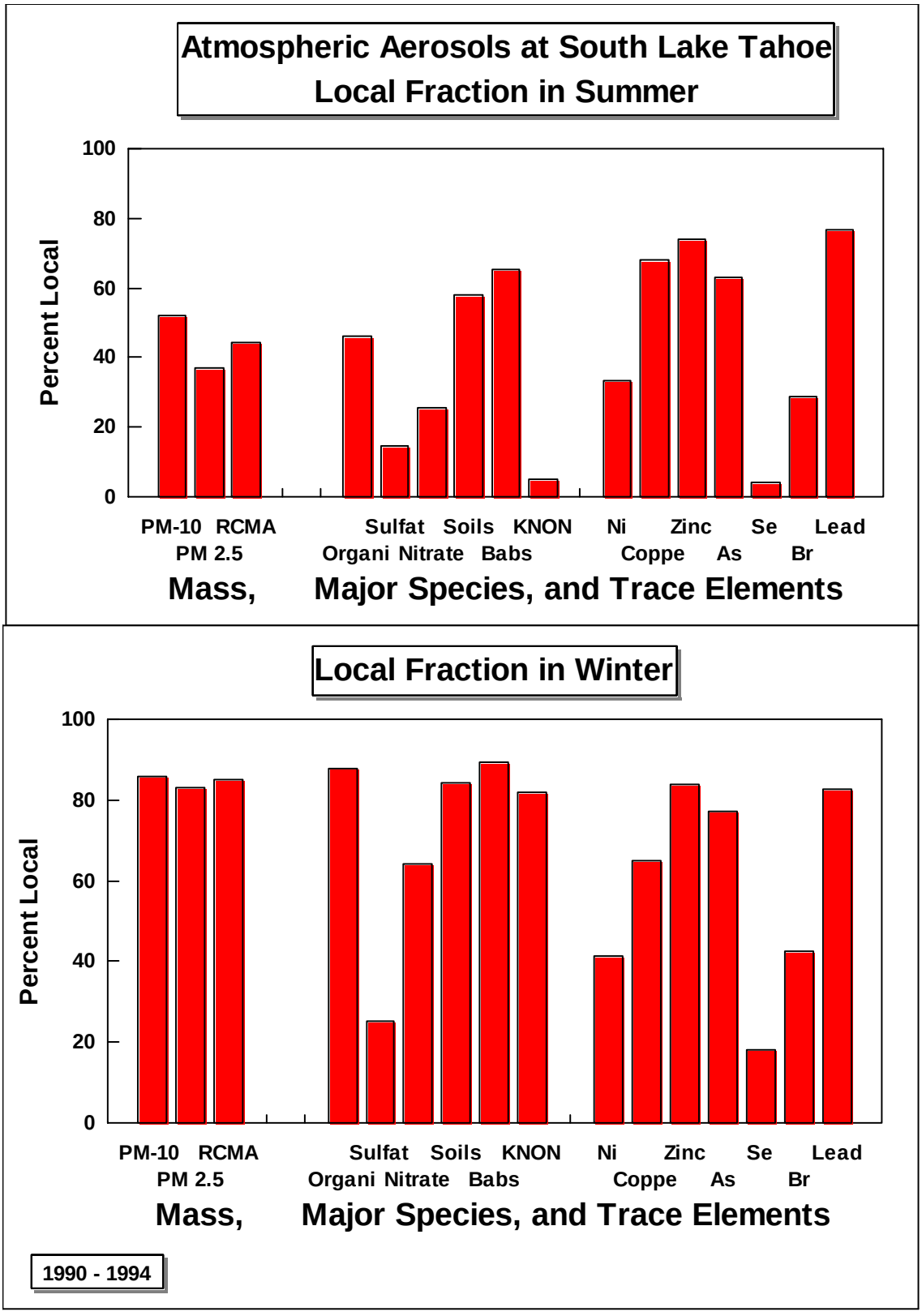


Figure 3-11—Percentage of locally generated aerosol mass and species at Lake Tahoe for the summer and winter.

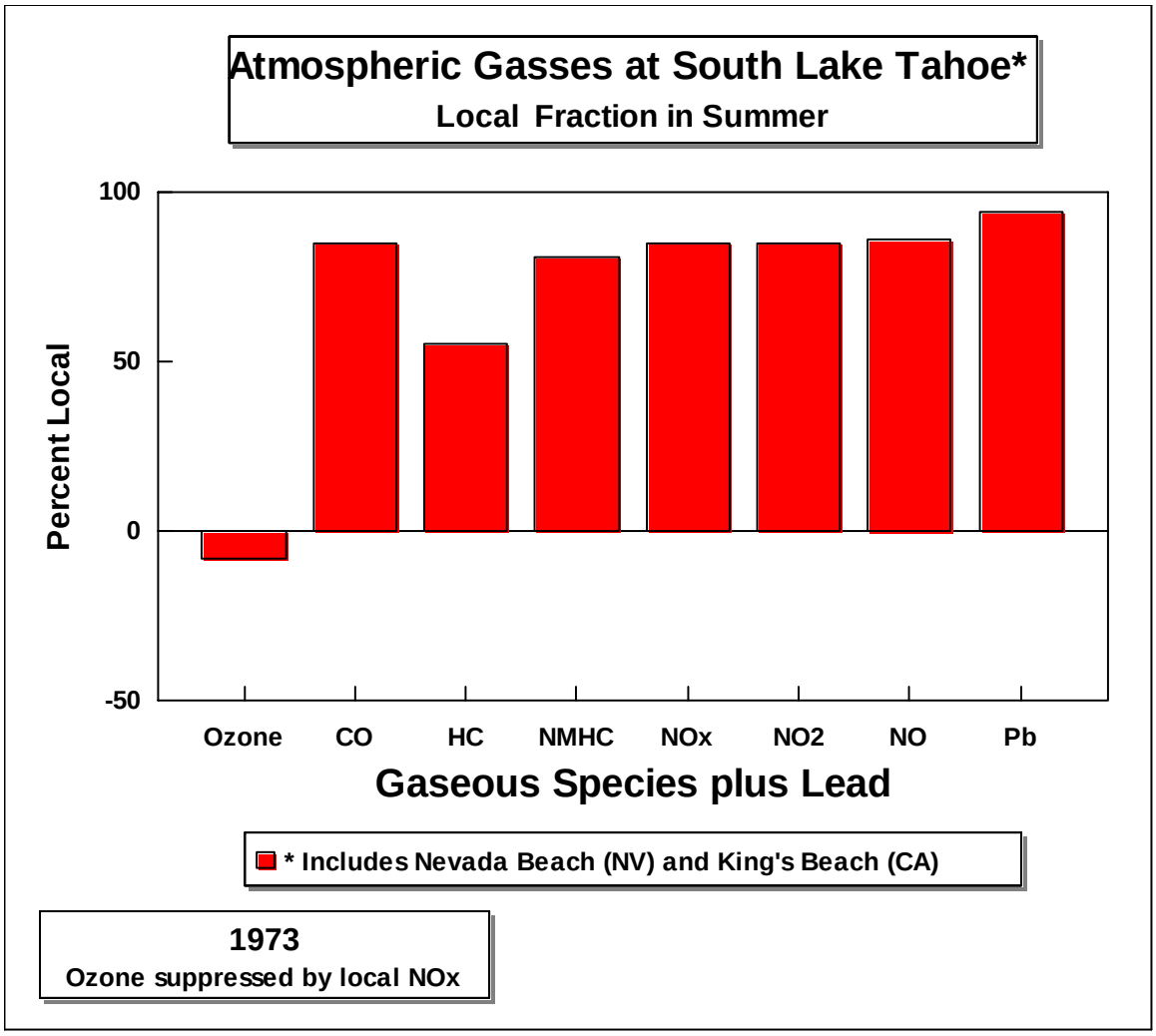


Figure 3-12—Percent of locally generated gaseous (plus lead) pollutant species at Lake Tahoe.

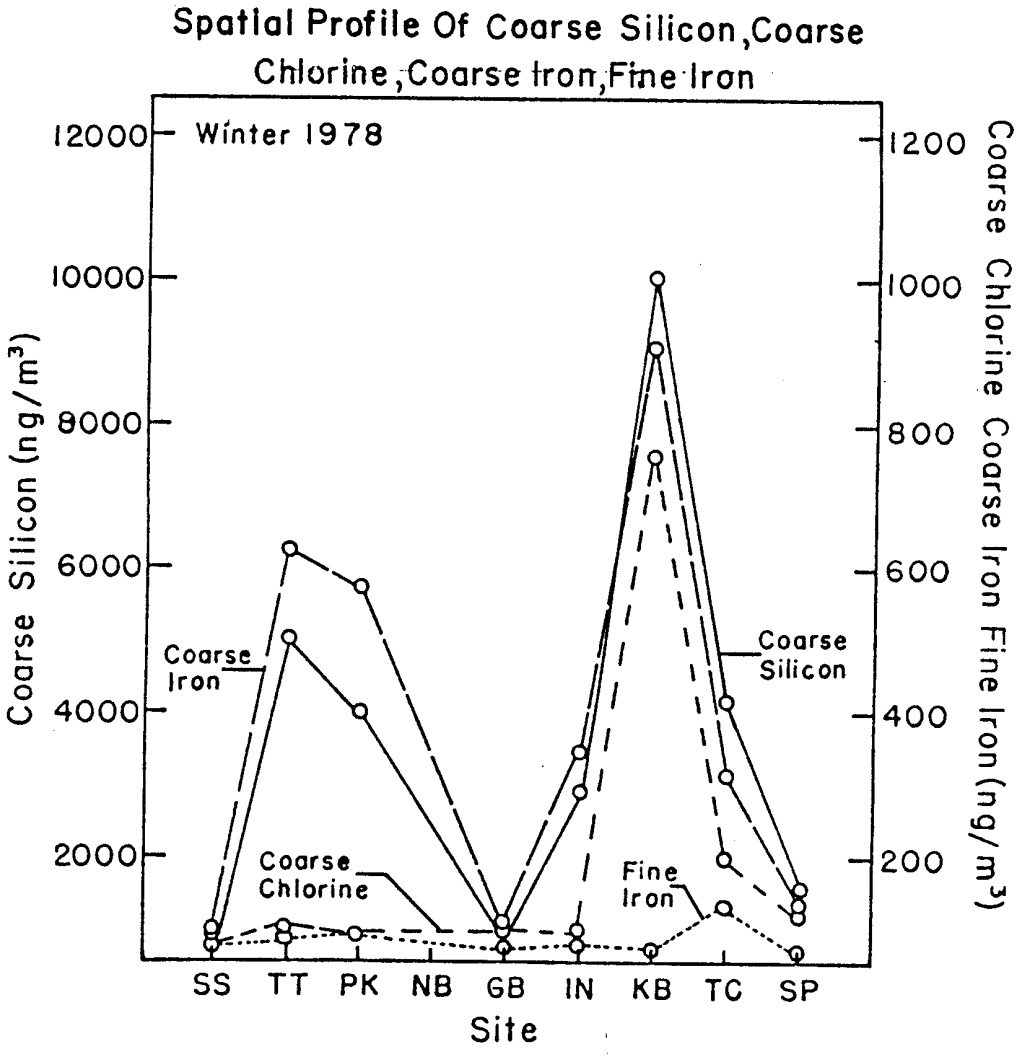


Figure 3-13—Concentration of coarse ($PM_{2.5\text{-}13\ \mu m}$) and fine ($PM_{2.5}$) particles at various sites, from the 1979 ARB/UC Davis air quality study at Lake Tahoe.

source strength. The LTAM, therefore uses a uniform upwind distribution of transported pollutants. An exception is made, however, for near-upwind sources such as prescribed fire, wildfire near the western airshed boundary. These near-upwind sources may not have traveled far enough to become uniform, as shown by the Cleveland fire comparison, Bliss to Truckee, in 1992. (Cahill 1996). Therefore, a second input in the LTAM allows manual input of gradients on a north to south transect. Meteorological measurements, observations of visibility, and calculation shows that most of the mass of transported sources lies in a band between a few hundred feet above the lake to about 10,000 feet (summer, CARB/UCD 1979), thus continue across the basin into Nevada. Local air pollutants are almost always emitted under the strong inversions that dominate Lake Tahoe and tend to stay within the basin. The major exception is forest fire, where the sources can lie well above lake level.

Emission estimates for local traffic are derived from the extensive studies conducted by such entities as CARB and CalTrans during the 1970s around lake Tahoe, which included both air

quality and traffic (figures 3-14, 3-15, and 3-16). These historical data are scaled to present conditions by the extensive ambient measurements at the CARB South Lake Tahoe station, a record that extends back into the late 1970s (see Section 6.1.1). The high correlation between the CalTrans local traffic density counts and ambient lead (Cahill et al. 1977; CARB/UCD 1979; Figure 3-17) allows one to scale other pollutants from the 1973 CARB ambient measurements and the 1974 CalTrans traffic counts. No equally extensive set of traffic and air quality measurements have been made since that time. The local traffic data can then be scaled to air quality ambient measurements, avoiding the complexities of the traffic density-meteorology connection.

The scaling approach is supplemented by limited direct emission estimates from research studies (especially CARB/UCD 1979) with the LTAM "sliding box model" used to connect emissions to ambient concentrations. Finally, traffic is resolved into four categories: heavy (H), with major diesel truck component (I-80), medium-heavy (MH), with considerable diesels in either bus or truck components (Hwy. 50), medium-light (ML) with some diesel and local trucks (parts of Hwy. 89 near Tahoe City, for example), and light (L), consisting almost entirely of cars and SUVs (for example, Hwy. 89 near Emerald Bay). The urban density map of CTRPA, 1976, (Figure 3-18) is used to identify urbanized areas of the Lake Tahoe basin, with some modifications for the growth of specific areas (Glenbrook, Nevada), which were almost totally rural in 1976 but are developed today. The emissions of these areas are then estimated from the South Lake Tahoe - Bliss SP comparisons, summer and winter.

Finally, the LTAM uses an input page to modify variables such as location of point sources (e.g., prescribed fire, forest fire, boats), density of traffic on one of the 26 road segments, transfer rates, and proportional wind velocity (figures 3-19a and 3-19b). A model run example for nitrogen dioxides (NO_x) for a typical summer period is shown in Figure 3-20. For this example, the values in Truckee are estimated at 35,000 vehicles/day because there are no traffic data from the CalTrans study. The output for the model run for traffic from the LTAM (Figure 3-20) preliminarily indicates that Tahoe City is an important source of pollutants in the basin due to the funneling effect of the Highway 89 corridor from Truckee. Further investigation of the importance of Tahoe City is warranted, especially in light of the significant atmospheric contribution of transported nitrogenous pollutants reported by Jassby et al. (1994).

LTAM Model Prioritization

The number of important air quality parameters for model input and output is high even in the limited area of the Lake Tahoe basin airshed. Thus, a ranking of important terms has been determined for the sake of model focus. The ranking we are using is lake clarity, visibility, forest health (biotic integrity), and human health. The first priority is the potential role of air quality as a significant factor in the continuing decline in the water clarity of Lake Tahoe. Atmospheric visibility, the second priority, is clearly dominated by atmospheric contaminants and could be degraded by implementing such programs as increased prescribed fire to improve forest health. Although forest health/general biotic integrity is clearly a major factor in the vitality of the Lake Tahoe airshed, this was given a lower priority because present damage, mostly from ozone, is modest. The potential for future impacts, however, is significant. Furthermore, evidence of loss of biotic integrity due to poor air quality in the Tahoe basin has not been reported. Finally, while the air quality at Lake Tahoe is generally good, there are some actual and future potential violations of state and federal human health-based air quality regulations.

Each of these ecosystem impacts then can be matched to the most important of the many atmospheric pollutants that contribute to the effect:

- Lake clarity:
  - Nitrogen, gasses, and particles
  - Phosphorus, particles
  - Fine soils, particles
- Air clarity:
  - Organic compounds
  - Nitrates, particles
  - Sulfates, particles
  - Fine soil, particles

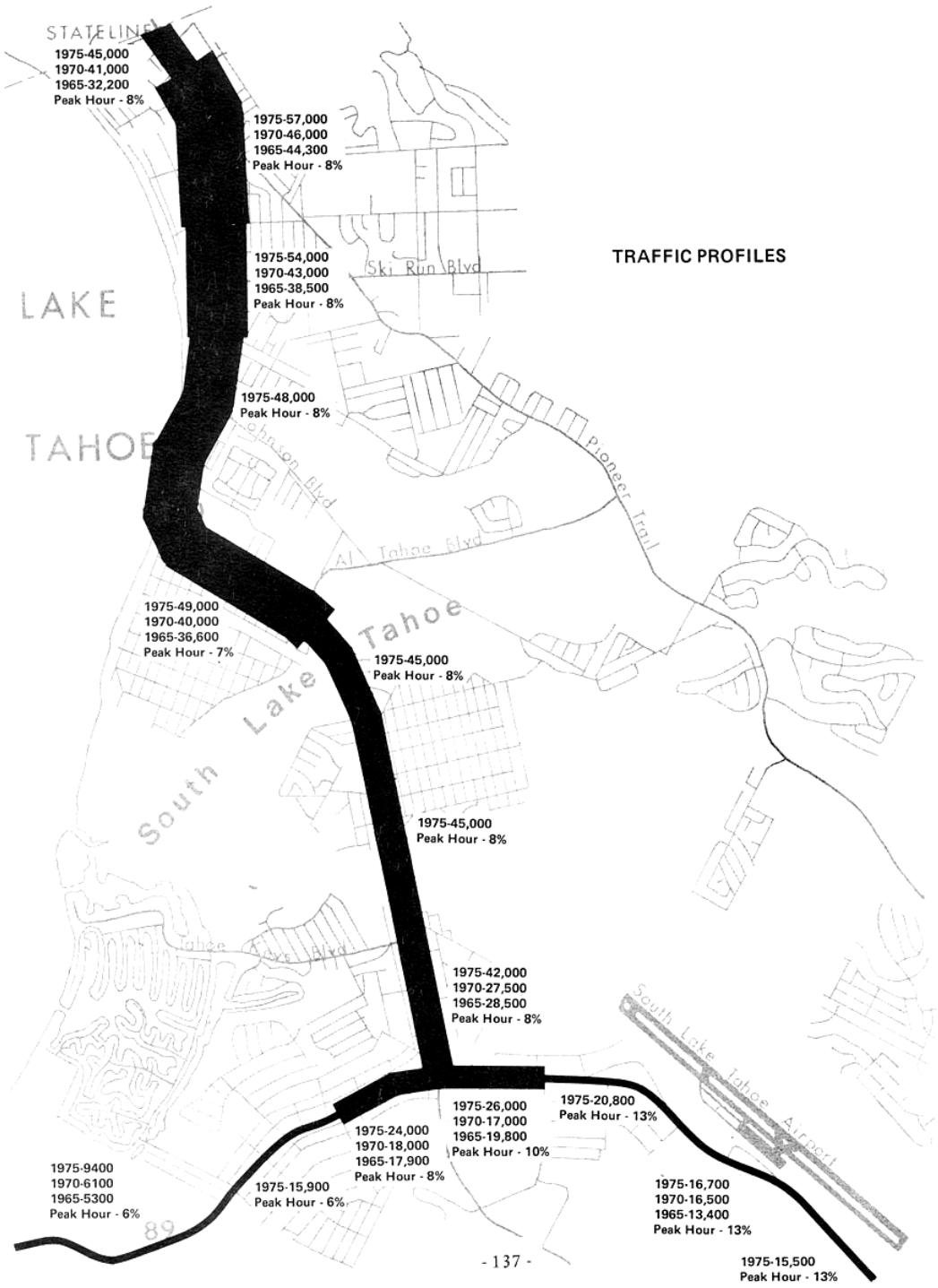


Figure 3-14—Traffic volume at South Lake Tahoe, from 1976 CTRPA Regional Transportation Plan.

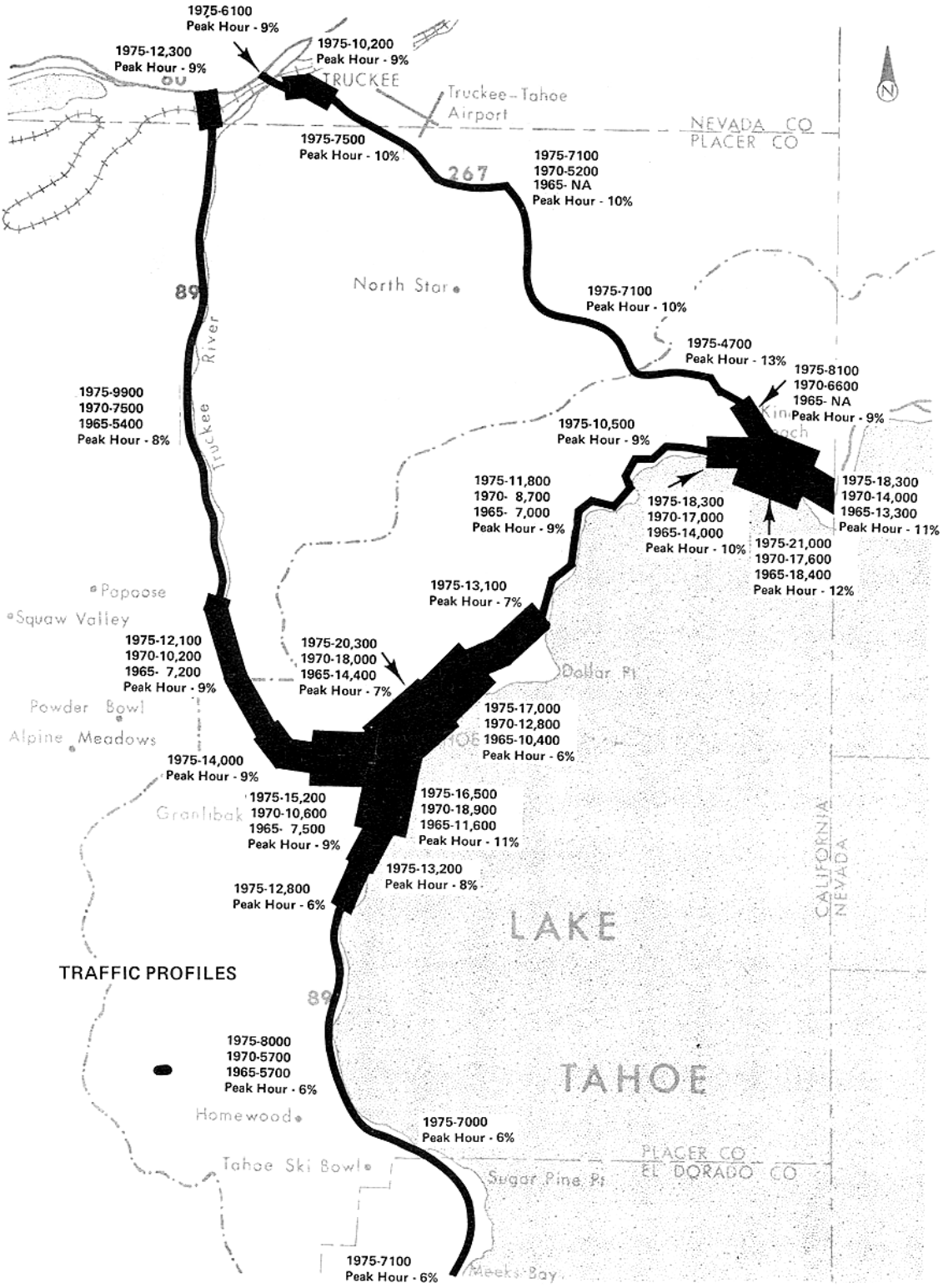


Figure 3-15—Traffic volume at the north and west shores of Lake Tahoe, from the 1976 CTRPA Regional Transportation Plan.

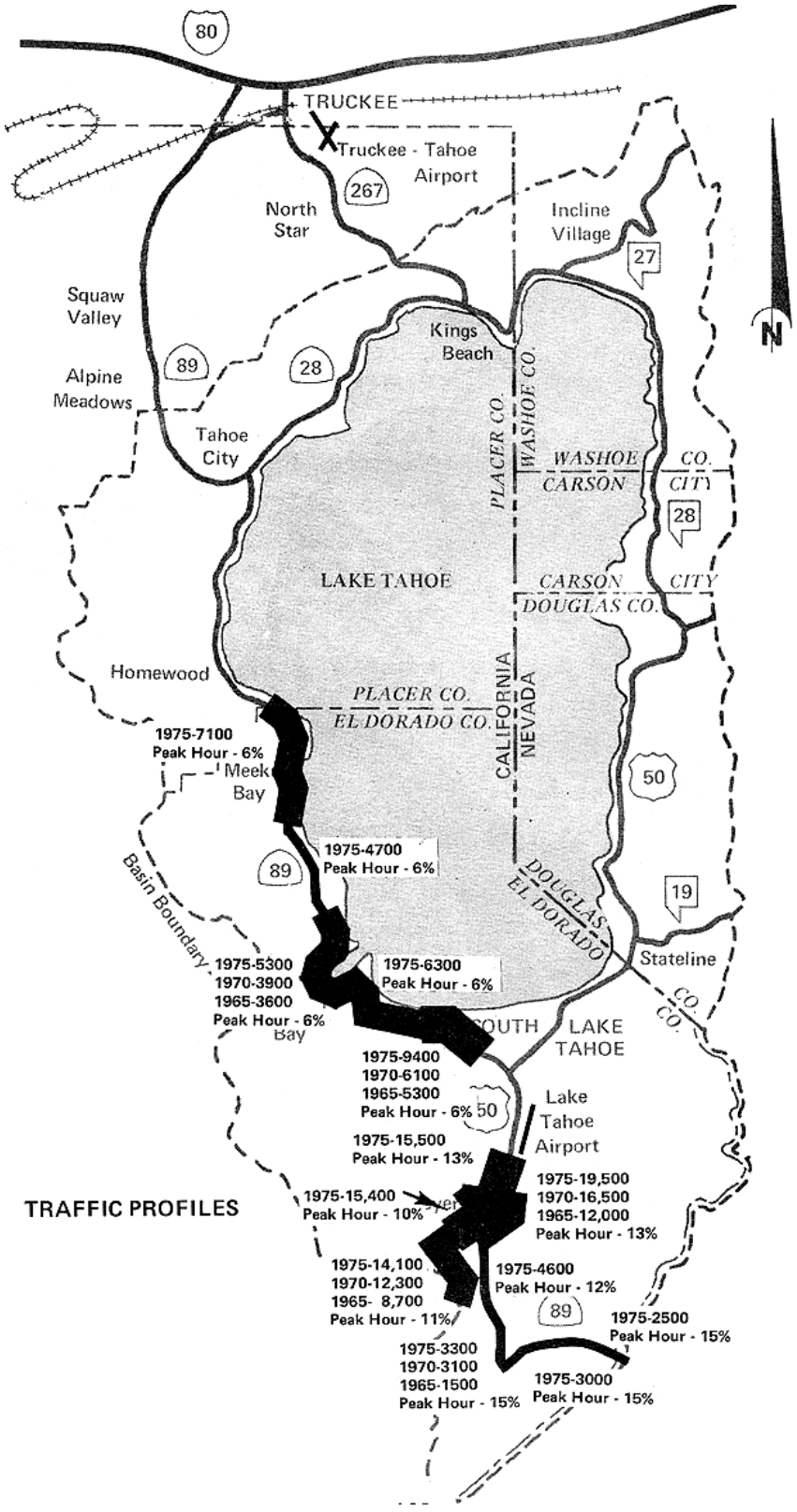


Figure 3-16—Traffic volume on highways 89 and 50 on the west and south shores of Lake Tahoe, from the 1976 CTRPA Regional Transportation Plan.

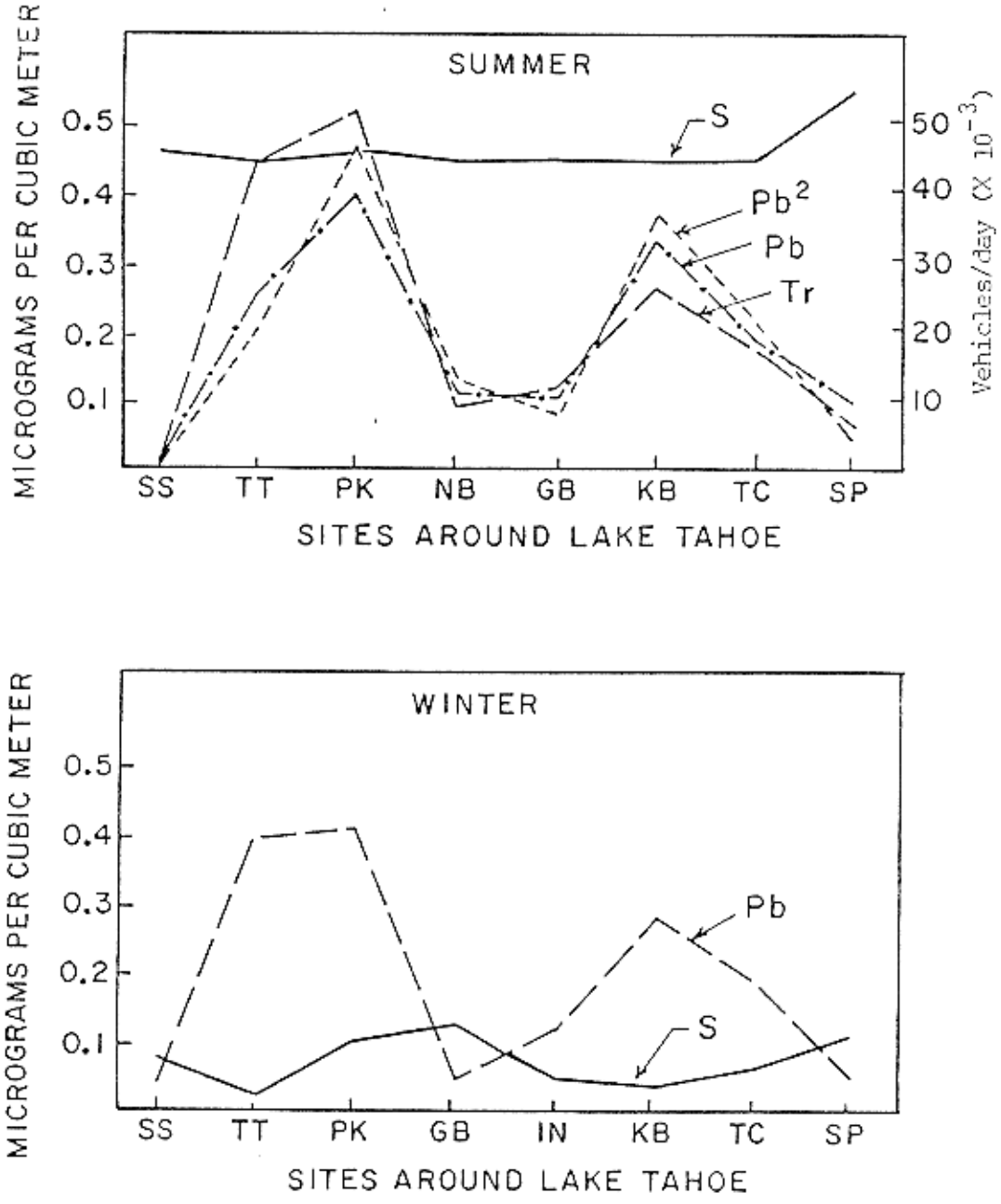


Figure 3-17—Concentration of lead and sulfur, correlated with traffic volume at sites around Lake Tahoe for summer and winter, from the 1979 ARB/UC Davis Air Quality study.

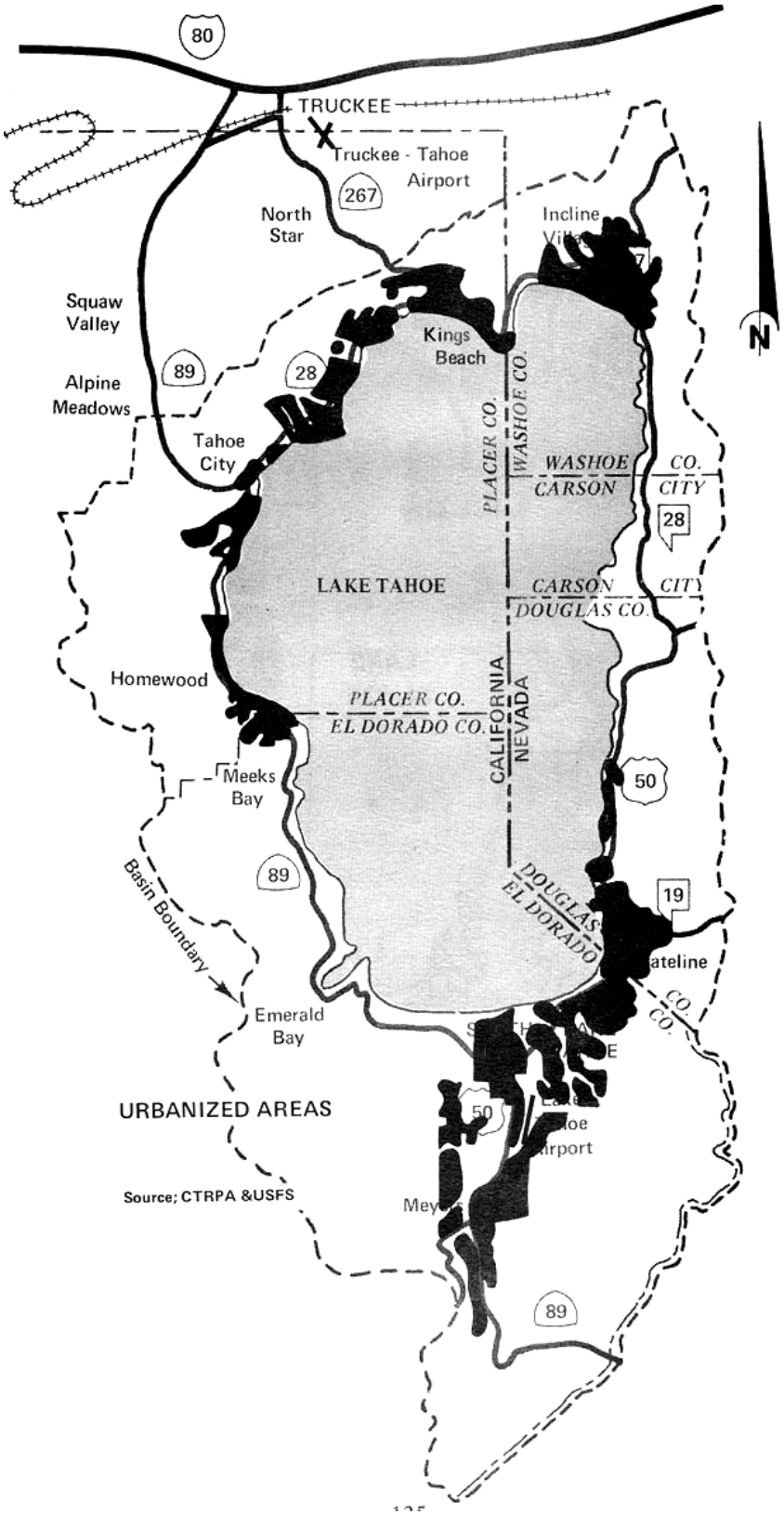


Figure 3-18—CTRPA map of urbanized areas, from 1976 Regional Transportation Plan.

Lake Tahoe Airshed Model (LTAM) for NO_x

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DELTA Group, University of California, Davis

Values used in equations (User Input Variables)

Between Cell transfer rate (over water)	0.94	94	% Goes into the next cell
Between Cell transfer rate (over forest)	0.94	94	% Goes into the next cell
Long range transport (from out of basin)	0	µg/m³	

Road NO_x	Manual Input	µg/m³
Interstate 80	100.0	µg/m³
Highway 267 from Truckee to KB	14	µg/m³
Highway 89 from Truckee to Squaw	20	µg/m³
Highway 89 from Squaw to Tahoe City	24	µg/m³
Tahoe City Local	40	µg/m³
Highway 28 from TC to Kings Beach	26	µg/m³
Highway 28 Kings Beach to Incline	36	µg/m³
Incline Local	42	µg/m³
Highway 431 over Mt. Rose	6	µg/m³
Highway 28 from Incline to 50	7	µg/m³
Highway 50 over Spooner	24	µg/m³
Highway 50 Glenbrook to Stateline	24	µg/m³
Highway 207 Kingsbury Grade	6	µg/m³
Stateline South Lake Tahoe	84	µg/m³
Pioneer Trail	10	µg/m³
Highway 50 Echo Summit to Meyers	28	µg/m³
Highway 50 Meyers to the "Y"	30	µg/m³
Highway 89 from "Y" to Camp Richardson	18	µg/m³
Highway 89 from CR to Meeks Bay	12	µg/m³
Highway 89 from Meeks Bay to TC	50	µg/m³
Highway 89 over Luther Pass	10	µg/m³
Kings Beach Local	42	µg/m³
Meyers Local	30	µg/m³
Urban NO_x emission	15	µg/m³

Lake cell equation (type B with variable wind) for Summer Day

proportion north-west wind =	0.1	10	% N-W Wind
proportion west wind =	0.3	30	% W Wind
proportion south-west wind =	0.6	60	% S-W Wind
These must sum to one!	1		

Lake cell equation (type C with variable wind) for Summer Day

proportion north-west wind =	0.6	60	% N-W Wind
proportion west wind =	0.3	30	% W Wind
proportion south-west wind =	0.1	10	% S-W Wind
These must sum to one!	1		

Lake cell equation (type B with variable wind) for Summer Night

proportion north-west wind =	0.3333	33.33	% N-W Wind
proportion west wind =	0.3333	33.33	% W Wind
proportion south-west wind =	0.3333	33.33	% S-W Wind
These must sum to one!	0.9999		

Lake cell equation (type C with variable wind) for Summer Night

proportion north-west wind =	0.3333	33.33	% N-W Wind
proportion west wind =	0.3333	33.33	% W Wind
proportion south-west wind =	0.3333	33.33	% S-W Wind
These must sum to one!	0.9999		

Lake cell equation (type B with variable wind) for Winter

proportion north-west wind =	0.3333	33.33	% N-W Wind
proportion west wind =	0.3333	33.33	% W Wind
proportion south-west wind =	0.3333	33.33	% S-W Wind
These must sum to one!	0.9999		

Lake cell equation (type C with variable wind) for Winter

proportion north-west wind =	0.3333	33.33	% N-W Wind
proportion west wind =	0.3333	33.33	% W Wind
proportion south-west wind =	0.3333	33.33	% S-W Wind
These must sum to one!	0.9999		

Figure 3-19a—Input page for roadway NO_x and wind parameters in the LTAM.

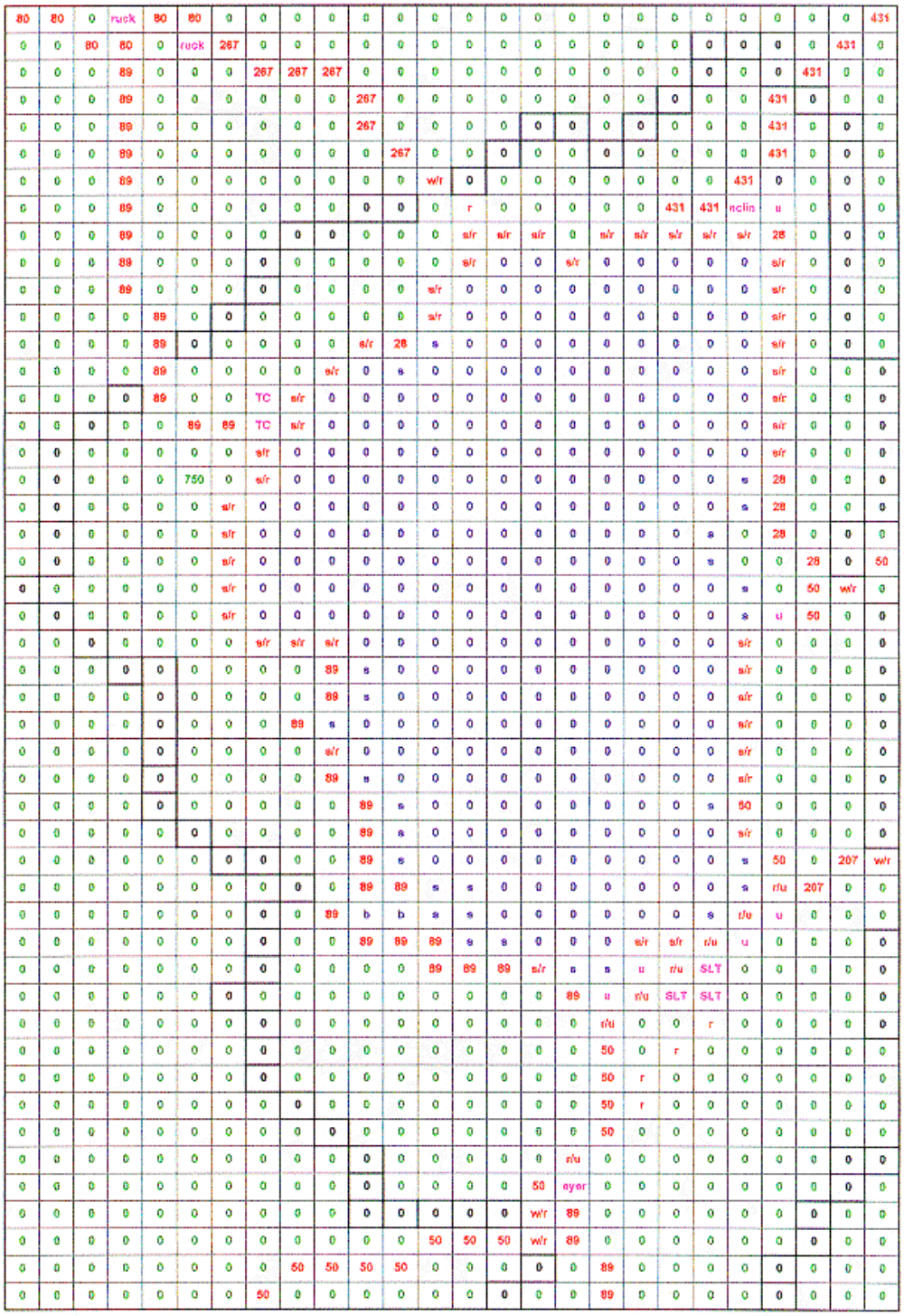


Figure 3-19b—Input map for the LTAM. Note input of source is possible for any forest (green) or lake (blue) square. Each square represents 2.56 square kilometers in the LTAM. Road inputs are entered on a separate sheet.

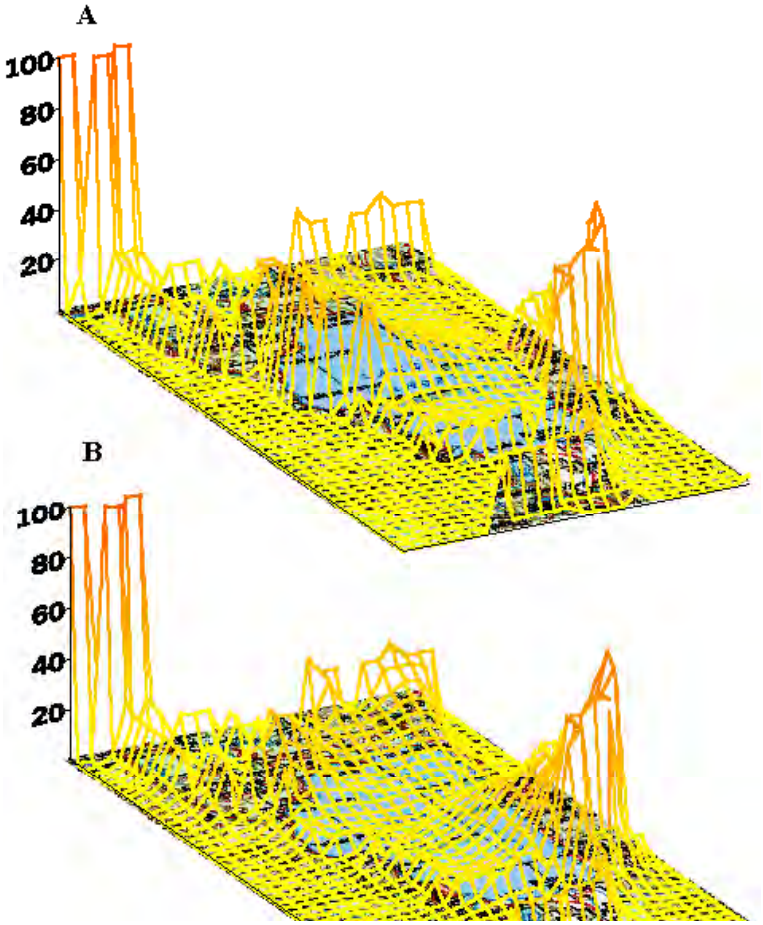


Figure 3-20—LTAM output for NO_x for average summer day (top) and summer night (bottom) 12-hour period. The baseline is set a 0 µg/m^3 and is at a maximum at 100 µg/m^3. Note that during the day the LTAM predicts significant transport of NO_x from the Highway 89 corridor extending southeast from Tahoe City. Although Tahoe City is not a large urban center, the addition of pollutants from I-80 and Highway 89 is predicted to be highly important for pollutant interaction with the Lake Tahoe surface. The output for summer night stagnation from the LTAM predicts that pollutants stay in close contact with the lake during this period.

- Human health and regulatory impacts:
  - Carbon monoxide, gas
  - $PM_{2.5}$ particles, fine particles
  - PM_{10} particles, intermediate sized particles
  - Ozone, gas
- Forest health:
  - Ozone, gas

Then for each of these impacts, model analysis can be accomplished for three conditions that dominate the weather in the Lake Tahoe basin-- summer day summer night winter and spring for some parameters.

Currently, efforts are focused on nitrogenous pollutants (NO, NO_2, NO_x, ammonium nitrate, nitric acid, and nitrogenous organic material) phosphate (TSP, PM_{10}, and $PM_{2.5}$ particles) and fine soils because of their importance in lake eutrophication and atmospheric visibility concerns. Gaseous pollutants, such as ozone (O_3) and carbon monoxide (CO), which are important for forest and human health, can be modeled using the general gas model portion of the LTAM for all three

meteorological regimes. For atmospheric inputs to lake clarity, knowledge of the concentration is not adequate by itself and needs what fraction actually enters the water by either direct (surface deposition) or indirect means. This deposition and uptake by the lake should be the subject of future research in the Lake Tahoe basin.

Derivation of Model Parameters

Within the Lake Tahoe basin a number of particulate and gaseous pollutants are important for lake clarity, forest health, and human health. The ability of the LTAM to predict concentration of these species throughout the basin lies in the quality of data input into the model. Invariable pollutant parameters included in the model are derived from the aforementioned studies (CARB 1974; CARB/UCD 1979). The derivation of the model parameters is broken down into pollutant type by specific concern. In this effort, a comprehensive representation of each pollutant responsible for each individual ecosystem concern prioritized above is given.

In Table 3-2 and the summaries that follow, actual measured values are in bold-face type, certain to $\pm$ 15%. All parameters in normal type are predictions based on theory, extrapolations, or estimates, with a nominal uncertainty of $\pm$ 30%. Parameters in italics are even more uncertain, varying by up to a factor of 2 in either direction, while estimates, some of the crudest sort, are in italics plus a question mark. Parameters listed include: C_{uw}, which is the upwind concentration in micrograms per cubic meter ($\mu g/m^3$), S (local), which is the local source of the pollutant, D_w, which is the dispersion of pollutant per km over water, D_f, which is the dispersion of pollutant over forest, v_d, which is the velocity of deposition, and finally a parameter that is the ratio of efficiency for haze or retention in the lake, or the human health-based standard.

Pollutants Tied to Lake Clarity

Nitrogen oxides (NO_x)—Upwind out-of-basin NO_x sources are set to zero (Figure 3-19). Although there is likely some input of NO_x from the Highway 50 and Highway 80 corridors, data supporting this hypothesis do not exist. With the new Echo Summit CARB site, there will soon be data on this source. For local roadway NO_x, we use the results of a comparison of traffic and NO_x concentration at sites around the basin (Figure 3-21), where 50,000 vehicles/day equals a concentration in major roadway cells of 120 $\mu g/m^3$. We then can include a technological improvement factor based on Highway 50 traffic increases over the period from 1980 to 1994 (x%) and the observed decrease of pollutants at the South Lake Tahoe CARB site (y%). Using +15% for x and - 20% for y, we can arrive at a value of 44% lower than the estimated source from Figure 3-21, or 84 $\mu g/m^3$ NO_x per 50,000 vehicles/day. This new value then is coded into each of the 23 model road segments (r) and scaled proportional to traffic volume within the typical estimates from the 1976 CTRPA traffic study. Traffic on any segment can be modified to observe the change in NO_x concentration, which then is propagated downwind. Note that the CARB 1973 measurements were not always close to the largest road; while some were almost next to the road (King's Beach, for example), others were quite far removed (Tahoe Keys, Nevada Beach). On the average, sites were within half a km of the road. Thus, some urban sources also were included in the measurement.

For the cells coded "urban" (u) but lacking a major road, we used an estimate of traffic density based on a few measurements (CARB 1979-1994) and the California emission fraction of roadway to nonroadway NO_x sources. However, because the area lacks heavy industry, this ratio had to be lowered, while heavier local space heating, even in summer but especially in winter, raises the ratio. Urban cells are coded with a fixed value of 21 $\mu g/m^3$. These sources then are added to all cells marked with highway number, city name, r, r/u, and u in the LTAM input page.

Nitrogenous particles—The source of nitrate particles (NO_3) is largely upwind transport in the

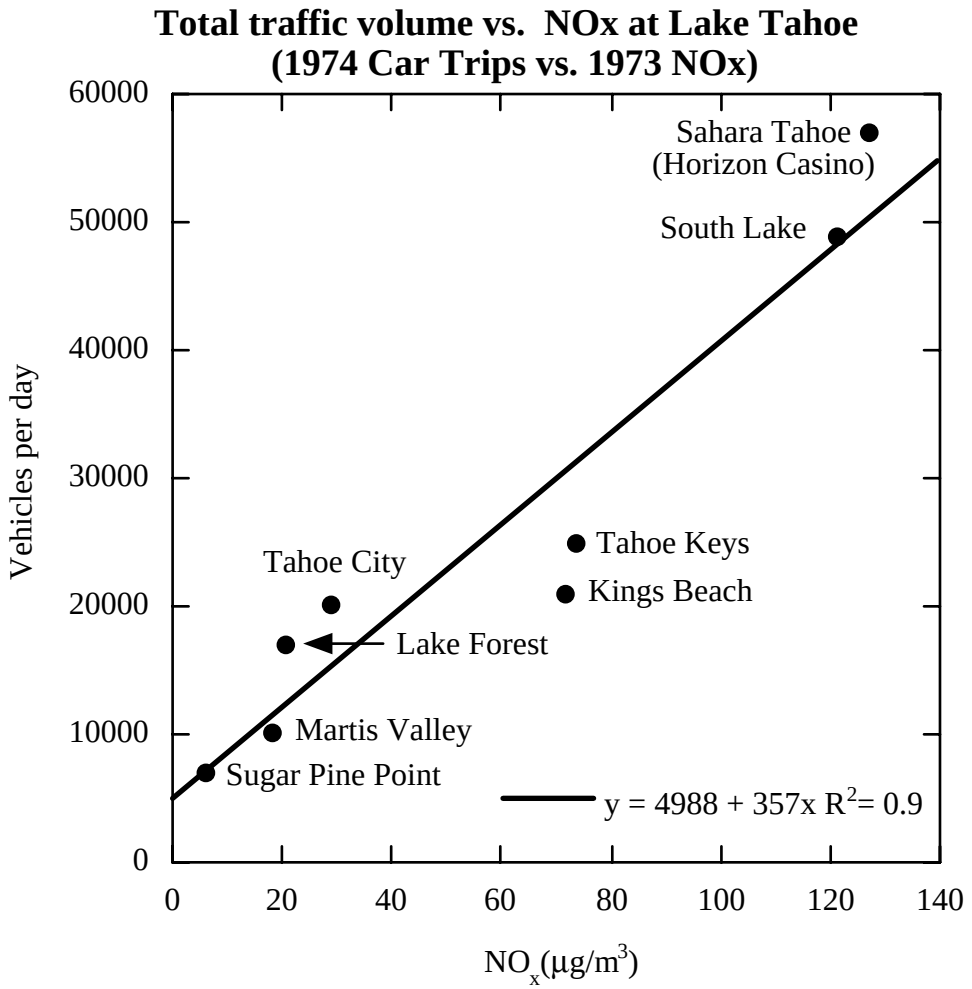


Figure 3-21—Correlation between traffic volume and NO_x concentration in the Lake Tahoe basin. The traffic data is from the 1974 CalTrans study, and the NO_x data is from the 1973 ARB study. Note that at 5,000 cars (the y-intercept) NO_x is seen as negligible for purposes of the LTAM.

summer, labeled t, and from local sources in the winter (Figure 3-11). The winter nitrate values correlate weakly with both NO_x (automotive) and wood smoke (urban). Ammonium (NH_4) is derived from ammonium sulfate and ammonium nitrate and thus also shares the same summer-winter dichotomy. While there is no transport into the basin at night, the long residence time predicts that the basin is uniformly filled with fine nitrate particles each summer night left over from the previous day. Published nitrate values are 24-hour averages.

Organic nitrogen arises almost entirely from such biological sources as pollen and from such biodebris as pine needles. The small amount of data on this potentially large source is weak. The LTAM uses values that are based on summer pollen measurements, using CARB 1973 data from TSP samplers with a roughly 30 micrometer diameter intake restriction. The potential nitrate component of the biodebris then is estimated and set as a default (i.e., no variable input to the model).

Phosphorous—Phosphorus is found only in nanogram amounts in $PM_{2.5}$ particles, but significant levels were seen in a limited number of samples collected in 1970s before strict adherence to PM_{10} and $PM_{2.5}$ collection was implemented. Thus, we

assume that most phosphorus occurs in particles above 10 micrometers in diameter but less than 30 micrometers aerodynamic diameter. This latter point is important because particles that occur in flakes, such as many types of ash, may be much larger than 30 microns in lateral dimensions but settle slowly to the surface and thus may transport more efficiently than expected based only on particle size. Although only limited data on phosphorous concentration of super-PM_{10} particles exist, deposition studies by the Tahoe Research Group at the University of California at Davis indicate a significant atmospheric contribution of this important nutrient (Jassby 1994).

Fine soil particles—Local fine soils have a roughly equal local and transported component, set at 1/2 in the model (Figure 3-11). Transported sources are in spring, summer, and fall and are assumed to be uniform across the basin. The local source of fine particles is largely from roadways, and particles are usually about 10 microns in size. This can be seen from the ratio of TSP to PM_{10}, which is typically 0.5. These soils also have a phosphorus component, but the amounts are low and the availability for biological activity is unknown.

NO_x

	C_{uw}	S (local)	D_w	D_f	v_d	Retention in lake
Summer day	0.08	r, u	0.9/km	**0.4/km**	2 cm/s	0.1
Summer night	0.07	r, u	0.9/km	0.4/km	2 cm/s	0.1
Winter	0.04	r, u	0.9/km	0.15/km	2 cm/s	0.1

NO_3:

	C_{uw}	S (local)	D_w	D_f	v_d	Retention in lake
Summer day	**0.4**	t, u	1.0/km	1.0/km	0.03 cm/s	1.0
Summer night	**0.4***	t, u	1.0/km	1.0/km	0.03 cm/s	1.0
Winter	0	r, u	0.8/km	0.15/km	0.03 cm/s	1.0

NH_4:

	C_{uw}	S (local)	D_w	D_f	v_d	Retention in lake
Summer day	**0.4**	t, u	1.0/km	1.0/km	0.03 cm/s	1.0
Summer night	**0.4***	t, u	1.0/km	0.6/km	0.03 cm/s	1.0
Winter	0	r, u	0.15/km	0.3/km	0.3 cm/s	1.0

Organic Nitrogen:

	C_{uw}	S (local)	D_w	D_f	v_d	Retention in lake
Summer day	*1.5*	f	0.4/km	0.150/km	2 cm/s	1.0
Summer night	*1.5*	f	0.15/km	0.05/km	2 cm/s	1.0
Winter	?	?	0.15/km	0.05/km	2 cm/s	1.0

Phosphorus:

	C_{uw}	S (local)	D_w	D_f	v_d	Retention in lake
Summer day	?	u, f	0.4/km	0.15/km	2 cm/s	1.0
Summer night	?	u, f	0.15/km	0.05/km	2 cm/s	1.0
Winter	?	u	0.15/km	0.05/km	2 cm/s	1.0

Fine soil particles:

	C_{uw}	S (local)	D_w	D_f	v_d	Retention in lake
Summer day	1.4	t, r	0.4/km	0.15/km	2 cm/s	1.0
Summer night	1.4	t, r	0.15/km	0.05/km	2 cm/s	1.0
Winter	1.1	r	0.15/km	0.05/km	2 cm/s	1.0

Pollutants Tied to Atmospheric Visibility

Visibility in the Lake Tahoe basin is probably the best understood of the major air quality impacts, largely due to the successful TRPA effort to measure and analyze visibility as part of the basin carrying capacity exercise that began in the late 1980s. These capacities were evaluated for both regional (basin-wide) and subregional (South Lake Tahoe) scales and are summarized in Molenar et al. (1994). The relative importance of each parameter is given in Table 3-3.

Organic compounds—Organic matter in the atmosphere over Lake Tahoe is overwhelmingly derived from wood smoke from upwind, urban, or forest sources. There is a contribution, however, from vehicles that can become important in winter in heavily traveled corridors. In this component, visibly smoking vehicles, including older cars and diesel cars, trucks, and buses, dominate the source.

Nitrogenous particles—The sources and implications of nitrogenous particles are described above; here, we include only the visibility component.

Sulfate particles—Sulfate particles are overwhelmingly derived from upwind transport in both winter and summer (Figure 3-11). Thus, they are assumed to be uniform across the basin for the purposes of the model.

Fine soil particles—The implications and sources of fine soil particles are described above; included here is only the visibility portion.

NO_3:

	C_{uw}	S (local)	D_w	D_f	v_d	Efficiency for haze
Summer day	**0.4**	t, u	1.0/km	1.0/km	0.03 cm/s	1
Summer night	**0.4**	t, u	1.0/km	1.0/km	0.03 cm/s	1
Winter	0	u, r	0.8/km	0.15/km	0.03 cm/s	1

NH_4:

	C_{uw}	S (local)	D_w	D_f	v_d	Efficiency for haze
Summer day	**0.4**	t, u	1.0/km	1.0/km	0.03 cm/s	1
Summer night	**0.4**	t, u	1.0/km	0.6/km	0.03 cm/s	1
Winter	0	u, r	0.15/km	0.3/km	0.03 cm/s	1

Sulfate particles:

	C_{uw}	S (local)	D_w	D_f	v_d	Efficiency for haze
Summer day	**0.4**	t	1.0/km	1.0/km	0.03 cm/s	1
Summer night	**0.4**	t	1.0/km	1.0/km	0.03 cm/s	1
Winter	01	u, r	0.8/km	0.15/km	0.03 cm/s	1

Fine soil particles:

	C_{uw}	S (local)	D_w	D_f	v_d	Efficiency for haze
Summer day	**0.6**	t, r	0.4/km	0.15/km	2 cm/s	0.3
Summer night	**0.6**	t, r	0.15/km	0.05/km	2 cm/s	0.3
Winter	**0.1**	r	0.15/km	0.05/km	2 cm/s	0.3

Table 3-3—Contribution of fine aerosol components to visibility at Lake Tahoe.

Regional Reconstructed Scattering, Absorption, and Extinction (Mm^{-1}) Bliss State Park, Fall 1990 to Summer 1992					
Aerosol b_{scat}	**Spring**	**Summer**	**Fall**	**Winter**	**Yearly**
Sulfates	3.4	4.7	3.0	1.3	3.0
Nitrates	1.7	1.3	1.3	1.3	1.4
Organic Carbon (OC)	2.3	4.2	5.2	2.9	3.6
Light Absorbing Carbon (LAC)	0.5	0.6	0.6	0.3	0.5
Fine Soil	0.9	0.6	0.4	0.3	0.6
Course Mass	2.3	2.6	2.3	2.0	2.3
Total b_{scat}	11.1	14.0	12.8	8.1	11.4
b_{abs}	5.0	7.4	7.8	4.4	6.2
Rayleigh b_{scat}	10.0	10.0	10.0	10.0	10.0
Total b_{scat}	26.1	31.4	30.6	22.5	27.6
Visual Range (km)	150	125	130	175	140

Subregional Reconstructed Scattering, Absorption, and Extinction (Mm-1) South Lake Tahoe, Spring 1989 to Summer 1992					
Aerosol b_{scat}	**Spring**	**Summer**	**Fall**	**Winter**	**Yearly**
Sulfates	4.3	6.0	3.8	2.1	4.3
Nitrates	2.1	1.7	2.1	4.3	2.6
Organic Carbon (OC)	8.8	7.5	11.4	22.4	12.7
Light Absorbing Carbon (LAC)	1.7	1.5	2.1	3.2	2.1
Fine Soil	1.9	1.4	1.1	1.3	1.4
Course Mass	7.1	8.1	7.3	13.0	8.9
Total b_{scat}	25.9	26.2	27.8	46.3	32.0
b_{abs}	22.4	20.7	28.2	42.8	28.5
Rayleigh b_{scat}	10.0	10.0	10.0	10.0	10.0
Total b_{ext}	58.3	56.9	66.0	99.1	70.5
Visual Range (km)	65	70	60	40	55

Source: Molenar et al. 1994

Pollutants Tied to Forest Health

The primary air pollution impact on the Sierran forest is ozone (Cahill 1996). The key parameter that best matches the decline of the most important sensitive species, Jefferey pine, is ozone dose (concentration multiplied by time) above 0.09 ppm. This level of pollutant is rarely seen at Lake Tahoe, and surveys of ozone damage (Pedersen 1989) show only marginal signs of impact. However, unlike almost any other California location, ozone levels slowly continue to climb at Lake Tahoe and are approaching the point where damage probably will occur in the future. This O_3 increase is most likely due to the rapid development of the foothill communities east of Sacramento and Stockton.

Air Pollutants with Health and Regulatory Issues

Carbon monoxide gas—Carbon monoxide (CO) is a human health pollutant that is derived primarily from combustion. A secondary, and more minor, source of CO is from oxidation of methane and nonmethane hydrocarbons in the formation of ozone. At Lake Tahoe the CO measured at most sites is locally generated. Currently, CO is not a

major concern in the Lake Tahoe basin, as advances in combustion technology have largely curbed this source. In fact, CARB data indicate a leveling off or decline of CO at most measured sites in the basin.

Fine and intermediate sized atmospheric particles—Fine or $PM_{2.5}$ particles have sizes that usually are dominated by particles around 0.5 micrometers in diameter. The settling velocities of such particles are extremely small but are readily incorporated into fog and rain, and are removed by wet deposition. Roughly half the measured concentration each summer is from upwind sources and half is from local sources, while in winter the sources are more than 80 percent local. The mixture of particles at South Lake Tahoe and Bliss State Park as a function of season is shown in Figure 3-22 and Table 3-4. The new US EPA federal standards are 65 $\mu g/m^3$, 24-hr, and 15 $\mu g/m^3$, annual average, although these standards are under review by the courts and the EPA (see Issue 3 regarding air quality standards).

PM_{10} or intermediate sized particles include some transported particles in summer, because PM_{10} includes $PM_{2.5}$ particles, with roughly half transported, half local. In winter, they are again largely local in origin. The mix of particles at South Lake Tahoe and Bliss State Park as a function of season is shown in Figure 3-22. A few violations of the 24-hr California standard have occurred.

Tropospheric ozone—Ozone (O_3) at Lake Tahoe is low to moderate during most of the

O_3:

	C_{uw}	S (local)	D_w	D_f	v_d	CA Standard for Tahoe
Summer day	0.08	t	1.0/km	1.0/km	2 cm/s	0.09 ppm
Summer night	0.07	t	1.0/km	1.0/km	2 cm/s	0.09 ppm
Winter	0.04	t	1.0/km	1.0/km	2 cm/s	0.09 ppm

Carbon monoxide:

	C_{uw}	S (local)	D_w	D_f	v_d	CA Standard for Tahoe
Summer day	0	r	0.9/km	**0.3/km**	2 cm/s	0.06 ppm
Summer night	0	r	0.9/km	0.3/km	2 cm/s	0.06 ppm
Winter	0	r	0.9/km	0.3/km	2 cm/s	0.06 ppm

$PM_{2.5}$:

	C_{uw}	S (local)	D_w	D_f	v_d	EPA Standard
Summer day	4	u, f, r	0.6/km	0.8/km	0.03 cm/s	65 $\mu g/m^3$
Summer night	4	u, f, r	0.3/km	0.6/km	0.03 cm/s	65 $\mu g/m^3$
Winter	2	u, f, r	0.15/km	0.3/km	0.03 cm/s	65 $\mu g/m^3$

PM_{10}:

	C_{uw}	S (local)	D_w	D_f	v_d	CA Standard
Summer day	7	u, f, r	0.4/km	0.15/km	2 cm/s	50 $\mu g/m^3$
Summer night	7	u, f, r	0.15/km	0.05/km	2 cm/s	50 $\mu g/m^3$
Winter	3	u, r	0.15/km	0.05/km	2 cm/s	50 $\mu g/m^3$

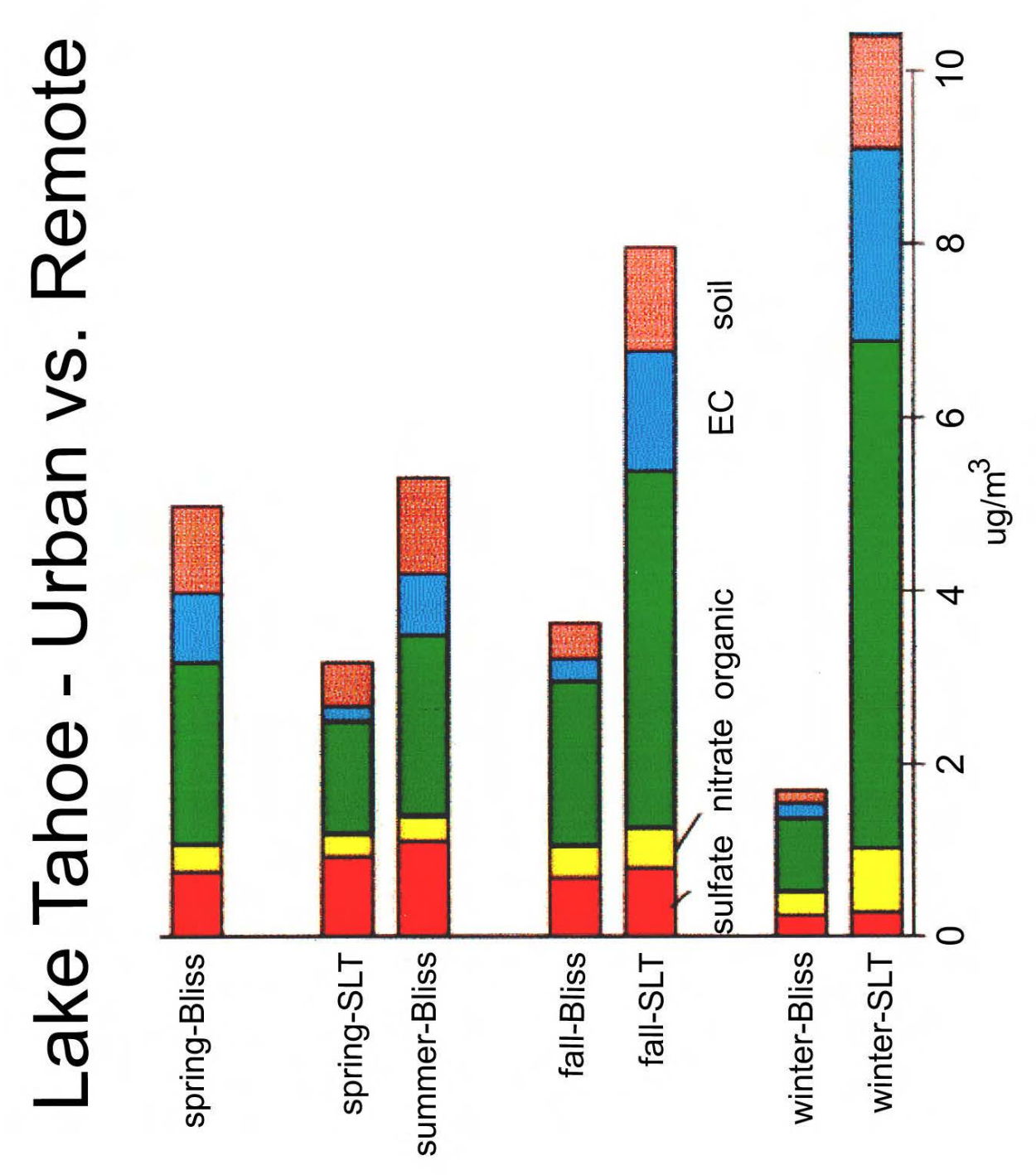


Figure 3-22—Comparison of aerosol components at South Lake Tahoe and D. L. Bliss State Park for both the winter and summer periods.

Table 3-4—Components of fine mass at Lake Tahoe and other Sierran/Cascadian sites.

Comparison of Sierra-Cascade Aerosol Concentrations from 1992 to 1993 High Elevation Sites

Major Constituents	(Micrograms/m^3)						
	Sequoia NP	Yosemite NP	Bliss SP	**South Lake Tahoe**	Lassen NP	Crater Lake NP	**Washington DC**
Coarse Mass	(x.09)						
PM_{10}	N.A.	11.00	5.85	**18.20**	7.05	6.21	**23.10**
Fine Mass							
$PM_{2.5}$	8.49	5.04	3.39	**9.65**	3.05	2.87	**19.70**
Estimated Sum	6.86	4.17	2.90	**9.21**	2.55	2.41	**18.50**
Organics	2.94	1.84	1.16	**5.52**	1.18	0.98	**5.12**
Sulfates	2.14	1.19	0.84	**1.03**	0.65	0.62	**9.54**
Nitrates	1.58	0.48	0.29	**0.53**	0.11	0.14	**2.41**
Soil	0.73	0.52	0.44	**0.88**	0.03	0.39	**1.03**
Smoke Tracers							
b(abs) (10-8m-1)	13.50	7.83	5.66	**29.30**	4.99	5.25	**41.80**
Estimated Mass (micrograms/m^3)	0.14	0.08	0.06	**0.29**	0.04	0.05	**0.42**
KNON (ng/m^3)	37.89	23.80	14.80	**41.60**	12.40	6.58	**16.40**
Trace Elements	(Nanograms/m^3)						
Nickel	0.19	0.09	0.07	**0.13**	0.07	0.08	**3.53**
Copper	1.58	0.47	0.44	**1.41**	2.53	0.84	**4.76**
Zinc	3.12	1.55	1.29	**5.13**	1.52	3.33	**18.60**
Selenium	0.28	0.19	0.12	**0.12**	0.09	0.06	**2.08**
Bromine	2.65	1.56	1.16	**1.63**	0.91	0.75	**5.12**
Lead	1.29	0.78	0.68	**1.71**	0.53	0.96	**6.99**

Notes:
Sequoia x 0.9 entry corrects to Giant Forest elevation, 6,000 feet.
Sites in bold – urbanized.
Ni, As, and Se often below detectable limit.
NP = National Park.
SP = State Park.

year, with few violations of the state (0.09 ppm hr) standard and no violations of the state 8-hour or the federal 1-hour (0.12 ppm) standards. However, unlike almost any other California city, ozone levels continue to slowly climb in South Lake Tahoe and are approaching the point where violations probably will occur (Figure 3-23). This is likely due to transport of O_3 precursors emitted in the rapidly developing foothill communities east of Sacramento and Stockton.

Preliminary Validation of the LTAM

In order to determine the validity of the predictions derived from the LTAM it is necessary to perform some simple field experiments. For example, $PM_{2.5}$ sampling during a prescribed fire of

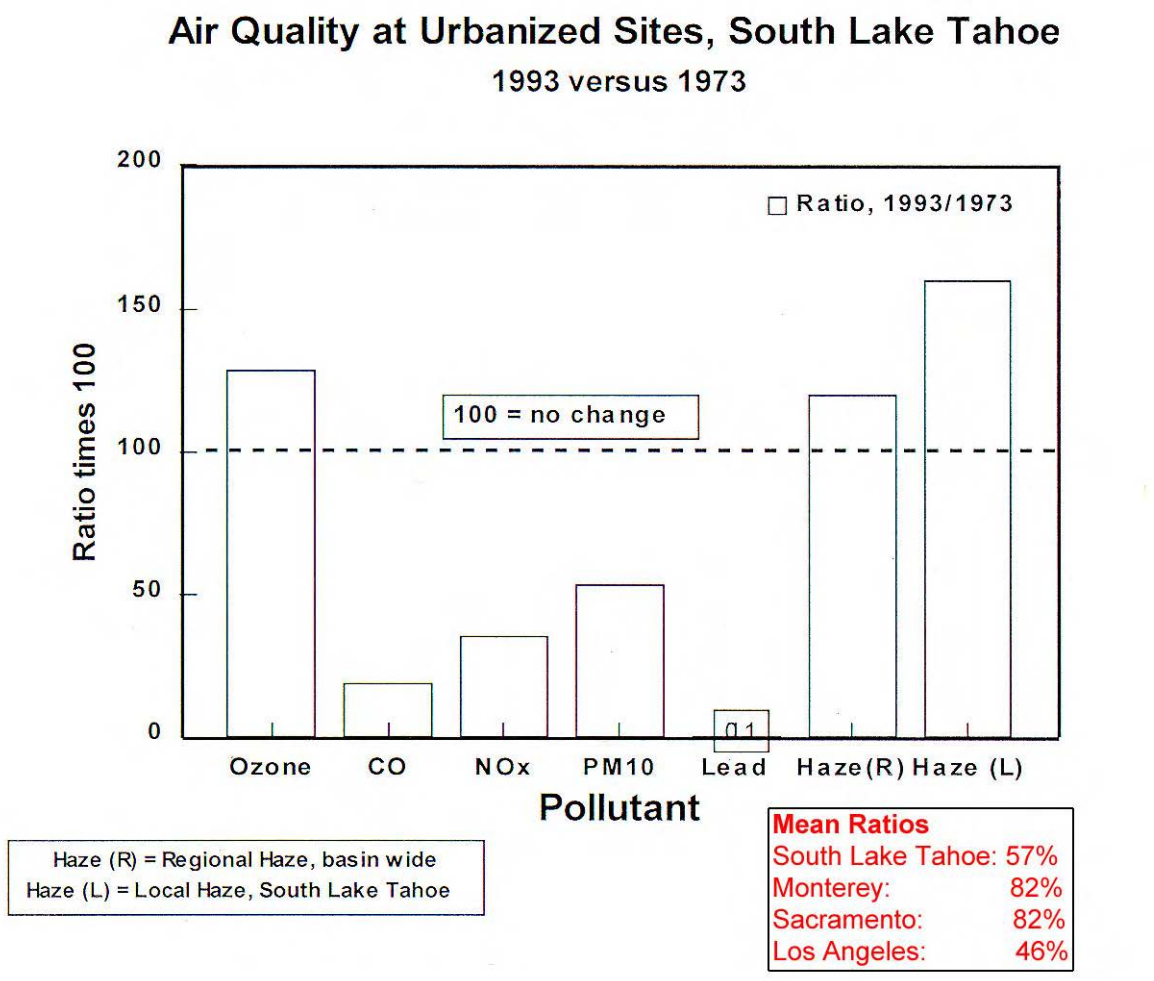


Figure 3-23—Change in concentration of pollutant and coefficient of haze at Lake Tahoe from 1973 to 1993. Note sharp reduction in CO, NO_x, PM_{10}, and lead over this period. Ozone increase at South Lake Tahoe is unique to urbanized areas over this period, possibly resulting from increased development of the foothill communities east of Sacramento.

magnitude similar to modeling scenarios would lead to qualitative validation of model output for the scenarios. As part of this validation effort, we were able to perform one limited experiment during the course of the assessment process for prescribed fire modeling. On June 9, 1999, a prescribed fire near Spooner Summit commenced. This fire, the Captain Pomin Prescribed Burn, consumed approximately 45 acres on June 9. The total planned burn area for this fire is 350 acres. For a fire of this size, the LTAM predicts (not shown, see historical fire output, Figure 3-24) a significant visibility reduction over Lake Tahoe for the inversion period, from sunrise until about 11 AM. Typically a west to southwest wind is present during the daytime, and most smoke will not directly affect the basin. However, in the late evening and early morning hours the inversion in the basin, as modeled by the "summer night" meteorological conditions in the LTAM, forces smoke to settle near the lake surface until the winds pick up again the following day. The LTAM preliminarily predicts that a 45-acre fire on the east side of the basin would obscure the west shore and mountains above during this inversion period. Photographs taken on the

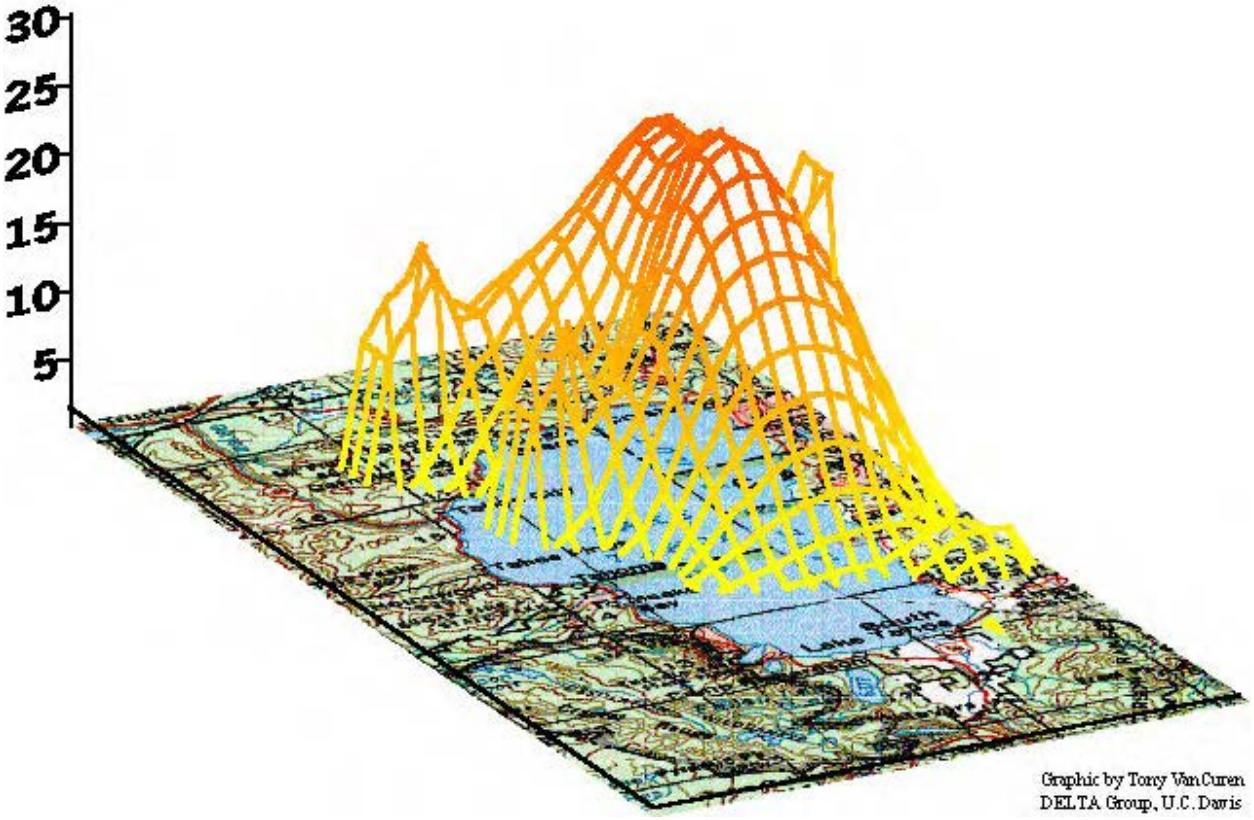


Figure 3-24—LTAM output for $PM_{2.5}$ concentration distribution in the Lake Tahoe basin (underlying map) from historical fire situation based on a 24-hour average. The inputs for this model run are three small wildfires (~10 acres), one in the Ward Creek Watershed, one in the forested area near Meeks Bay, and one near Sand Harbor on the east shore. The proposed federal 24-hour standard is 65 $\mu g/m^3$ for $PM_{2.5}$. The peak of 29 $\mu g/m^3$ is well below this standard and corresponds to a visibility range of more than 19 miles at lake level and more than 50 miles at ridge tops.

morning of June 10, 1999, from the lakeshore in Glenbrook, Nevada, qualitatively confirm this LTAM prediction (figures 3-25, 3-26, and 3-27). Furthermore, photographs taken from the Lake Tahoe overlook at Echo Summit on Highway 50 (Figure 3-28) indicate a rather uniform distribution of smoke over the lake, with a slightly greater density near the center. As discussed in Issue 1, Question 2, Section 4 for the hypothetical natural historical conditions, the LTAM predicts similar features. Most of the visible smoke from combustion is $PM_{2.5}$, due to the high efficiency for scattering light. Visible smoke then can be a good qualitative indicator of $PM_{2.5}$ concentration, which is what is modeled by the LTAM. At the time of this writing, quantitative mass measurements were unavailable for prescribed burns in the Tahoe basin. Future studies are expected to provide concentration and chemical composition of the smoke from fires that may have an impact on lake clarity and the ecosystem as a whole. Further research of this sort is sorely needed to determine the validity of any predictive model in general and the LTAM in particular.



Figure 3-25—Photograph of smoke from prescribed Captain Pomin fire looking southwest from Glenbrook, Nevada. The mountain range above the southwest shore is barely visible below Rubicon Peak, as preliminarily predicted by the LTAM (photo courtesy Steven S. Cliff).



Figure 3-26—June 10, 1999, photograph, looking northwest from Glenbrook, Nevada, showing the shoreline near Tahoe City completely obscured by smoke from prescribed Captain Pomin fire (photo courtesy Steven S. Cliff).



Figure 3-27—Photograph of west shore of Lake Tahoe, showing complete loss of visibility of the shoreline to the north and partial loss to the south. Taken from Glenbrook, Nevada, on June 10, 1999, following the prescribed Captain Pomin fire (photo courtesy Steven S. Cliff).



Figure 3-28—Photograph taken June 10, 1999, from Echo Summit. Smoke covering the Lake Tahoe basin the day following the 45-acre prescribed Captain Pomin fire near Spooner Summit reduced visibility over the lake below 15 miles.

Summary

The LTAM is designed for use as a heuristic tool to gather disparate sources of air quality data at Lake Tahoe into a consistent framework. The value of the LTAM is in its ability to predict air pollution impacts of both ambient conditions and specific source events. Sources of pollutants, such as fires, transportation, urban, space heating, and upwind transport can all be input into the model. Calculation of dispersion in the atmosphere and lake and forest deposition result from the LTAM. The most significant finding from the construction and use of the LTAM is that pollutants are most likely to deposit to the lake surface and hence potentially degrade lake clarity at times of intense inversion. Atmospheric inversion at Lake Tahoe is the most predominant meteorological condition during summer evenings and all day throughout the inter-storm winter period. Photographs taken during a recent prescribed burn near Spooner Summit preliminarily validate the predictions of the model. Although this validation is qualitative, it is the first approach to linking the predictive capabilities of the LTAM with empirical results from research studies. Further investigation of the source, transport, chemical transformation, and deposition mechanisms of atmospheric pollutants, both algal nutrients and fine particles, in the Lake Tahoe basin is imperative for integrating scientific and management-based models.

What are the scenarios that were developed for demonstration of the watershed models for the assessment, and what output is given by the LTAM?

Scenarios for watershed assessment modeling integration were developed to present the type of modeling results that are possible with single medium (in this case air quality) models designed specifically for the Lake Tahoe basin. The scenarios evaluated prescribed burns in the Ward Creek watershed on 40- and 20-year cycles occurring in October and a wildfire that would burn approximately 75 percent of the forested part of the Ward Creek watershed in August. In this modeling effort a number of parameters were derived that provide input to the LTAM.

The current integrated modeling scenario places prescribed burns in October for the Ward Creek watershed. Because October is the transition between summer and winter conditions, a combination of both meteorological regimes is represented. For the wildfire scenario, summer conditions are applied. No account is taken for specific meteorological conditions that may be present in a specific year, but rather the general LTAM meteorology for summer and winter.

Derivation of Model Input

Due to the fact that a wild or prescribed fire will dominate all other emission sources for particulate matter (PM) during October, road PM is set to 0 for the integrated fire scenario in the Ward Creek watershed. Urban emissions, however, are included and are derived from an estimated nonhighway traffic component plus the difference between the D. L. Bliss and South Lake Tahoe TRPA aerosol data. Following spring thaw, road aerosol emission is far from negligible. Model parameters for fire emission and loss rate are derived from a number of sources. Particulate emissions from fires is statistically derived from the USFS Grand Canyon Commission Fire Emission Project Database Model (VanCuren 1996). Data from 110 fires in the Lake Tahoe area dating back to 1980 were used to derive PM emission estimates. Forest and lake falloff parameters were derived from data collected during the 7,000+ acre/day Cleveland fire of 1992 (Figure 3-29).

Since the LTAM has a cell dimension of 2.56 km^2, emission numbers need to be calculated relative to the size of a theoretical "box" that has a two-dimensional area equivalent to one cell. The volume of the box is given by this area multiplied by the height of the air parcel within the box. In the case of both prescribed fires, the total area of the fires is less than one cell in the LTAM. For the wildfire, nearly eight full cells in the LTAM are used for the emission source. Derivation of pollutant emission factors involves calculating essentially three parameters, the volume of the box, wind speed, and particulate emission per unit area. The box volume is

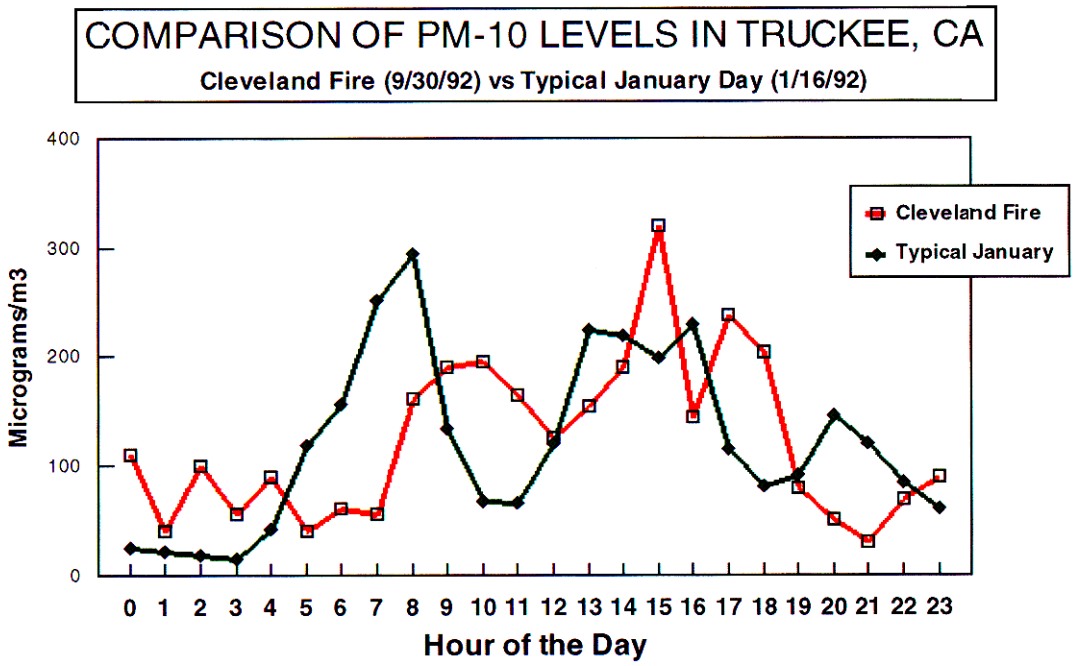


Figure 3-29—Diurnal concentration of $PM_{2.5}$ for a day during the 1992 Cleveland Fire and a typical winter day at Truckee, California. Note that on a typical winter day $PM_{2.5}$ concentration is equal in magnitude to the upwind 7,000-acre per day Cleveland Fire.

determined by area burned multiplied by the theoretical height of the box. Box height for PF1 is assumed to be 0.1 km, PF2 is 0.5 km, and WF is 3 km. These box heights are determined by observations of smoke from the various fire types. The wind speed is factored into the emission rate by the number of times clean air is transported into the box, i.e., at a wind rate of 1.6 km/hr, each cell in the LTAM would have an average air change of once per hour. Finally, emission per acre is determined as the average derived emission from the USFS Grand Canyon Commission Wildfire Emission Project Database Model (VanCuren 1996). For the current scenarios, this is determined to be 0.06 metric tons (MT) $PM_{2.5}$/acre, 0.06 MT PM_{10}/acre, and 0.09 MT TSP/acre. The error associated with these estimates is quite large, on the order of a factor of 10, but the LTAM predicted concentration based on a specific event (see previous section on validation) is accurate to within 20 percent, nevertheless. The total acreage of the Ward Creek watershed is 25.23 km^2 (6,234 acres), about 80 percent of which is forested. This gives 20.18 km^2 (4,986 acres) of forested area. The 40-year return burn period (2.5%/year) gives a fire size of 0.5 km^2 (124 acres), and the 20-year return burn period (5%/year) gives a fire size of 1.0 km^2 (248 acres). For the August wildfire, approximately 15 km^2 (3,700 acres) are burned, consuming 75 percent of forested area of the Ward Creek watershed.

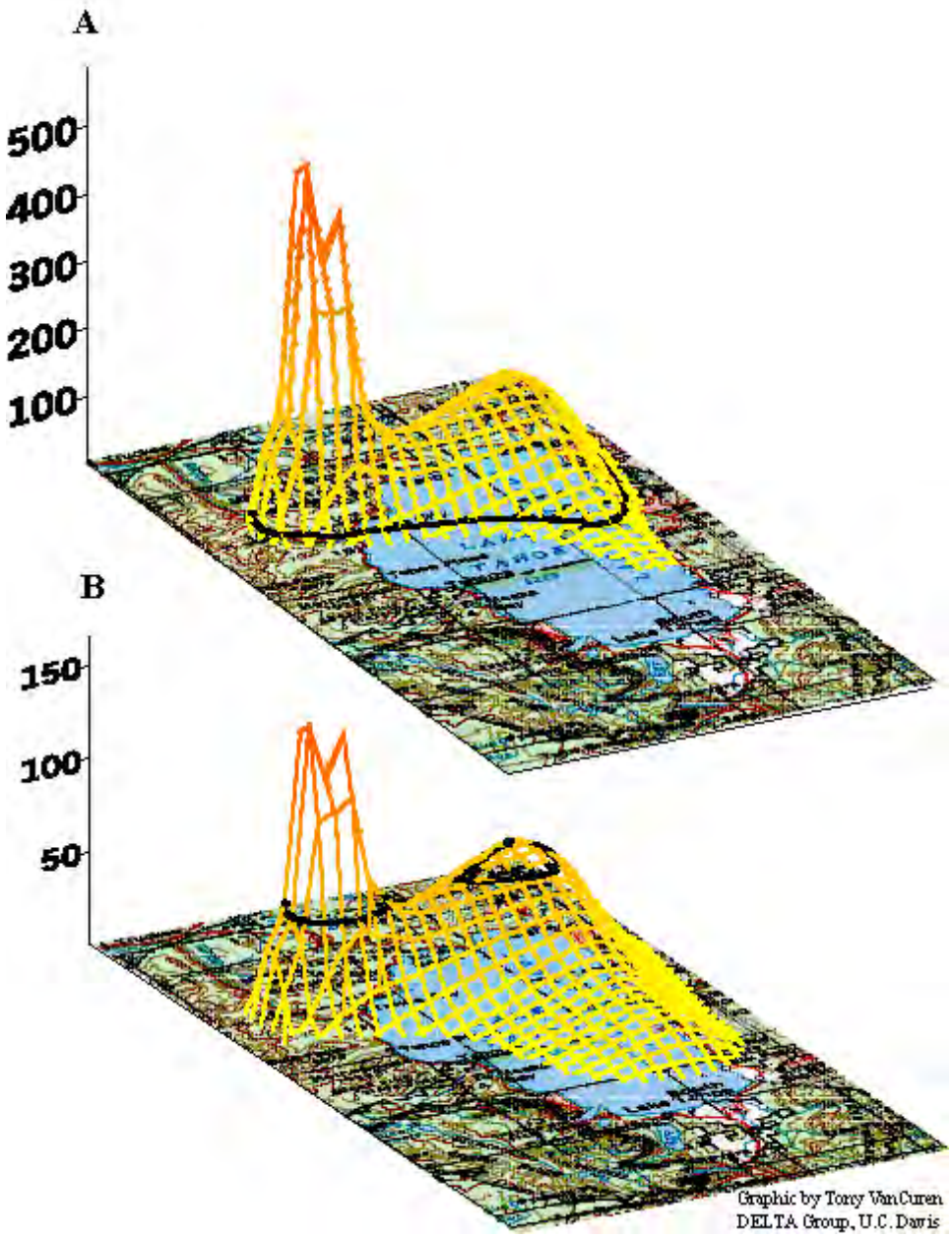
It is apparent from the emission estimates that over 90 percent of the PM_{10} falls in the $PM_{2.5}$ category. Furthermore, $PM_{2.5}$ is the primary pollutant effecting visibility, lake clarity, and human-health. For these reasons, the LTAM modeling output for these scenarios includes only $PM_{2.5}$. Although we focused on $PM_{2.5}$, using the LTAM it is possible to predict the concentration of a variety of pollutants across the basin. Other pollutants include TSP (total suspended particulate), NO_x, and hydrocarbons. Essentially any pollutant species that is known to be emitted from combustion can be examined.

Model Output for Scenario

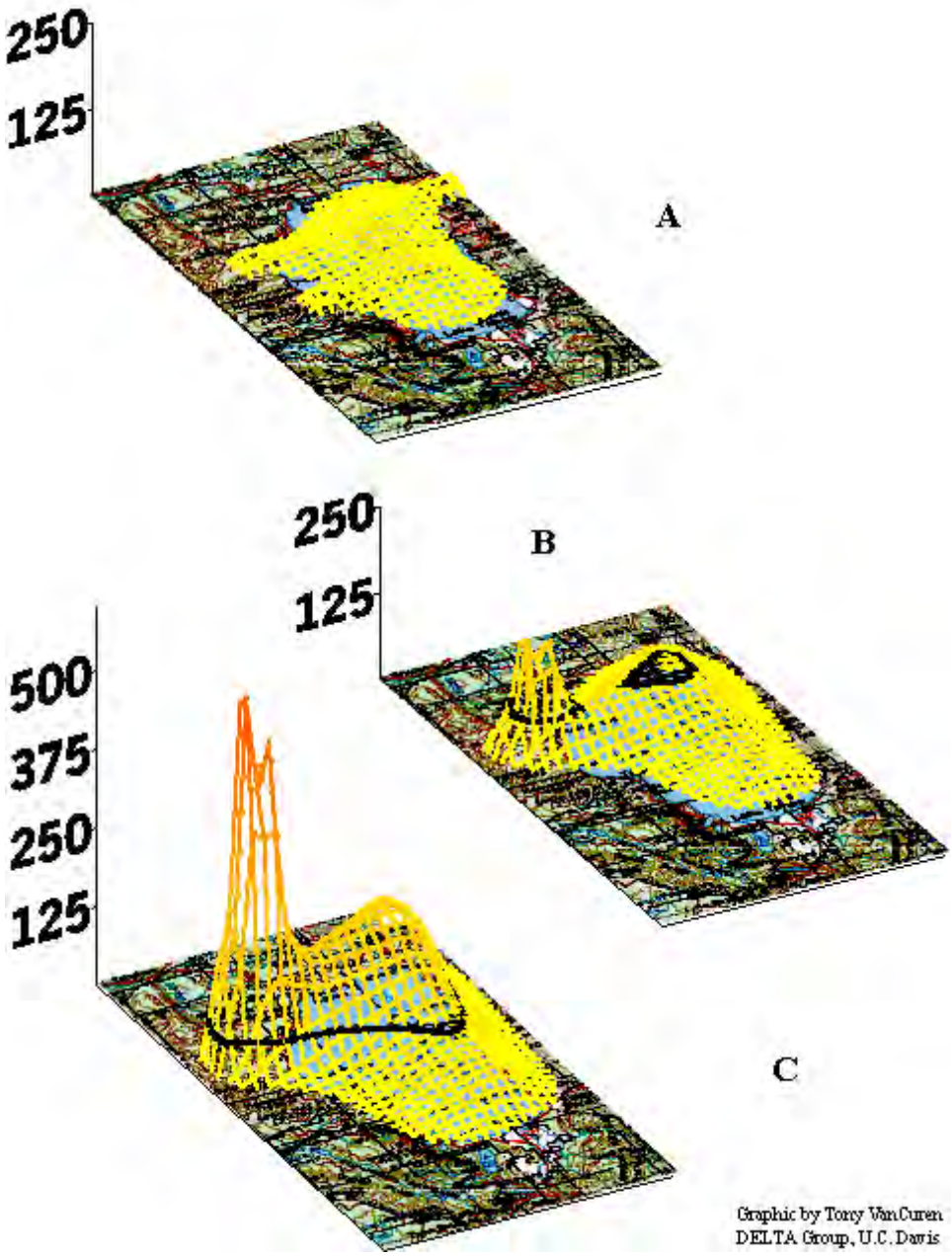
From the calculated emission parameters for the wildfire and prescribed fire scenarios, the LTAM calculates the falloff in smoke $PM_{2.5}$ across the basin. The resultant values from the LTAM are graphed as a concentration versus location and then are plotted over a map of the area represented by the model (Figure 3-4). Contrasted with the historical wildfire comparison (Figure 3-24), the LTAM is seen to predict massive violations of federal and state $PM_{2.5}$ standards for the 20-year return scenario (Figure 3-30a). The historical wildfire is an analysis of past conditions, based on a 40-year return in the basin divided among the total burn season, equaling about 30 acres burned per day in three small (10 acre) wildfires. The 40-year return scenario predicts localized violations for the October period (Figure 3-30b). A model run for the same scenario for a typical summer period (not shown) predicts fewer violations, mostly due to the increased ventilation of the basin during that time. A comparison of the three scenarios (excluding the large wildfire) is shown in Figure 3-31. The hypothetical wildfire during August, burning over 3,700 acres, is predicted to completely fill the basin and beyond with smoke (Figure 3-32). The output is broken up into three days of burning, with day one consuming about 60 percent of the acreage, day two at 25 percent, and day three at 15 percent. Some smoke carryover from the previous day is included in days two and three in the LTAM predictions. Although the wildfire burns an order of magnitude more land than the prescribed fires, the number of resultant violation days is predicted by the LTAM to be roughly equivalent. That is about two to three violation days for the 40-year fire, three days for the 20-year fire, and four to five days for the wildfire. The apparent discrepancy of this fact is due mostly to the increased ventilation of the basin during the late spring and summer. Furthermore, increased lofting of smoke in a wildfire results in impact at greater downwind distance than in a prescribed fire situation. The LTAM is capable of only limited predictions at this time. Further study of the impact of fire on the Lake Tahoe ecosystem, especially the impact of smoke on lake clarity, visibility, and human health, is necessary to better define parameters for integrated management models in general and the LTAM in particular.

Summary

The smoke concentration in the form of particulate matter with an aerodynamic diameter less than 2.5 micrometers ($PM_{2.5}$) has been evaluated by the LTAM for hypothetical wildfire and prescribed fires in the Ward Creek watershed. The result of this evaluation indicates that, for the prescribed fires, a fall burn is particularly troublesome from the standpoint of air quality. The atmospheric inversions that tend to be present during the fall inhibit ventilation of the Lake Tahoe basin and hence allow concentrations of $PM_{2.5}$ to build up. Currently, not enough is known about the chemical composition and speciation of prescribed fire smoke to evaluate the impact of these prescribed fires on the clarity of Lake Tahoe. It is known, however, that $PM_{2.5}$ is a pollutant from the perspective of human health. The potential for violations of federal, state, and basin air quality standards based on visibility is also expected from prescribed fire. Wildfire, whether natural or anthropogenic, burning in the summer at a time of great ventilation is predicted by the LTAM to violate all basin-wide air quality standards. Ground level peak concentration of $PM_{2.5}$ in the wildfire scenario is expected to be lower than the prescribed fires due to this increased ventilation of the basin in the summer and greater lofting of smoke in a large fire. A better evaluation of the impact of forest fires on ecosystem health at Lake Tahoe will require further study. It is imperative to understand the link between emission, transport, and deposition of smoke constituents throughout the basin to more effectively constrain integrated modeling tools for management use.



Figures 3-30a and 3-30b—$PM_{2.5}$ 24-hour average concentration from LTAM output superimposed on the basin map for prescribed fire scenario. The 20 year return (five percent per year, or 250 acres) is shown in 30a, and the 40-year return (2.5 percent per year, or 124 acres) in 30b. The black isoplith indicates the proposed federal 65-$\mu g/m^3$ limit. Figure 30a has a maximum concentration of about 500 $\mu g/m^3$ $PM_{2.5}$ with violations over the federal limit predicted for more than a third of the basin. Figure 30b shows predicted local violations near the fire source.



Figures 3-31a, 3-31b, and 3-31c—$PM_{2.5}$ concentration predictions from LTAM based on a 24-hour average superimposed on the basin map. Comparison of three fire scenarios in the Lake Tahoe basin. Top figure is the historical wildfire from Figure 24. Figures 31b and 31c are hypothetical prescribed fire scenarios located in the Ward Creek Watershed. Figure 31b is a 124-acre prescribed fire, and 31c is a 248-acre prescribed fire representing a 40- and 20-year total fire return time to the basin, respectively. The black isoplith is set at 65 $\mu g/m^3$, which is the proposed federal 24-hour standard for $PM_{2.5}$. The peak concentration for 31a, 31b, and 31c are 29, 165, and 500 $\mu g/m^3$, respectively.

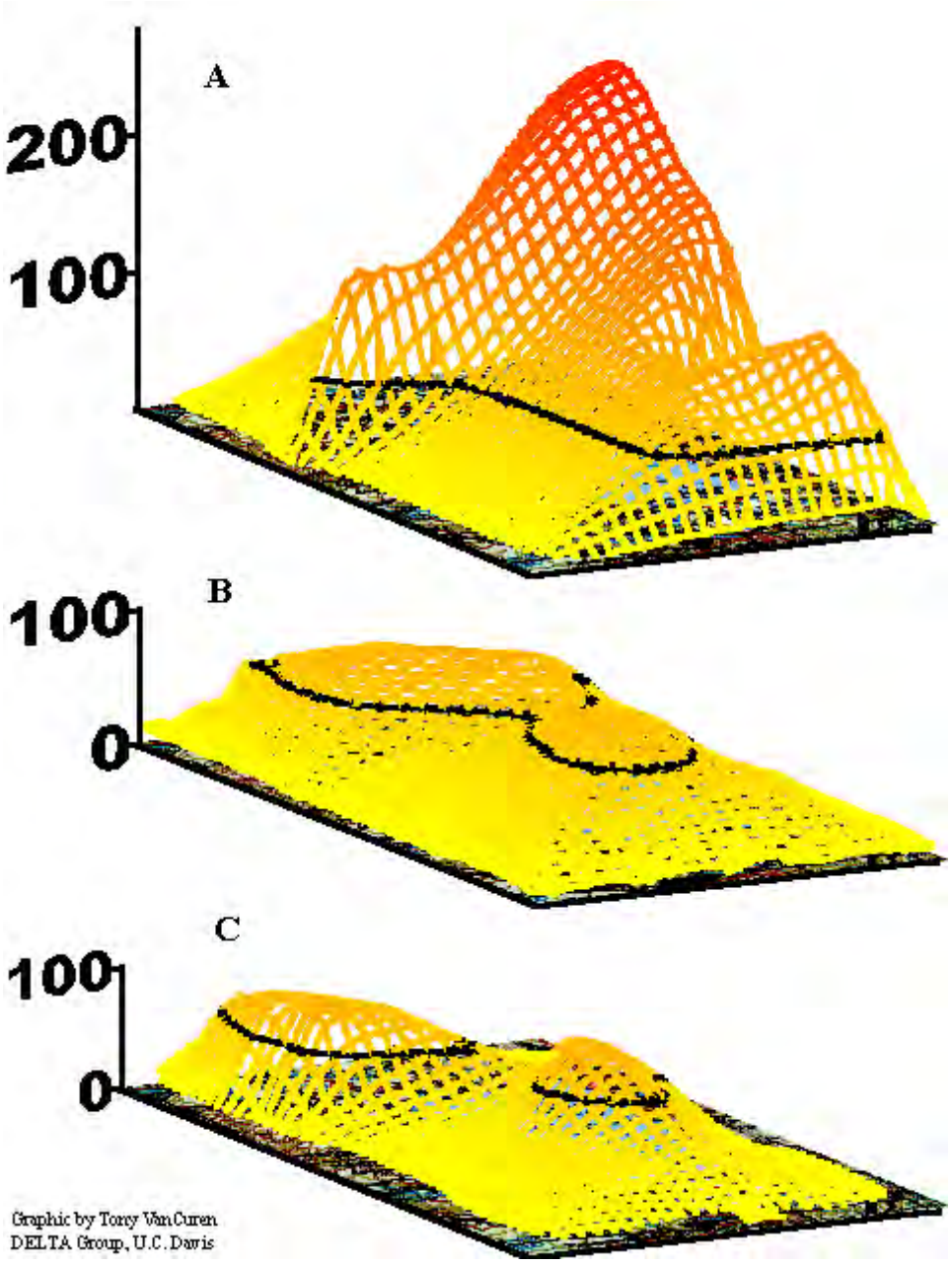


Figure 3-32—24-hour average $PM_{2.5}$ concentration LTAM output superimposed on the basin map for hypothetical wildfire (3,700 acres) in the Ward Creek watershed. The wildfire is broken up into three days of burning. Day 1 is 60 percent of the total acreage, day 2 is 25 percent, and day 3 is 15 percent. The black isoplith indicates the proposed federal limit of 65 $\mu g/m^3$ $PM_{2.5}$ 24-hour average. By day 3 the plume is breaking up as fire is theoretically suppressed. By day 4 the smoke is expected to drop below 65 $\mu g/m^3$ for the given scenario. Day 1 indicates a maximum $PM_{2.5}$ 24-hour average of 200 $\mu g/m^3$.

Issue 2: The Need to Determine Spatial Location and Natural versus Anthropogenic Origin of Pollution that Degrades Air Quality in the Lake Tahoe Basin

What are the relative contributions of in-basin versus out-of-basin air pollution sources, especially sources in the Sacramento Valley and western slopes of the Sierra Nevada, that affect the Lake Tahoe basin?

Air pollution at Lake Tahoe is implicated in a number of ecosystem impacts. Air quality within the basin is determined by both local and upwind sources. Most air pollutants measured in the Lake Tahoe basin are local in origin, with some important exceptions. Ozone in the summer is transported almost entirely from urban primary sources in the Sacramento Valley and damages Jeffrey pines in the basin. Fine particulate smoke, sulfate, and nitrates are transported efficiently from the Sacramento Valley each summer, providing roughly half of the mass and dominating the regional basin-wide haze. Smoke from wildfires on the western slope of the Sierra Nevada can blanket the basin, reducing visibility, violating health-based air standards, and causing algal blooms in the lake. An extensive discussion of in-basin versus out-of-basin sources of air pollution that contribute to air quality at Lake Tahoe is given in Issue 1 with regard to the development of the LTAM. In this section an overview of techniques that are available to determine local versus transported sources is presented.

Source Evaluation Techniques

There are several techniques that can be used to identify the source of an air pollutant in a specific area. The most confident identifications occur when two or more independent techniques can be used together. The tools that are available for understanding pollutant sources in the Tahoe basin include techniques based on source inventories, techniques based on transport (transport from meteorology, diffusion, and direct measurements along a transect), techniques based on pollutant transformation, techniques based on removal mechanisms, techniques based on receptor characteristics (both statistical and chemical mass balance methods), and techniques based on stable isotopic analysis.

Source evaluation techniques based on source inventories use emission inventories to give both the location and rate of emission of pollutants. The source rate and location information is given for both primary and secondary pollutants. A primary pollutant is a compound that is directly emitted. An example of a primary pollutant is carbon monoxide (CO), where CO is directly emitted from incomplete combustion of hydrocarbons. A secondary pollutant is an atmospheric compound that is made in a reaction during transport. Typically, both precursor species and sunlight are required for this transformation to occur. Ozone (O_3) is a secondary pollutant in that it is formed as a product of the oxidation of hydrocarbons in the presence of NO_x. It is known, for example, that almost all sulfur dioxide (SO_2) gaseous emissions in northern California come from a small area of oil refineries near the Carquinez Strait. Measurement of pollutant concentration at Lake Tahoe allows certain transport parameters to be estimated when the source is as unambiguous as in the case of SO_2. Furthermore, emissions can vary in time, and this aids in identifying the specific source. This type of identification is illustrated by the correlation of highway pollutants with traffic volume, as long as meteorology is included.

Another tool available for determining sources are techniques based on transport of pollutants. Meteorology can be used for identifying sources by determining the trajectory of an air parcel with time. Forward and back trajectories are often used to determine the traveled path of an air parcel from either source to receptor or receptor to source, respectively. Also, local gradients, such as pollutants measured across a road, or transport gradients for greater distances can be useful. Typically local gradients are dramatic in variation, whereas transport gradients are more subtle. Diffusion of an air parcel containing specific pollutants by lateral wind variability can smooth out the source profile. An example of this smoothing is seen with both sulfate and ozone at Lake Tahoe. Both sulfate and ozone are derived from upwind sources and are essentially uniform across the basin. Alternatively, local sources,

both roadway and urban, strongly correlate with the density of traffic and number of dwellings.

Direct measurement of a pollutant species along a transport corridor can be used to measure compounds as they move from source to receptor. In 1978, CARB/UCD studies placed stations from the Bay Area to Lake Tahoe and measured sulfates along the entire trajectory. Sulfates, derived mostly from Bay Area oil refineries, were found to be transported to Lake Tahoe from outside the basin. Also, beginning in 1989, a station was established at Bliss along the transport vector from the Sacramento Valley to South Lake Tahoe, allowing easy separation of transported particles from local particles in this one area.

Another useful technique for evaluating pollutant sources is by examining pollutant transformation. Secondary pollutants, such as ozone, take time to be converted from precursor to product. Typically, although not always, these pollutant transformations require such conditions as sunlight. This is illustrated at Lake Tahoe by ozone levels that often peak in the late evening, when the sun has set. Because sunlight and time are both required to convert hydrocarbons and NO_x to O_3, this is robust support for upwind sources. This technique, coupled with the relatively uniform distribution seen at other times, as mentioned earlier, strongly suggest upwind sources.

Identification of sources based on removal mechanisms or sinks is often useful. Some pollutants are rapidly removed from the air once they are away from their sources. For example, coarse soil particles settle rapidly to the ground, while fine soil particles can travel great distances. At Lake Tahoe this is especially important due to the role that fine particles play in scattering light both in the lake, where they reduce clarity, and in the air, where they reduce visibility. Some pollutants, transported from a great distance, can have a large impact on the basin.

Also available for determining pollutant sources are receptor characteristics. Statistical correlations can be made between pollutants of known sources and pollutants with several possible sources. For example, in an air sample fine lead (from studies conducted before leaded gasoline was banned), which comes only from cars, can be evaluated with gaseous NO_x, which has several possible sources. A correlation can be strong evidence that most of the NO_x is derived from automobiles. Chemical mass balance correlation, where the source of a species at a receptor site can be determined by analyzing tracer elements, is a more complicated method of determining source characteristics. An example of this is the unique chloride-to-sulfate ratio derived from oceanic emission. Based on its unique signature, the contribution of sea spray to an air sample can be statistically determined. This may be a technique that can be used at Tahoe to determine smoke sources by using a unique tracer for different types of smoke, such as pine versus brush.

An additional technique available for determining sources of pollutants at Lake Tahoe is stable isotopic analysis of pollutant compounds. Because the isotopic composition of an atmospheric species is set by the precursors and processes that form the molecule, a fingerprint for a source can be determined. For instance, SO_2 from Bay Area refineries will have a distinct isotopic signature for both sulfur and oxygen. As this species is transported, however, oxidation and coagulation will occur, producing sulfate particles. These sulfate particles will likely retain a signature of the original process, on which the chemical transformation signature is superimposed. In the case of nitrogenous species at Lake Tahoe this would be particularly useful in determining both sources and transformation mechanisms (oxidation). The relative influence of transported and locally generated nitrogenous nutrients then could be assessed. Although a technically difficult process, stable isotopic analysis can simplify the process of determining the impacts of in-basin and out-of-basin pollutant sources, especially when combined with other analysis techniques.

Summary

In all, there are a number of techniques available for determining the sources of air pollutants. Although a moderate accounting of pollutants has been conducted for the Lake Tahoe basin, a gap in the knowledge exists. Lacking in the information database is a connection between the

concentration of pollutants in air and the deposition to the Lake Tahoe surface. It is unclear what is the source of phosphorous seen in the deposition studies reported by Jassby et al. (1994). Furthermore, agreement between the deposition of pollutants reported by Jassby et al., and atmospheric measurements does not exist. Not only are the sources of phosphorous unknown, the concentration of phosphorous in the measured particles is not adequate to explain the deposition results. Past atmospheric studies appear to have excluded the collection and analysis of this important species. A complete understanding of the connection between lake and air relies on these deposition data. Finally, measurements of prescribed fire emissions are necessary to determine the relative influence of these large local pollutant sources versus transported pollutants on the Lake Tahoe ecosystem.

What are the relative impacts of natural versus anthropogenic sources, especially the relative contribution of smoke from wildfires versus prescribed fires?

Atmospheric pollutants that contribute to overall air quality at Lake Tahoe derive from both natural and anthropogenic sources. For instance, wildfires, volatile organic compound emissions from trees, and windblown dust all are natural phenomena. In contrast, automotive and industrial pollutants, prescribed fire smoke, and human-caused wildfire smoke all derive from anthropogenic sources. Impacts from natural wildfires is not seen today because numerous, small noncrown fires in summer and fall have not been seen since the mid-19th century. The prediction would have been for spotty but persistent smoke in relatively low concentrations around the basin. Present day wildfires are almost always started by humans and are always enhanced by humans due to fuel buildup resulting from fire suppression. Wildfires are infrequent but have massive impacts on the Lake Tahoe basin, degrading visibility, causing algal blooms in the lake, and probably violating state and proposed federal air quality standards. There are few air quality data on the impacts of prescribed fire beyond the obvious smoke plumes seen near such burns.

Results from the LTAM indicate that large smoke contributions to pollution will be seen for prescribed and wildfire scenarios (figures 3-30 and 3-32). The relative contribution of these sources will depend on individual fire scenarios, such as the time of year, acreage burned, specific meteorology, and composition of fuel. This question was extensively addressed in Cahill (1996); some of that material is presented here.

Sierran Smoke Sources

It is surprisingly difficult to establish the effects of various independent smoke sources on air quality in the Sierra Nevada. Smoke has a visual impact out of proportion to its mass, so that smoke levels must be extreme before the record of particulate mass reflects a major impact. Yet the only 24-hour federal particulate standard is for particle mass below 10 micrometers in diameter (PM_{10}), which is not violated until visibility drops to about two miles. Most of the air particulate sampling in the Sierra Nevada measures only PM_{10} mass, thus is of limited use in identifying small and moderate smoke impacts. These sites operate only on a one-day-in-six cycle and, due to urban locations, are of little use to establish nonurban smoke levels. Furthermore, data on how many acres are burned each day from either wildfires or prescribed burns are often difficult to access. Meteorological measurements in the mountains are scarce and terrain effects are major.

The IMPROVE database is somewhat better in several regards. The measurement units are for $PM_{2.5}$, which is a better match to the size of smoke. The sites operate Wednesday and Saturday, in nonurban, nonvalley locations and have full meteorological, chemical, and optical analysis. However, there are only two such sites in the Sierra Nevada—Sequoia and Yosemite National Parks. Fortunately, the paired stations at Lake Tahoe, operated for TRPA using full IMPROVE protocols, provide a very important third site, as well as an invaluable nonurban to urban comparison. In addition, data are extended by using similar sites in the Cascade Range and San Bernardino Mountains.

Analysis of aerosol data from several sites in the Sierra Nevada indicates that the most severe impacts on air quality occur from large wildfires and shows little effect of controlled fires at remote locations. Using data from the IMPROVE air sampler at Turtleback Dome in Yosemite National Park as an example (Figure 3-33), the highest levels of particulate pollution occurred during a prescribed natural fire that burned in the park from July 3 to August 18, 1994. On only one occasion, however, did the pollution exceed the state air quality standard of 50 $\mu g/m^3$ for PM_{10}. The presence of smoke at the site during this episode is evident from the unusually high peaks in nonsoil potassium (K-non), a tracer of biomass smoke, and from human observations. Relatively low levels of particulate matter were seen during the subsequent fall season when the majority of agricultural waste burning is occurring in the San Joaquin Valley, as well as controlled burning in nearby forests for fire suppression and silviculture.

In contrast, frequent high levels of PM_{10} occur in the heavily developed Yosemite Village (in Yosemite Valley) during the same period, even when no large fires are burning in the area. Many small local sources (campfires, fireplaces, and vehicles) and the micrometeorology of the valley, which tends to trap air under a nighttime inversion, result in a high background level of pollution.

Another comparison of local anthropogenic sources versus wildfires and controlled burns occurs in the Tahoe basin. Air quality data taken near the relatively urbanized Highway 50 corridor in South Lake Tahoe show high levels of aerosol pollution in the winter. Large peaks occur in both organic matter and in K-non, indicating wood smoke as the source. At D. L. Bliss State Park, located in a largely undeveloped area where there are few fireplaces, the winter is the cleanest season. This suggests that residential wood combustion is the primary source at South Lake Tahoe. The only period in which occasional elevated levels of smoke are detected at both sites, indicating a source outside the basin, is the late fall when large amounts of cropland are being burned in the Sacramento Valley and

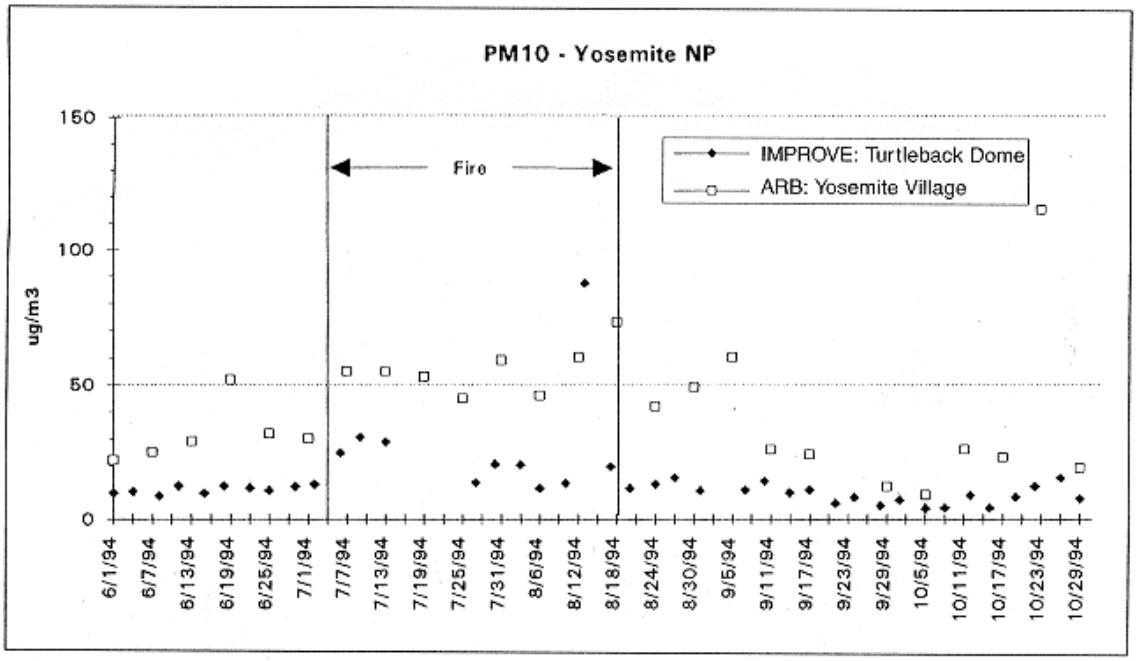


Figure 3-33—PM_{10} concentrations in Yosemite Village, Yosemite National Park, from the Turtleback Dome prescribed fire in 1994 from IMPROVE and ARB samplers. The parameters derived from this data are used for PF1 values in the LTAM.

controlled burning in the surrounding national forests is at its peak. But the smoke levels, even under these conditions, are far lower than the winter peaks, roughly 20 percent, at South Lake Tahoe and are of much shorter duration.

A final direct comparison between wildfires and residential wood burning was made in Cahill et al. (1997) for Truckee, California. The availability of a new type of particulate measuring unit, a TEOM, allowed mass to be measured hourly. The intense Cleveland fire of 1992 was located south of Interstate 80 and upwind of Truckee. This fire burned 5,500 acres on September 29, 7,000 acres on September 30, and 7,500 acres on October 1, when a light rainfall (0.1 inch) greatly aided fire suppression, limiting further acreage to roughly 3,500 acres until the fire was declared out about one week later (McKey 1995). The smoke levels were comparable for these two cases (121 $\mu g/m^3$ for the Cleveland fire and 124 $\mu g/m^3$ for a typical January day), but one has to remember that the Cleveland fire lasted for only a few days, while winter smoke episodes at Truckee are extremely common under the characteristic winter subsidence inversion found in almost all high mountain valleys. The peak winter day level in January 1992 was 179 $\mu g/m^3$, measured by TEOM, but the TEOM probably understates the equivalent filter mass by 30 percent because the TEOM filter is heated, which drives off some of the water. Thus, in terms of person-dose, a typical winter day level is at least a factor of 10 or greater more important to health than a major local forest fire.

On the same day as the Truckee data, September 30, 1992, samples were taken at Bliss State Park as part of the regular Wednesday-Saturday IMPROVE-compatible protocol for TRPA. Bliss was not affected nearly as much as Truckee because the wind was driving the smoke northeast. However, the level of PM_{10} was 13 $\mu g/m^3$ versus 121 $\mu g/m^3$ for Truckee, during the Cleveland fire. Even so, the September 30 reading was the highest PM_{10} recorded on 16 sampling days between September 2 and November 30, 1992, more than double the annual average of 5.85 $\mu g/m^3$ recorded 1992-1993. The corresponding fine mass was 5.35 $\mu g/m^3$ versus an annual average of 3.39 $\mu g/m^3$. A strong nitrate signal was received, in fact the highest level seen all year, at 1.45 $\mu g/m^3$ versus an annual average of 0.29 $\mu g/m^3$. This raises the question whether a significant component of the strong nitrate peak seen in South Lake Tahoe in winter could be from residential combustion of pine wood. Another more likely possibility is that the nitrate resulted from the volatilization of dry deposited nitrate on pine needles. Other species reached the highest level during the fire, including trace amounts of chloride, arsenic, selenium, and bromine. The K-non smoke tracer reached its second highest level on June 30, supporting the theory that much of the smoke in the mountains was from valley grasses, which have a K-non/mass ratio of at least ten times that of pine.

The results of the Cleveland fire help put into context the smoke from controlled burns, which for an entire season might total 7,000 acres, roughly as much as was consumed per day in the Cleveland fire. In addition, the Cleveland fire occurred at a dry, hot period of the summer, without the meteorological mitigation built into controlled burns. Hence, the absence of any obvious signature due to controlled burns at Bliss, along with only one day of moderate impact at Yosemite, now can be readily understood because so little fuel is burned per day, as compared to the uncontrolled Cleveland fire.

The relative importance to human health of local wood burning, as compared to forest fires, can be explained by higher population densities in urban areas, the regular pattern of residential wood fires, the penchant for these urbanized areas to be in valleys rather than ridges, and the common nighttime inversions that trap smoke close to the ground. Wildfires, by their very nature, generate lots of heat and tend to loft much of their pollutant load into the sky.

The smoke produced by biomass combustion is composed of water vapor, other gases, and particles less than 2.5 μm in diameter ($PM_{2.5}$), but a significant amount of larger particles also may be produced by large intense fires due to entrainment of soil and partially combusted matter in the strong updrafts. Significantly larger particles present little threat to health or visibility and typically do not persist in the atmosphere for more than a few

hours before they settle out due to gravity. Fine particles, $PM_{2.5}$, however, are very effective in reducing visibility because they scatter light and aid the condensation of water vapor in the air. These smaller particles also contain a significant quantity of organic compounds known collectively as polycyclic aromatic hydrocarbons (PAH), which include a number of toxic and potentially carcinogenic substances. Because the fine particles are readily inhaled and retained in the lungs and may settle onto the surface of vegetation, increased concentrations of smoke represent a potential hazard to both human health (Larson and Koenig 1994) and the environment. These concerns are not limited to emissions from forest fires. Research data indicate that burning grasses, agricultural wastes, and other types of wood produce even higher concentrations of PAHs (Jenkins et al. 1995).

Wood burning emits a variety of gaseous pollutants (Jenkins et al. 1993). These are primarily composed of CO_2 and H_2O, with the remainder dominated by CO and a variety of hydrocarbons, including PAHs. Because CO is relatively inert and disperses readily, it should not have any significant impact on air quality beyond the immediate area of the fire. Hydrocarbons, on the other hand, can be transported over large areas and contribute to ozone formation in the presence of other pollutants. NO_x also is produced, as in all combustion, but in relatively small concentrations in comparison to their emissions from vehicles and industrial sources.

Evidence exists that part of the water of combustion of wood smoke may be trapped in the smoke, especially in cold, humid, winter conditions (Molenar 1994) and seen also in the 30 percent difference between TEOM and standard PM_{10} filters (above). If even a small fraction of the water is trapped, it can greatly raise the smoke mass. More detailed analyses are needed before this can be resolved. Nevertheless, a certain caution should be retained about ways to reduce wood smoke by reducing temperature of combustion and air flow, as opposed to an oxygen-rich open flame. Low temperature smoke is far more chemically complicated than high temperature smoke, retaining compounds that are known mutagenic (and perhaps carcinogenic) agents.

Autumn 1995 saw a good deal of activity in the area of fire pollution. That fall was exceptionally dry, with the first significant rain occurring in early December. The meteorology was stable, with weak winds and strong inversions forming in the Central Valley. Several prescribed natural fires and controlled burns persisted into periods of poor ventilation, with major smoke impacts on local communities. This occurred for fires in and near Sequoia National Park, which totaled about 9,000 acres by early December. Prescribed fires were ignited near Mineral King and in a chaparral zone about 10 miles upslope of Three Rivers. Heavy smoke was recorded in local communities, resulting in four violations of the 150 $\mu g/m^3$ federal 24-hour PM_{10} regulations, with the maximum value of 194 $\mu g/m^3$ (Ewell 1995). Another fire burned for about a month in the Lake Tahoe basin, in Bliss State Park near the TRPA aerosol site. Smoke impacts were regularly reported (Mahern 1996). Both of these fires represent patterns of prescribed and controlled burns that may become more likely in the future, and the experience gathered in these events will be useful in avoiding such impacts. Clearly, the concentration of so much burn acreage in a single watershed of air basin at times of poor ventilation resulted in unacceptable levels of smoke, although the anomalous weather of fall 1995 was a major factor in these episodes.

Finally, there was a major wildfire/prescribed fire workshop sponsored by the WESTAR Council, an association of air resource agencies from western states, Alaska to the Dakotas, in San Francisco from November 27 to 29, 1995. Recommendations of this meeting have several points of interest (WESTAR 1995). One of these recommendations was made by a speaker from the US EPA on separating smoke from "ecological burns" and "activity burns" and possible trade-offs against wildfire smoke. The logic is that the ecological burns are really a way of avoiding future smoke from the much more serious crowning wildfires, as well as a way to maintain a healthy forest. The consensus also was reached that the nuisance effects of smoke, including visibility reduction, will become more important as a

constraint on burning than possible violations of federal fine particulate air quality standards. In the Lake Tahoe basin specifically, however, TRPA visibility violations are an important constraint on prescribed burning.

Overall, current data suggest that controlled forest burns are not as significant a source of particulate mass in populated areas of the Sierra Nevada as residential wood combustion and campfires. Large wildfires produce severe short-term impacts on air quality, but because they are rare, average smoke dose to individuals is generally limited. Prescribed or controlled burns are more common, but the amount of materials burned are more modest, and the measures to limit human smoke impacts are generally quite effective, leading to very low contributions to PM_{10} particulate loading in inhabited areas. Thus it would appear that prescribed fires are usually performed in such a way as not to cause a significant threat to regional air quality as measured by fine particulate mass. The obvious exception is for some local visibility reduction, but this must be compared to improved air quality by decreasing the impacts of major wildfires. Given that fire is a natural part of the Sierra Nevada ecosystem (Phillips 1995), the beneficial effects on the Sierra Nevada ecosystem of increased fire use should not result in widespread violations of state or federal fine particle health standards. This rule, however, appears not to hold in the Lake Tahoe basin, according to the model results of the LTAM (Figure 3-31).

The very real problems of perceived smoke and visibility reduction must be addressed, however. One way is to couple the presence of modest summer smoke with the overall health of the forest and the reduced chances of major wildfires, which drastically reduce visibility and increase direct and indirect health effects. The other is to ascertain the relationship between visibility reduction and smoke mass, showing that even in visibly dense smoke, mass loadings are modest. Using results of studies of Oregon and Washington fires (Radke et al. 1990), a relationship can be measured. Visibility due to smoke must be reduced to 3.0 +/- 1.8 km (1.9 +/- 1.1 mi) before one reaches the federal particulate air quality standard of 150 $\mu g/m^3$ six miles before one reaches the California standard of 50 $\mu g/m^3$. The same relationship is found for IMPROVE's fine ($D_p < 2.5$ µm) particulate mass. A best fit between visibility and mean annual mass at forty-four sites gives 3.0 kilometers (1.9 miles) for the federal standard of 150 $\mu g/m^3$, assuming no contribution from particles greater 2.5µm diameter (Copeland 1995). The corresponding visibility at the 50 $\mu g/m^3$ California standard is 9.1 km (5.7 miles). The problem of visibility is compounded by the fact that for fires that occur in scenic areas, where visibility reductions are obvious. The plumes tend to be well above the ground, which makes them more visible and reduces ground level mass concentrations. The same effects do not occur for the even greater smoke densities in such towns as Truckee during the winter, for example, because the densely populated core of the town is less than one mile long.

There are also indirect effects of fires, in which they act as a means of transporting materials from one location to another. An example is agricultural burning in the central valleys of California. The mass of smoke by itself may not be a serious factor in terms of particulate mass, but when smoke affects cities, asthmatics are more likely to seek medical attention (Cahill et al. 1998). The answer appears to be in the reactions of sensitive populations to all the other materials lofted into the atmosphere with the smoke, which in the valleys include pollens, fungal spores, partially pyrolized pesticides and herbicides, and other components.

Summary

Questions regarding the impact of smoke in the Sierra are difficult to resolve based on limited compositional and transport data on this source. In the Lake Tahoe basin, knowledge is lacking for meteorology for much of the lake, as well as deposition to the lake surface. Furthermore, few measurements have been made of emissions from wildfires and prescribed fires for both mass and chemistry. The LTAM would greatly benefit from increased knowledge of these parameters. Large wildfires are reported to affect Lake Tahoe by

causing algal blooms in the lake. The impact of prescribed fire, however, is relatively unknown. Other atmospheric pollutants, such as NO_x, O_3, sulfate, and fine particles, also affect the basin. These pollutants are discussed in Issue 1 of this chapter.

How has air quality changed from prehistoric to present times?

Historically, air quality at Lake Tahoe has been excellent in winter and spring and is somewhat degraded in summer and fall from persistent small wildfires burning in the basin and on the western slopes of the Sierra Nevada. The most common pollutant, ozone, was elevated in summer due to transport into the basin from the Sacramento Valley but at levels that were still quite low (0.02 to 0.03 ppm).

There is a paucity of data on factors within the Sierra Nevada that affected air quality in prehistoric times. From historical data on fires and the natural timing of lightning-induced fires, we can infer two to four times as much area burned on an average summer day than in present times, with removal of timber plus present-day catastrophic fires redressing the biomass balance. Thus, it is expected that there was much more summer smoke in the past and less smoke in spring and fall, the time where prescribed natural fires and controlled burns are now encouraged. An example can be found in the Blue Mountains of northeastern Oregon, which were noted and named in the past for having much fire smoke commonly present in the summer.

The extent of transport of smoke into the Sierra Nevada from the Central Valley, a major factor at present, is not known from presettlement times. It may have been less than at present, based on statements on what the explorers observed, however, native Americans were known to encourage fires to favor generation of oaks and for other purposes.

In an attempt to derive the extent of presettlement smoke at Lake Tahoe, we can use records on burn frequency and location of wildfires at Lake Tahoe derived from such data as tree ring scars. Reburn rates vary widely in the basin, from high frequency on the eastern shore to low frequency in the moist western shore, and these will be incorporated in the model runs when available. An assumption can be made that the entire forested area burned once in 40 years, generally in the form of low intensity, lightning-initiated fires from May through October. Thus, we can estimate that 2.5 percent of the forested area, totaling about 156,000 acres, will be burned each year—about 3,900 acres/year. A natural burn period of five months (May through October, with the first and last months partial weighting) gives a burn rate of roughly 25 to 30 acres/day. Results from modeling the historical wildfire scenario from the LTAM (Figure 3-24) indicate that visibility would be greater than approximately 32 kilometers (20 miles) in the early morning within the basin. After inversion breakup at about 11 AM each day during the burn period, visibility would again increase to bring the north and south shores into view. If these preliminary modeling results are correct, historical wildfires would not have exceeded the current TRPA visibility threshold of at least 26 kilometers (16 miles) for at least 90 percent of the year.

Historical burns generally occurred at times of excellent air transport so that the smoke was rapidly diluted and transported across and out of the basin during the days. At night, however, the common inversion would pull the smoke downslope and over the lake so that each morning there would be smoke present at many areas of the lake. This persisted until the late morning winds re-established the daytime transport pattern. The efficient summer transport mechanisms, natural sources of hydrocarbons and oxides of nitrogen in the Sacramento Valley and typical summer high temperatures, lead to the prediction that there was significant ozone on the western slope of the Sierra Nevada that would in part be transported into the Lake Tahoe basin. These levels were probably in the range of 0.03 to 0.04 ppm, but during short periods of very high foothill temperature, they might be significantly higher.

Historic Air Quality

In early historic periods, there was extensive logging in the basin. This reduced natural wildfires by removing the forest but added smoke from habitat and logging activities. Historical photographs of the Lake Tahoe area often show smoke. However, at the time of these pictures (late 19th century)

massive human impact was evident as this was the peak of the Comstock lumbering period. In the early 20th century, the Lake Tahoe basin probably reached a minimum in smoke contamination. The forest was essentially gone and not yet regrown, and the USFS initiated a policy of fighting fires. Local habitation was very low and mostly in summer when smoke removal was efficient (E. B. Scott 1957).

The summer of 1973 saw the beginning of large-scale, reliable measurements of gaseous and particulate pollution at Lake Tahoe (CARB 1974). These data were analyzed for the CARB (Cahill et al. 1977) and led to an evaluation of the in-basin and out-of-basin sources. The continuous record of the CARB site at South Lake Tahoe can be used to compare gaseous air pollutants at South Lake Tahoe, 1973 versus 1993. Figure 3-23 compares the 1973 values of ozone, carbon monoxide, oxides of nitrogen, PM_{10} mass, and lead to the 1993 values. Some averaging of South Lake Tahoe sites from 1973 was needed to compare to the present CARB Sandy Way site. In general great reductions in most pollutants has been achieved, the sole exception being ozone which has risen roughly 30 percent in the past 20 years. This is an exception to a general California trend because all other sites with consistent records, including Sacramento, show ozone decreases. The present hypothesis is that the rapid growth in the foothills of El Dorado and Placer counties is adding ozone precursor pollutants directly into the transport corridors to Lake Tahoe; this is partially confirmed by the evening ozone peaks, often after the sun has set. On the same figure (Figure 3-23), the mean pollutant reductions for other California cites, Monterey (to 82 percent of the 1973 value), Sacramento (also 82 percent) and Los Angeles (46 percent), as compared to South Lake Tahoe (57 percent), were added. These reductions were achieved despite large increases in population and a doubling of vehicle miles traveled at most California sites. On the same plot is a comparison of haze, 1981 versus 1994 (Molenar et al. 1994) derived from the TRPA paired sites at Emerald Bay (Bliss State Park) and South Lake Tahoe. The regional haze, Haze (R) refers to the basin wide haze, the local haze, Haze (L), refers to South Lake Tahoe. There is a 25 percent increase in regional haze and a 65 percent increase in local haze in this period. Haze is dominated by fine ($PM_{2.5}$) particles, for which no 1973 readings were available. However, analysis of a smoke tracer, K-non, from the 1979 CARB/UCD report also shows a significant increase in smoke, from 1978 to 1994, in support of this observation.

Summary

In order to understand the change in air quality at Lake Tahoe, a careful examination of trend data is needed. Trend information is becoming available from the paired TRPA sites at Bliss State Park and South Lake Tahoe, and these should be carefully averaged to obtain trends in fine particles from 1989 to 1999 and beyond. Obtaining air quality data prior to the published studies by the CARB, NDEP, and UC Davis is difficult at best. Sediment records in the lake coupled with modern data may provide some information about atmospheric deposition to the surface over time. Presently, scaling of current air data to the recent historical past with the aid of the LTAM is the best resource available for determining air quality changes at Lake Tahoe.

How does air quality degradation generated within the basin affect downwind recipient areas, such as the Carson Valley?

Air quality in the Lake Tahoe basin is typically quite good, but some locally generated pollutants may have impacts beyond the watershed boundary. Although little work has addressed what specific impact basin air quality has on downwind area, the general meteorology at Lake Tahoe leads to conclusions regarding potential transport out of the basin and its impact on downwind sites. In the fall, winter, and spring, there are typically no downwind air quality impacts due to persistent inversions within the basin and weak downwind transport. In the summer, however, basin-generated gaseous pollutants transport readily downwind, with perhaps some modest enhancement of ozone within the Carson Valley. Most notably, smoke from basin fires has a high potential of affecting the Carson Valley, with impacts on $PM_{2.5}$ mass and degradation of visibility.

Pollutant Sources and Transport

The three major sources of air pollutants within the Sierra Nevada are forest smoke (wildfires, prescribed natural fires, controlled burns), urban sources (again mainly smoke, some vehicular), and the partially or completely desiccated Mono Lake and Owens Lake (alkaline/saline dusts). The urban sources contribute little to total emissions (tons/year), and their high winter concentrations are mainly due to severely limited dispersion; thus there is no theoretical or empirical evidence that their influence is much more than local. The other two sources, however, are large enough that their influence is well documented. The impact of Sierran forest smoke on the Central Valley of California has been mentioned earlier, a consequence of nighttime downslope winds that may be especially important in fall due to decreased ventilation in the valleys, which increases the residence time of smoke, combined with prescribed natural fires and controlled burns in the mountains. However, this is also a period in which agricultural acreage is burned in the valleys, amounting to many hundreds of thousands of acres each fall. Renewed interest in the impact of these Sierra Nevada sources on air quality downwind (east) of the range is partially a consequence of the activities of the Grand Canyon Commission, charged under the Clean Air Act amendments of 1990 to evaluate all sources of visibility reduction in that area. The commission's task groups are aware of plans to increase burning in forested areas and is looking at such sources as the Sierra Nevada.

Data from the Sierra Nevada can place this evaluation in perspective. The results at Lake Tahoe show efficient transport of smoke aerosols (and other components, such as ozone) from the California Central Valley into the Tahoe basin, across passes at roughly 7,000 feet and around mountains that rise to 10,000 feet. This occurs during much of each spring, summer, and early fall. These pollutants certainly influence the Great Basin air quality, although levels are modest. The results of the Cleveland fire of 1992 show massive transport of smoke downwind of the range, but such events are infrequent. Conversely, the valley to mountain transects in Sequoia National Park, 1987, show a sharp reduction in ozone and aerosols between Giant Forest at 6,000 feet and Emerald lake at 10,000 feet. The Emerald Lake site is west of the Great Western Divide, and the peaks to the east of it rise to over 14,000 feet. This supports a very limited pollutant transport efficiency over the mountains to downwind sites in the central and southern Sierra Nevada, both for local forest smoke and valley smoke. Finally, there is well-documented transport across Tehachapi Pass into the Mojave Desert (Pitchford et al. 1984), where elevations decline to around 4,000 feet. As temperatures drop each fall, mountain transport processes weaken and smoke of all kinds tends to stay in the Central Valley. This was certainly the experience in the dry fall of 1995, when smoke from the Sequoia National Park prescribed fires drifted downslope into the valley. In summary, fires that burn under summertime conditions contribute smoke downwind of the range, while spring and fall fires tend to have greatly reduced transport east of the mountains and, conversely, have the greatest local impact. The wintertime inversions in the Central Valley and lack of fires in the Sierra Nevada indicate little Sierra Nevada influence at downwind sites.

A final piece of evidence concerning transport into the intermountain area can be gathered by comparing aerosols at Bliss State Park, Lake Tahoe, with the Great Basin and Grand Canyon national parks. The characteristic signatures of wood smoke are, in order of uniqueness, excess fine potassium (K-non), organic carbon from carbon (C) and hydrogen (H), optical absorption, and elemental carbon. The mean values for each are as follows (IMPROVE 1995):

	Bliss State Park	**Great Basin**	**Grand Canyon**
K-non	8.77 ng/m^3	6.70 ng/m^3	7.83 ng/m^3
C	1.12 $\mu g/m^3$	0.79 $\mu g/m^3$	0.63 $\mu g/m^3$
H	1.17 $\mu g/m^3$	1.01 $\mu g/m^3$	0.87 $\mu g/m^3$
Optical absorption	5.42 Mm^{-1}	4.18 Mm^{-1}	4.26 Mm^{-1}
Elemental carbon	0.15 $\mu g/m^3$ (?)	0.12 $\mu g/m^3$ (?)	0.09 $\mu g/m^3$ (?)

The (?) indicates values close to the detectable limit and thus are statistically weak.

These data show no convincing evidence that there is major transport from the Sierra Nevada into the Great Basin region or the Grand Canyon National Park, because such long distance transport would cause values to decrease as particles are lost during transit. Moreover, because the highest values at Bliss occur in summer and come from the Sacramento Valley floor, a better case can be made for the impact of agricultural burning in California on air quality in the Great Basin region.

Summary

In order to fully characterize the air quality impacts on downwind sites, some additional information is necessary. For instance, a comparison of Carson Valley air quality to data from the east shore of Lake Tahoe, South Lake Tahoe, and Incline would help link pollutant emission in the basin to measured quantities downwind from the basin. Potentially, measurements of pollutants along the transport corridor (Highway 50 over Spooner Summit) would answer questions regarding transport of pollutants out of the basin. The most apparent potential impact, smoke from prescribed fire or wildfire, should have obvious links to sources within the basin. Indeed, anecdotal evidence would indicate that fires within the basin readily affect downwind sites within the Carson Valley. Future research into the impact of prescribed fire smoke on these downwind sites, especially in light of potential increased burning, is warranted.

Issue 3: The Need to Determine the Adequacy of Existing Air Quality Standards to Protect the Tahoe Watershed's Terrestrial and Aquatic Resources through Existing Air Quality Control Programs

With contributions from Tony VanCuren

Responsibility for managing air quality in the Lake Tahoe basin is divided among several agencies at the federal, state, and local levels. Authority to control air pollutant emissions is similarly spread across all three levels of government. With the exception of visibility, the applicable air quality standards (and the pollution control programs that derive from them) are designed to protect public health. Ecosystem protection has not been a major concern in setting these standards, and attaining the specified air quality in the Tahoe watershed, while it may limit the frequency and severity of ecosystem effects due to air pollution, will not guarantee protection of the basin's terrestrial and aquatic resources. This is especially true for long-term cumulative ecosystem damage due to sustained low-level pollution.

What is the present structure of air quality management in the Lake Tahoe basin, and what are the applicable air quality standards?

The baseline air quality standards for the region are the National Ambient Air Quality Standards (NAAQS) established by the USEPA. The NAAQS cover the federally designated criteria pollutants: Ozone (O_3), PM_{10}, CO, NO_2, lead (Pb), and sulfur dioxide (SO_2). On May 14, 1999, the federal 8-hour ozone and $PM_{2.5}$ standards were invalidated in a decision by the US Court of Appeals for the District of Columbia. Enforcement of these standards is in abeyance pending an appeal and final disposition of that case.

California has adopted more stringent standards for the same criteria pollutants, as well as additional standards for sulfates, hydrogen sulfide (H_2S), and visibility-reducing particles (VRP). The state standards include special provisions for even lower permissible levels of CO and VRP for the state-designated Lake Tahoe Air Basin (LTAB), which encompasses the California portion of the Tahoe basin. At this time, the LTAB is classified as in "attainment" of these state standards, with the exception of the VRP standard, for which it is officially "unclassified" due to a lack of monitoring data using the measurement method set by California to determine compliance with the standard. Nevada also has adopted more stringent standards applicable in the Tahoe basin, matching the California LTAB standards for CO and visibility and cutting the 1-hour maximum ozone standard to equal California's statewide standard.

Under the federally chartered bi-state compact that created the TRPA, the authority to determine environmental thresholds to protect various resources was granted to TRPA. TRPA's

thresholds for visibility and CO are essentially the same as the California and Nevada state standards. The applicable air quality standards for the basin are summarized in Table 3-5. In addition to these fixed standards, the recently finalized federal Regional Haze program (USEPA 1999) requires states to determine the sources of anthropogenic visibility impairment at federal Class I areas (such as national parks and wilderness areas) and to develop long-term strategies to improve visibility in those areas. The first long-term strategy will cover 10 to 15 years, and will be reassessed and revised in 2018 and every 10 years thereafter. Under certain circumstances, the regulations allow until 2064 for a state to attain the goal. While these air quality goals cannot be known as of this writing, they may function as an additional set of de facto air quality standards tailored to individual Class I areas. While such goals may eventually put tighter restrictions on air quality in the Tahoe basin, the long lead time for the Regional Haze Program means that, for the near future, the existing standards will control air quality planning and regulatory activity.

At present, the Lake Tahoe area is classified as being in attainment or "unclassified" for all applicable standards except the 24-hour criterion of the California standard for PM_{10}, for which it is designated as being in non-attainment. The Lake

Table 3-5—Air quality standards relevant to the Lake Tahoe watershed.

Pollutant	Federal	California	Nevada
Ozone			
1-Hour Avg.	0.12 ppm	0.09 ppm* (not to exceed)	0.10 ppm
8-Hour Avg.**	0.08 ppm		
Respirable Particulate Matter (PM_{10})			
Annual Mean	50 μg/m³ (Arithmetic)	30 μg/m³ (Geometric)	
24-Hour Avg.	150 μg/m³	50 μg/m³	
Fine Particulate Matter ($PM_{2.5}$)**			
Annual Mean	15 μg/m³ (Arithmetic)		
24-Hour Avg.	65 μg/m³		
Carbon Monoxide			
1-Hour Avg.	20 ppm		
8-Hour Avg.	9.0 ppm	6.0 ppm (LTAB only)	6.0 ppm (above 5,000' MSL)
Nitrogen Dioxide			
Annual Mean	0.053 ppm (Arithmetic)		
1-Hour Avg.		0.25 ppm	
Visibility – Reducing Particles			
10:00 – 18:00 PST (RH<70%)		0.07/km (B_p)	
Visual Range			
Single Observation or Photograph (RH<70%)		30 mi.	

* California's "not to exceed" criterion is equal to Nevada's "not to equal or exceed."
** On May 14, 1999, the federal 8-hr ozone and PM2.5 standards were invalidated in a decision by the US Court of Appeals for the District of Columbia; enforcement of these standards is in abeyance pending an appeal and final disposition of that case.

Tahoe basin currently complies with all valid NAAQS and the invalidated 8-hour ozone standard, but likely would be classified as being in nonattainment for the annual average criterion of the invalidated federal $PM_{2.5}$ standard.

How is air quality regulated in the Lake Tahoe watershed?

Air quality measurement in the basin is divided among political subdivisions and agencies. CARB conducts routine public health-based air quality monitoring at two sites on the south end of the lake, one in central South Lake Tahoe, the other just west of the casinos at Stateline. CARB proposes to add $PM_{2.5}$ at the South Lake Tahoe site, while the Stateline site is scheduled to close. Although monitoring was discontinued at Tahoe City in 1996, CARB plans to establish a $PM_{2.5}$ monitoring site there in the near future. In addition, a new research monitoring site is planned for the Echo Summit area. Historically, the CARB monitoring has focused on locally generated PM_{10} and CO from motor vehicles, and that is expected to continue. The NDEP Bureau of Air Quality (BAQ) operates public health-based monitoring sites at Incline Village and at Stateline just east of the casinos; these, too, focus on PM_{10} and CO. TRPA operates two visibility monitoring sites in the basin, one on the south shore within the urbanized area of South Lake Tahoe, and the other at an elevated unpopulated site in Bliss State Park, just north of Emerald Bay. Data from these sites are being compiled into a long-term record of regional (Bliss) and local (South Lake Tahoe) fine particle mass and chemistry and are documenting visibility impairment in the basin.

In addition to the current monitoring activity in the basin, the federal IMPROVE program may become a permanent source of monitoring data for the unpopulated upland portions of the basin. California has proposed that the Bliss site be adopted as a regionally representative site in the IMPROVE network. As an IMPROVE site, Bliss would represent air quality in wilderness areas on the Sierra crest, including the Desolation and Mokelumne wilderness areas.

There have been and will continue to be a wide range of short-term special purpose monitoring programs in or near the Tahoe basin. The scope of these programs has ranged from seasonal measurements of "acid rain" accumulations to detailed microscale studies of pollutants in and around specific point sources, such as fires and cars. These special studies, some of which are discussed elsewhere in this report, have provided the details needed to put long-term monitoring in perspective and to illuminate the processes that govern the generation, transport, and eventual fate of air pollution in the Lake Tahoe watershed.

All states are required to show compliance with the NAAQS or to develop control plans designed to achieve compliance with them. The rules and policies developed under these plans are codified in federally enforceable State Implementation Plans (SIPs) that are submitted to the USEPA for approval. Under federal law, states are responsible for controlling stationary pollution sources and for insuring maintenance of motor vehicle pollution control devices. New car emission controls are set by the USEPA. California enjoys special status with regard to its ability to set standards for new motor vehicles, in recognition of the unique pollution problems in southern California.

California law delegates air pollution control authority to local air pollution control districts, primarily based on county boundaries. In the Lake Tahoe basin, the basic control responsibility for permitting stationary sources is held by El Dorado and Placer counties.

Nevada holds control at the state level, except for delegation to its two most populated counties, Washoe (Reno area) and Clark (Las Vegas). In the Lake Tahoe basin, Nevada permitting authority is thus split between Washoe County and the state (acting in Carson City and Douglas County).

Under the federal Clean Air Act, primary air quality planning authority is vested in the states. In California, CARB acts as an intermediary between the local air quality agencies and the USEPA. Along with its authority to set environmental thresholds, TRPA has been granted a role in managing air quality through its transportation and land use management authority. Under this structure, El Dorado and Placer counties, in consultation with

TRPA, jointly develop a plan for the LTAB; that plan then is subject to CARB and USEPA approval. In Nevada, TRPA cooperates directly with the state and Washoe County as the state develops its plans.

Will air quality improve, degrade, or remain unchanged under the present regulatory structure?

Emission Growth Potential and Regulatory Responses

The four major categories of air pollutant emissions in the Tahoe region are motor vehicle exhaust, residential wood combustion, road dust, and open burning (wildfires and prescribed fires). Of these, residential wood combustion and road dust are tightly linked to population size.

Wood Smoke

Residential wood combustion has historically been used to track population in the Tahoe area because wood was both less expensive and more reliable than propane and electricity. Over the past decade, natural gas service has been extended to a significant fraction of the basin. However, wood remains the fuel of choice in low-density and low income areas due to lack of alternatives, and it is preferred for its "charm" by many basin residents and visitors, even in areas served by natural gas. TRPA regulations requiring low-emission wood heaters and limiting the number of fireplaces and wood-fired appliances in new construction should reduce the rate of growth of wood smoke emissions, but these regulations alone are unlikely to reverse trends. Public awareness campaigns and "don't light tonight" strategies have proven useful in many urban areas to address occasional severe smoke impacts. However, such a program is of limited value in dealing with the daily smoke burden in the Tahoe basin because the fall and winter nighttime inversions are so persistent that almost every night could be a "don't light" night. In sum, chimney smoke is likely to grow slowly in future years, even if a program is implemented to reduce peak concentrations.

Wild and Prescribed Fire

Wildfire smoke in the Tahoe region is a relatively rare event, thanks to the efficiency of local fire departments, USDA Forest Service, and California and Nevada forestry crews. However, this efficiency has led to an accumulation of standing vegetation that creates both a growing potential for a truly large, catastrophic wildfire and a need for increased prescribed fire in the basin simply for fuel management for public safety. The current prescribed fire goal of the USFS's Lake Tahoe Basin Management Unit (LTBMU) of 2,000 acres of prescribed fire per year represents a significant increase over previous decades, and its air quality impacts have yet to be fully evaluated.

The actual potential for future forestry smoke emissions and the consequent impact on air quality is unclear. At present, the states and forest managers are negotiating a system of policies and practices for "smoke management," which is intended to balance the competing goals of forest management for fuel reduction and ecosystem health, and air quality protection for public health and visibility. The main thrust of this initiative is to control the direction of smoke drift to mitigate impacts on populated areas. At present, there are only limited data available on the emission potential of various types of fires and the efficacy of smoke management to modify emissions, so quantitative predictions of the effects of the planned prescribed fire programs are not available.

The LTAM, described elsewhere in this chapter, exists, in part, to provide a means to assess such issues. However, the model's full value as an aid to planning and decision-making depends not only on additional model development but also on additional field measurements to better characterize emissions and smoke behavior in the Lake Tahoe basin.

Motor Vehicles

Motor vehicle tailpipe emissions have not exhibited a good correlation with population growth due the counteracting effects of recent, more effective automotive emission control systems, especially the effects of improved catalytic converters, electronic fuel injection, and reformulation of gasoline (USEPA 1998). Over the last several years there has been a flat to slight downward trend in measured CO concentrations at South Lake Tahoe and Incline Village, and a sharp

drop at stations near Stateline. The decline in the Stateline area has eliminated measured exceedances of the federal CO standard, so that by 1998 both California and Nevada asked USEPA to reclassify both sites to attainment for CO (NDEP 1998; CARB 1999). Progress in reducing vehicular NO_x emissions has been less dramatic, with improved emission control roughly keeping pace with growth, such that NO_2 measured at Incline Village shows no upward or downward trend over the last several years (NDEP 1998).

Road Dust

Road dust is not a large factor basin-wide, but it can be a significant contributor to PM_{10} at certain times and places, especially along unpaved roads or road shoulders in summer and in areas of heavy traffic where sand is applied to assist traction in winter. This source is not well characterized in the basin at this time, but its growth potential is clearly related to traffic and population. Slow to moderate growth of these emissions is likely outside of the urbanized areas, while congestion and local "housekeeping" measures are expected to keep these at current levels in the densely populated areas.

How would the regulatory system respond to emission increases in the Tahoe basin?

The driving force in air quality regulation is the determination of attainment status for each pollutant for which there is an air quality standard. When standards are not violated, no new emission controls are required. This leaves open the possibility that emissions can grow and air quality can degrade until such time as standards are violated and a formal determination of nonattainment is made.

Population-related emissions in the basin are roughly proportional to total population, but peak concentrations are related to local population density. Therefore, it is possible that considerable emissions growth can occur without triggering new exceedances of the standards. For activity- or policy-driven emissions, such as prescribed fire smoke, the infrequent and spatially dispersed nature of emissions and the intentional policy of preventing smoke intrusions into population centers combine to minimize the potential for these emissions to reach the existing monitoring sites. This suggests that large emission increases could occur and that local pollutant concentrations could exceed the state and federal standards, all without the official monitoring sites measuring exceedances of the standards. Once a decision is made to act, the controls that are implemented will reflect the policies and laws governing the regulatory agency whose standards have been exceeded.

NAAQS Attainment and Future Air Quality under Federal Law

No currently applicable NAAQS are being violated in the Lake Tahoe region, so there is no immediate federal impetus for more stringent emission controls.

The federal policy of Prevention of Significant Deterioration (PSD) exists to prevent emissions growth in attainment areas, but it is unlikely to contain emissions growth in the Lake Tahoe region because it applies only to large industrial facilities. Three federal programs have the potential to limit emissions growth in the basin, depending on future legal, administrative, and political actions. These are the re-establishment of the NAAQS for 8-hour ozone exposure, reestablishment of the annual and 24-hour NAAQS for $PM_{2.5}$, and the implementation of the federal Regional Haze Rule for Nevada and California.

If reinstated, the 8-hour average ozone NAAQS of 0.08 ppm probably would not be exceeded in the basin. Monitoring data from South Lake Tahoe, Stateline, and Incline Village show maximum 1-hour concentrations in the range of .07 to .09 ppm in recent years (NDEP 1998; CARB 1999), and 8-hour calculations for South Lake Tahoe for 1997-1998 range from .066 to .075 ppm (CARB 1999). Because a considerable fraction of the ozone in the basin is transported from the upwind population centers of the San Francisco Bay Area and Sacramento Valley, it is unlikely that, even if exceedances were recorded, control efforts would focus on local Tahoe basin sources of ozone precursor emissions.

The $PM_{2.5}$ NAAQS, if reinstated, would limit both 24-hour and annual average concentration. The 24-hour $PM_{2.5}$ concentration limit of 65 $\mu g/m^3$ is only slightly above the peak mid-winter concentrations for PM_{10} measured at South Lake Tahoe in recent years (CARB 1999). Because the bulk of the PM_{10} in winter is wood smoke, which is well within the size range of $PM_{2.5}$, it is possible that this standard could effectively cap particulate emissions in this area at roughly current levels.

The annual average $PM_{2.5}$ concentration limit, 15 $\mu g/m^3$, is well below the annual average PM_{10} concentrations in South Lake Tahoe (ranging from 19 to 23 $\mu g/m^3$ in recent years) and Stateline (18 to 27 $\mu g/m^3$ over the last decade), and close to the values for Incline Village (15 to 18 $\mu g/m^3$ in recent years) (CARB 1999; NDEP 1998). While these numbers include data from summer, when PM_{10} is a combination of $PM_{2.5}$ and coarser material, if is possible that the annual average standard already is exceeded along the south shore. If this standard were reinstated, a chimney smoke reduction program requiring a roughly 25 percent emission reduction probably would be required on the south shore and chimney smoke emission growth would be prevented in other populated areas of the basin.

The federal Regional Haze Program requires states to develop plans to return to natural visibility conditions in Class I areas (in the Tahoe region, this means Desolation Wilderness). Unlike a standard, the haze rule requires a state to adhere to the following:

"Analyze and determine the rate of progress needed to attain natural visibility conditions by the year 2064. To calculate this rate of progress, the State must compare baseline visibility conditions to natural visibility conditions in the mandatory Federal Class I area and determine the uniform rate of visibility improvement . . . to attain natural visibility conditions by 2064." (USEPA 1999)

The effect of this program on the long-term allowable emissions in the Lake Tahoe region is unclear at this time. Preliminary analyses of data from TRPA's visibility monitoring program indicate that there is only a weak connection between air quality at lake level and that on the ridgelines around the lake. Because Desolation Wilderness is usually upwind of the basin, it is likely that any plans developed to return "natural" visibility conditions to Desolation Wilderness would focus on upwind areas to the west and could involve little or no emission reductions in the populated areas of the basin. More problematic is the question of the impact of the regional haze rules on prescribed fire emissions. Evolving federal policy suggests that at least some prescribed fire smoke would be allowed as a "natural" emission in wilderness areas, but the manner in which this distinction would be drawn is unknown at this time (WESTAR 1995).

State Standards

Unlike federal standards, standards in California and Nevada are not linked to automatic triggers for new emission control programs, nor are there mandated time frames to achieve compliance. When and if state standards are violated, it is incumbent on local agencies, such as counties and TRPA, to initiate efforts to impose additional controls or to ask the states to impose controls. Historically, such local actions have been limited or nonexistent outside the Tahoe basin, so it is difficult to predict the speed and scale of state responses to new or continuing evidence of violations of state standards.

CO standards conforming to the threshold set by TRPA (6 ppm, 8-hour average) have been adopted by both California and Nevada. Monitoring data from South Lake Tahoe and the CARB Stateline site show maxima of 2.4 and 4.3 ppm, respectively. The Stateline data show a downward trend, with no values in excess of 5 ppm since 1990 and current values ranging from 2.1 to 2.8 ppm. Incline Village data show a similar trend, with recent values ranging from 1.6 to 2.5 ppm (CARB 1999; NDEP 1998). At this time there is no reason to expect any automotive emission reduction efforts in the basin aimed at reducing CO.

Ozone standards more stringent than the NAAQS also have been adopted by California and Nevada (California: "not to exceed .09 ppm"; Nevada "not to equal or exceed .10 ppm"). Monitoring data from South Lake Tahoe, Stateline, and Incline Village show maximum 1-hour concentrations in the range of .07 to .09 ppm in

recent years (NDEP 1998; CARB 1999). Although these are close to the allowable limits, neither state has expressed any concern that they will be exceeded in the near future. Because a considerable fraction of the ozone in the basin is transported from the upwind metropolitan areas, it is unlikely that, even if exceedances were recorded, control efforts would focus on local Tahoe basin sources of ozone precursor emissions.

Visibility standards adopted by California and Nevada provide protection for the Tahoe basin at a level roughly equivalent to a visual range of 30 miles. The monitoring being conducted by TRPA indicates that the standard is violated infrequently in remote upland areas of the basin and that it is regularly violated in densely populated areas such as South Lake Tahoe, where visibility often drops below 20 miles. Although both states are aware of these conditions, lack of routine monitoring in a form compatible with state standards has prevented either state from formally declaring the basin as being in nonattainment for visibility.

TRPA Thresholds

The TRPA thresholds for gaseous pollutants are not being violated at this time, but the subregional and regional thresholds for smoke and visibility are being exceeded. Fine particle ($PM_{2.5}$) concentrations must be reduced by 25 percent basin-wide and 65 percent in South Lake Tahoe to attain the "basin carrying capacity" visibility goal set by TRPA in 1981 (Molenar et al. 1994).

TRPA does not have direct emission control authority, so no immediate regulatory actions are forthcoming. TRPA can respond to these violations by pursuing further reductions in new source construction (fireplaces and wood-fired appliances) and in working with the state and local air pollution agencies to develop additional measures to reduce wood smoke.

Are the present standards and programs adequate to prevent adverse effects on the scenic, terrestrial, and aquatic resources in the basin?

The various air quality standards discussed above derive from legal authority to protect public health and welfare (enjoyment of the environment). The extent to which they provide protection for other resources is serendipitous, and there is no assurance that these standards will be retained or strengthened on the basis of such benefits. The following discussion explains why current air quality standards and their associated pollution control programs do not fully protect the nonhuman resources in the Tahoe basin.

Scenic Resources

The scenic resources of the Tahoe basin are among its most important attractions for both residents and visitors. Any degradation of visibility detracts from the social and economic value of the Tahoe basin. The current regulatory structure explicitly recognizes the importance of visibility in the basin through the state visibility standards and the TRPA regional and subregional thresholds. These standards were tailored for the Tahoe basin and as such are presumed to be appropriate to protect the basin's scenic quality. If further study indicates that the protection is inadequate, TRPA has the mandate to reconsider the standard levels with the explicit goal of protecting visibility in the Tahoe basin.

Terrestrial Resources

"Terrestrial resources" are intended to include the soil, plants, and animals of the Lake Tahoe basin. While not all elements of the terrestrial ecosystems in the basin have been studied for their sensitivity to air pollution, many are known to be sensitive to the direct phytotoxic effects of ozone and sulfur dioxide. Secondarily, there is a potential for natural nutrient cycles to be disrupted due to deposition of acids, primarily nitric acid derived from NO_x emissions.

There do not appear to be sufficient sources of SO_2 in the Tahoe region to directly threaten terrestrial vegetation or wildlife. Ozone, however, is known to cause some visible vegetation damage in the basin. Studies of ozone damage in other areas of California indicate that the current damage levels are modest and may not pose any immediate threat to the health of Tahoe's forests. However, a critical review of ozone injury data compiled by CARB (CARB 1987) concluded that, because vegetation injury is due to growing-season

accumulated dose, short-term health-based ozone standards may reduce the frequency and severity of plant damage, but they do not fully protect against it, It is reasonable therefore, to conclude that the present ozone damage in the basin will persist unabated under current air quality standards. In fact, CARB's review suggests that, even if the federal 8-hour standard is reinstated, some vegetation injury would be allowed under the standard.

While ozone concentrations in the Tahoe basin appear to be stable, and they are well below levels found in urban California, they are still far above natural concentrations. A general consensus is emerging that average daily peak summer ozone levels at pristine, mid-northern latitude sites are about 0.03 to 0.04 ppm, based on remote site measurements, such as those taken at NOAA's Mauna Loa Observatory in Hawaii. Because summer ozone levels in the northern Sacramento Valley, where anthropogenic influences are modest, approach those levels today (0.059 ppm in Redding, 0.052 ppm in Chico), preindustrial ozone levels in the central and southern Sacramento Valley can be estimated as being somewhere between 0.035 and 0.05 ppm. Present summer ozone concentrations in the San Joaquin Valley and southern Sacramento Valley regularly double or triple these preindustrial levels. Because these areas are the sources of air advected into the Sierra Nevada, it is reasonable to conclude that the entire west slope of the range is experiencing ozone concentrations well above natural levels.

Acid deposition also may harm vegetation at low levels through a synergistic heightening of sensitivity to ozone and at high levels by direct injury. Present data suggest the damage is minimal, if any, in the Tahoe basin (CARB 1989). The major precursor pollutant for acid deposition in California is NO_x. Because NO_x control is a major element of California's ozone control program, continued efforts to control ozone in the upwind cities and to reduce vehicular NO_x statewide probably will prevent any increase in deposition from transported pollutants and limit or prevent the growth of nitric acid deposition from locally emitted NO_x in the Tahoe basin.

Soil resources consist of both biotic communities and mineral and organic nutrients stored in the soil. Air pollution can threaten soil when wet- and dry-deposited acids accumulate and when acids are released during spring snowmelt. Acidity alone can change the pH of the soil water, increasing the solubility of certain ions and promoting leaching. Mobilized ions also may damage roots and soil biota, while the acid ions themselves (especially nitrogenous species) can act as fertilizers, upsetting the nutrient balance in the soil. As with direct vegetation injury, CARB has determined that current acid deposition rates are not sufficient to pose significant short-term risk to soils, and large increases in deposition in the future seem unlikely (CARB 1989).

Aquatic Resources

Air pollution damages aquatic resources in the Tahoe basin by fertilizing surface waters, which promotes algal growth and consequent loss of lake clarity. Principal sources of these excess nutrients are nitrates and nitric acid derived from NO_x emissions and phosphorous from wood smoke. The exact pathways by which these pollutants reach the lake are not fully known, but it is likely that the pathways are both direct through deposition to water surfaces and indirect deposition via accumulation in snow with later release during spring melt.

A secondary pathway for air pollution to affect the Tahoe watershed's aquatic resources is by acid deposition, both direct and indirect. CARB's measurements of acid inputs in the Sierra (CARB 1989) show that precipitation in the South Lake Tahoe area has about 50 percent higher concentrations of acidic species than are found in less populated sites in the northern Sierra, such as Norden and Quincy. The reduced total precipitation at lake level, however, results in a net input of about half the annual flux of acidic species that is seen at Norden on the Sierra crest. To put the anthropogenic acidic impact in urbanized South Lake Tahoe in perspective, it is not large enough to produce any direct acidic impacts and is less than one third of the impact observed on the western slopes of Sequoia National Park, with its open

exposure to the San Joaquin Valley. Nonetheless, it should not be ignored as a potential pathway for airborne material to be collected and delivered to Lake Tahoe.

Overall there remain several areas of significant uncertainty regarding the timing, volume, and pathways of deposition to the lake, and additional work is needed to properly measure deposition fluxes (Jassby et al. 1994).

Issue 4: The Need to Assess the Relative Impact of Air Quality Sources to Other Sources in Lake Tahoe Basin Welfare

The commitment to maintain or to reestablish levels of ecosystem health at Lake Tahoe that are commensurate with health and welfare requirements must be directed intelligently in order to obtain the greatest possible benefit from the resources committed. This will require an appreciation of the relative role of air quality in degrading the ecosystem compared to other inputs from terrestrial and aquatic sources. The specific questions listed below summarize the more detailed information included in Issue 1, namely the requirement for a Lake Tahoe basin air model (LTAM). Issue 1 includes numerous tables and figures that support the conclusions summarized below. The information on terrestrial and aquatic inputs must come from other sections of the report, and thus a definitive answer must await a combination of the individual components of this report.

What are the relative impacts of transported versus local nitrogenous air pollutants on lake clarity?

The answer to this question requires information on the following independent factors, each of which has important areas of uncertainty:

1. What are sources of nitrogen in gaseous and particulate form over Lake Tahoe itself and over the surrounding terrain?
2. What are the concentrations of nitrogenous pollutants, gaseous and particulate, above the lake surface and surrounding terrain?
3. With what efficiency do these materials enter the lake, either directly by wet or dry deposition into the lake surface, or indirectly via runoff?
4. What is the impact of nitrogen in reducing lake clarity?

In reference to local versus transported sources on nitrogen, the location of the sources of particulate nitrates largely has been resolved. During spring, summer, and fall most particulate nitrate is transported from upwind sources. In winter, the particulate nitrate is local in origin, with heavy transportation sources but also including other forms of combustion. During all times, gaseous nitrogen, NO_X, is of local motor vehicle origin (Cahill et al. 1977). The distribution of gaseous nitrogen (NO and NO_2, which generally sum to NO_x) away from the single current CARB measurement point at South Lake Tahoe is derived in the LTAM model by using the 1973 CARB measurements, past and present traffic, relative emission rates, and NO_x trend data. LTAM then predicts concentrations of gaseous species over the lake and surrounding terrain.

The particulate nitrogen is in the form of ammonium nitrate, which in spring, summer, and fall is transported into the basin from upwind urban sources in the Bay Area, Sacramento Valley, and Sierra foothills. The mean concentrations are roughly 0.3 $\mu g/m^3$. Due to the fine size of the particles and the distance of transport, the values are uniform across the entire Lake Tahoe basin. The winter nitrate from urban areas is typically around 1 $\mu g/m^3$ at South Lake Tahoe but is not adequately characterized for confidently predicting concentration profiles away from the measuring site. Estimates are made from other particles in the LTAM to obtain concentrations over the lake surface near urban sites and the surrounding terrain. The result is that while the concentrations vary in space and time, total nitrogenous compounds in the air above and near the lake are overwhelmingly local in origin.

The rate of wet deposition into Lake Tahoe's surface, mostly as snowfall, is well known and subject to only minor uncertainties. The snow quality above Lake Tahoe is quite clean (Cahill et al. 1996a) and is typical of the near pristine conditions of the southern Cascade Range. Dry deposition into the lake, directly or indirectly, is especially uncertain,

as measurements have yet to connect the excellent long-term deposition record of TRG (Jassby et al. 1994) with the equally solid measurements of airborne nitrogenous compounds (Molenar et al. 1994). We have attempted to resolve these problems in LTAM. From the atmospheric data given above, LTAM makes calculations of dry deposition from the measured nitrate concentrations (Sehmel 1980). A mean transported nitrate concentration of 0.3 $\mu g/m^3$, from the Bliss site but averaged over the entire lake surface, yields deposition values between 0.4 and 1.0 ton/year, well below those inferred from the TRG measurements (Jassby et al. 1994). Adding in the local anthropogenic particulate nitrate, 0.3 $\mu g/m^3$, inferred from the South Lake Tahoe site after subtracting the transported component, assuming a somewhat larger particle size for humid winter conditions and averaging over that portion of the lake near urbanized areas, yields an additional 0.1 to 0.3 tons/year. In contrast, using local gaseous NO_x concentrations from vehicles and the same type of calculations, but this time over a 1-km wide band around the lake, yields a mean NO_x concentration of 22.6 $\mu g/m^3$, roughly 75 times the concentration of transported particulate nitrate. LTAM has performed these estimates over each square mile of the lake surface, showing that the direct deposition of local NO_x gasses always dominates transported particulate nitrates by factors of 10 to 100, depending on location.

Additional uncertainties arise from indirect deposition via inert surfaces at the edge of the lake. If only 10 percent of the NO_x is scavenged onto trees and surfaces to eventually reach the lake in spring snowmelt, this yields on the order of 20 (or more) tons per year into the lake, with a spatial pattern that closely matches observed maxima in algal growth. Since there are major uncertainties in making subsurface nitrate measurements from urban runoff, direct observation of this effect is difficult. Even these factors do not appear to explain the increasing turbidity of Lake Tahoe because NO_x levels have been steadily decreasing over the past 20 years, while lake conditions grow steadily worse. Atmospheric deposition is a major factor in nitrate input to the lake, resulting in a tons per year prediction of nitrate input to the lake. By comparison to the nitrate input from streams and runoff, this gives an atmospheric source that dominates nitrate input to the lake. However, dry deposition measurements are notoriously difficult to do accurately, and questions remain on input pathways of nitrogen (Jassby et al. 1994). Some of the dry deposition nitrates, impacted onto inert surfaces, will enter this lake through snowmelt and runoff, thus fertilizing the lake and contributing to the roughly 30 percent degradation in water quality observed since 1958 (Goldman 1994). Clearly, the question of local versus transported sources becomes critical, as does the ratio of these nutrients to those contributed to runoff from urbanized areas and soil disturbance from development. This is the subject of active investigation at this time and a clear consensus has yet to be achieved.

The effect of these nitrogenous inputs on lake clarity is included in the aquatic section of this report. However, there is some indication that although atmospheric NO_x has been declining over the last 30 years at Tahoe, the algal growth rate continues to increase (Figure 3-34). Because the situation for phosphorous is dramatically different (see next section), Figure 3-34 also shows a correlation between housing increases (as single-family housing units) and algal growth, where soil disturbance may release more phosphorous into the lake during the decline in atmospheric NO_x.

What are the relative impacts of transported versus local phosphate containing air pollutants on lake clarity?

Measurements of phosphate in TRG deposition buckets gives a significant component to all phosphate input into the lake. Yet, little or no phosphate is seen in TRPA aerosol measurements. The most likely conclusion is that the phosphate particles are in the form of large wood ash flakes that would be eliminated from the TRPA aerosol measurements. Some support for this was mentioned in early UCD/TRG aerosol measurements in 1976, before inlet restrictions were used, and in a single experiment in February 1999. Further, unlike the situation with atmospheric nitrogen, a good match is seen when one compares

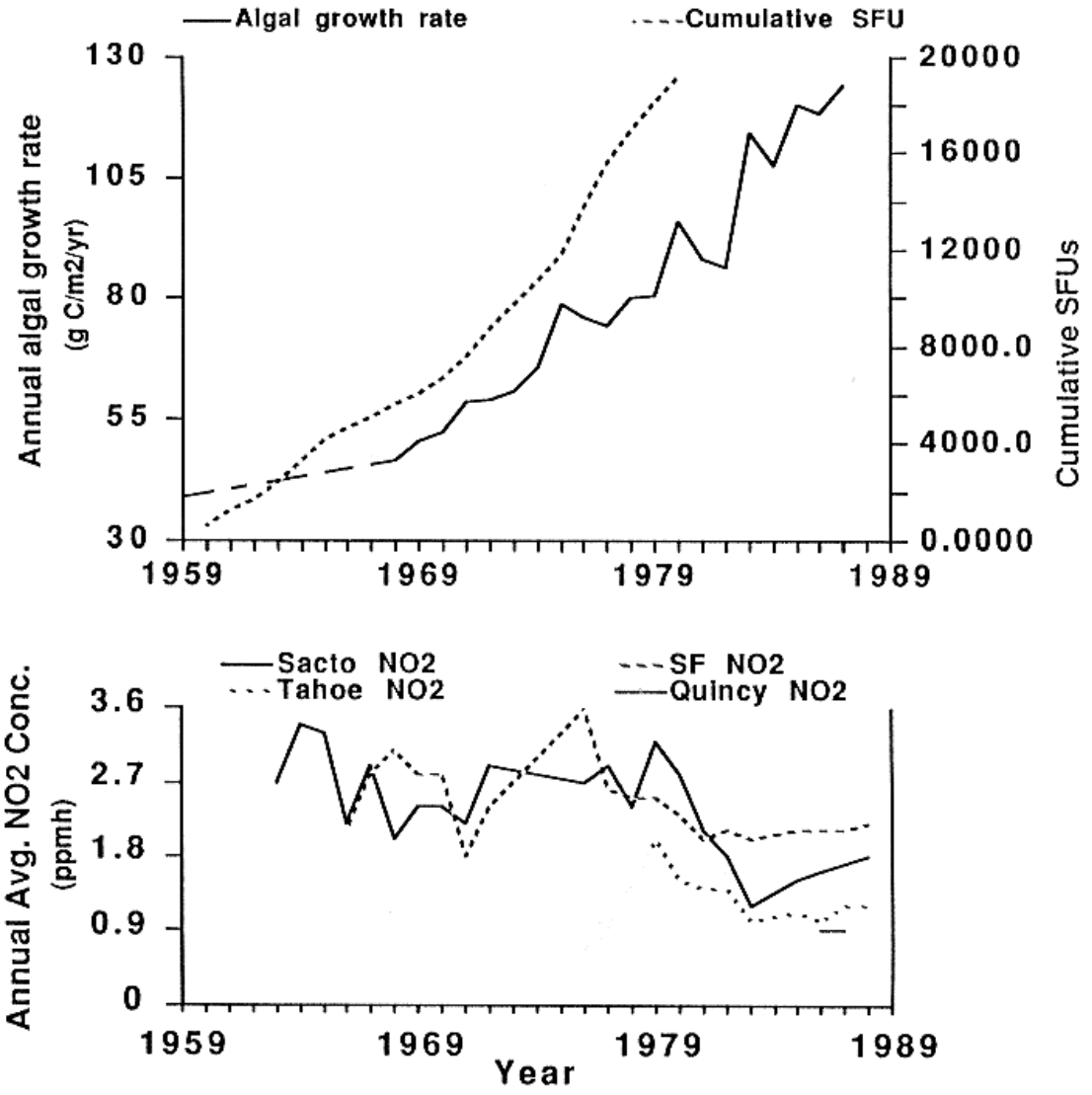


Figure 3-34—Correlation of single-family housing units (SFUs) and algal growth rate at Lake Tahoe (top). Concentration of atmospheric NO_2 for the same period showing steady decline when algal growth is increasing (bottom).

development around the lake, with development's attendant soil disturbance and mobilization of phosphorous, to algal growth. The increase in the levels of wood smoke, with a phosphorus component, and the increase in local traffic resulting in fine roadway dust in which there is a component of phosphate, support this hypothesis. Because these phosphate sources are entirely local, and thus there is essentially no transported contribution to the phosphate deposited into Lake Tahoe from airborne sources. The role of airborne phosphates on lake clarity is discussed in Chapter 4.

How well known are the deposition rates of atmospheric pollutants to Lake Tahoe?

Atmospheric deposition of gasses and particles are poorly known in general, as these rates depend not only on the concentration and, for particles, size, but the rate at which the gasses and

particles are emitted from the surfaces on which they are deposited. As an example, atmospheric nitrogen (N_2) is being continually deposited onto the surface of Lake Tahoe at an enormous rate because this gas makes up roughly 80 percent of the atmosphere. But it is being re-emitted back into the atmosphere at precisely the same rate because it is not retained in the water surface, where N_2 is not soluble to any significant extent. The counter example is that of a large particle, such as coarse soil dust. This has far lower concentrations in the atmosphere and thus lower deposition flux to the surface by a factor of about 100,000 less than N_2, but the re-emission rate is zero, as every particle is captured by a water surface. Coarse soil particles thus have a significant deposition rate, while atmospheric N_2 does not. The combined factors are usually included in a deposition velocity v_d, which for coarse particles with 100 percent retention rate, is just the settling velocity in the air. These are typically 1 to 2 cm./sec. Gasses and very fine particles, $D_p < 0.1$ μm, have about the same deposition velocities from diffusion but have vastly different retention rates. Very fine particles are retained at 100 percent, N_2 is retained at 0 percent, and everything else lies in between.

These considerations are discussed in length in Issue 1, which establishes the need for an atmospheric model. Deposition calculations have been incorporated into the LTAM model but this aspect has not been exercised, and no net deposition rates have been derived at this time. While this is due to a number of factors, including the very short time available to build and validate the model for a vast number of parameters, the most important reason is that the uncertainty of the deposition rates for several important species are so poorly known that calculations based on these rates could be misinterpreted.

In the face of these uncertainties in the atmospheric side of the equation, it is worthwhile to consider closely the deposition measurements of the TRG (Jassby et al. 1994). The TRG deposition collection started using standard wet-dry collectors, but in 1988 switched to a "dry" collector with a layer of water in the bottom. This was done to better mimic the lake deposition process and immediately tripled the collected nitrate. This raised TRG "dry" deposition rates far above those seen by CARB in its dry deposition network. However, no detailed studies were done of this new system against standard systems, such as aerosol collectors, leaving large uncertainties as to what is actually ending up in the "dry" water pool. The presence of a warm water pool in the bucket for the typical week of collection allows for a number of processes absent in standard dry deposition systems, the most important of which is the increased collection of NO_2, which does possess the ability to enter water. Thus, the TRG dry deposition value almost certainly includes some gaseous NO_2, which is then highly relevant to lake deposition processes. But there may be other processes, including bacterial attack on organic nitrate from forest debris, that must be studied and evaluated. Finally, the on-lake deposition measurements are limited in space and time, as this is very difficult work. In particular, there is a lack of deposition measurements near South Lake Tahoe during the periods of strong inversions and strong local sources, leading to high predicted deposition rates.

All of these aspects need additional focused research on exactly what deposition occurs in the conditions of Lake Tahoe in order to achieve closure between atmospheric concentrations, theoretical predictions, and measured deposition rates.

What are the relative impacts of prescribed fire (low temperature) smoke and wildfire (high temperature) smoke to lake clarity?

Coupling atmospheric concentration of pollutants to lake clarity is nearly impossible at this time. Needed are measurements of specific pollutants in air with varying season and conditions and coupled measurements of these pollutants in the water column as a measure of deposition. Furthermore, precise measurements of the source of degraded lake clarity, i.e., fine particles versus algae, are necessary. There is some evidence of algal blooms after wildfires, which makes sense because all three components needed for degrading lake clarity (phosphate, nitrate, and fine particles) are abundant in the smoke of wildfires. Little is known about the effect of prescribed fire and lake clarity

from an atmospheric perspective. Measurements of emission from fire sources are sorely needed in the Lake Tahoe basin to accurately predict effects of fires on Lake Tahoe.

Questions of lake clarity are considered in Chapter 4.

What is the nature of smoke from different types of wildfire (ground, passive crown, active crown) and prescribed fire?

Crown fires have a major potential to cause declines in lake clarity due to simultaneous generation of three key contributions to algal growth in Lake Tahoe—nitrates, phosphates, and fine particles. These are greatly reduced in prescribed fires in which temperatures are lower and nitrate rich needles are generally preserved, and the strong vertical lofting of wild fires is absent or greatly reduced. There is evidence of substantial differences in smoke from fire types (Turn et al. 1997) and recent data show nitrate loss from crowning fires that is probably not involved in low temperature ground-based litter burns of prescribed fire. However, measurements of these effects are spotty. The intense nitrate peak seen at the TRPA Bliss site during the 1992 Cleveland fire (active, crowning) supports the theories, as does the lack of a nitrate spike during prescribed fires at Yosemite National Park in 1992 (Cahill et al. 1997). No direct evidence of the phosphate and fine particle contributions have been developed for any of the fire types. This is clearly a key area for immediate research if the smoke from future prescribed fires lingers over Lake Tahoe under the inversion and thus with high deposition potential, according to LTAM.

Issue 5: The Need to Establish the Means by which Emissions Can Be Reduced to Levels Necessary to Avoid Deleterious Effects

The rationale for mitigation efforts is based on the details contained in the answers in this report and the extensive literature referenced, especially Cahill et al. (1996a). In this section we list major opportunities for mitigation, the reasons for these choices, and some indication of the impact of the mitigation. But the answers will direct us to the specific and focused research needed to provide quantitative estimates of mitigation efficacy. Further, efficiency of mitigation will depend on the costs involved, which lies outside of the scope of this report.

Lake Clarity

Since the early 1980s, phosphorus has been the most sensitive addition to enhancing algal growth in Lake Tahoe. The estimates are that airborne phosphorus is about half the total phosphorus input to the lake, yet existing measurements of PM_{10} and $PM_{2.5}$ aerosols indicate only very small (ng/m^3) concentrations in the air above the lake. There are only two options to make these results agree: phosphorus must be depositing in the TRG buckets either from a gaseous form or from particles larger than 10 microns in diameter. Because no source for gaseous phosphorus is known in nonindustrial situations, we must assume as a working hypothesis that there are coarse phosphorus particles present at the TRG deposition sites. Because this is seen even in the middle of the lake, then we must have a coarse particle that does not settle out as rapidly as coarse particles would if they were from typical soils. We are thus led to a large and known phosphorus source at Lake Tahoe, wood fires. Fire ash is large, flaky, and of low density such that it can travel over the lake. Still, it would eventually settle with high efficiency onto the lake, especially because wood smoke is most present in late fall, winter, and spring, when ventilation is often weak over the lake. Assuming that this is the somewhat mysterious source of phosphate seen in the TRG dry deposition buckets, phosphate could be mitigated by screens placed on the chimneys of all open fireplaces and by the use of low emission hardwood fuels and low emission wood stoves. Mitigation should include proper handling of all phosphate-rich wood ash, which we suspect is often just dumped on the ground because putting hot ashes into waste cans is prohibited.

Nitrogen continues to be an important factor in lake eutrophication at Lake Tahoe. Important uncertainties continue to hinder a clear resolution of the relative impacts of airborne and aquatic sources of nitrogen, despite long-term and credible measurements of both airborne and aquatic nitrogen, because the relative importance of nitrogen emission sources to TRG deposition data is still undetermined. Until the importance of nitrogen

emission sources is determined, a firm strategy for mitigation cannot be crafted. Lacking that, the safest approach is to mitigate both components roughly in proportion to their importance and the cost for removal, generally crafted in the metric dollars per ton removed. If the gaseous component derived from local traffic is the major factor, controlling nitrogenous emissions becomes the major component. In this regard, diesels emit far more NO per mile than gasoline-powered cars, especially at high altitude where cars emit less NO than at sea level. Thus, the most efficient strategy is one based on actual emissions, as a small number of vehicles are probably a large fraction of the total emission load. Two possible ways to control the use of diesel in the basin is to limit access to diesel in South Lake Tahoe and to impose a local tax on diesel to support environmental efforts. Of secondary importance, traffic reduction in general is a useful mitigation component and has been used successfully at Lake Tahoe. To see this, the traffic volume has risen very little in the past 20 years, while single-family housing units have more than doubled. Finally, moving traffic away from the lake edge reduces the efficiency of transport from roadways into the lake. As an example, if the Pioneer Trail in South Lake Tahoe were made into Highway 50 and bypassed on the upslope side of the Nevada-California state line, our model predicts sharply reduced lake impact. In addition to the general falloff in transport, deposited nitrogen has a much longer biological filter to traverse before reaching the lake. This also allows an attractive "Old Highway 50" corridor on the lake, ideally supported by light rail.

If the dominant nitrogen sources are particulate nitrogen, most of this material in summer comes across the mountains in the summer wind. In this case, only upwind controls can be effective, a much more daunting task. There is still an important component of local nitrogen-containing particulate matter in winter, tied to both traffic and wood burning. The authors of this chapter lean toward local gaseous pollutants as the most important factor and are pursuing, together with TRG, the definitive measurements that could solve this problem.

Fine soil particles have both a local and transported component, roughly 50-50, with a spring peak in both cases. This is unfortunate because this is exactly the period when algal growth accelerates in the lake. Local sources are unpaved road (much less now than in prior years), dust from roadways each spring as a consequence of winter sanding and spring runoff onto roads, and other sources. Transported sources are largely agricultural in origin, from disturbed soils in the Sacramento Valley.

Air Clarity

Air clarity at Lake Tahoe from roughly 1900 to 1960 was probably considerably better than at any time before or since. The natural fires were greatly reduced or absent because so much of the forest had been clear cut, what wild fires occurred were being extinguished by the USFS, housing and year round residential activities were low, and traffic was modest. The recent situation is summarized well in Molenar et al. (1994), and, unlike water clarity, there are few uncertainties regarding the causes of degradation of air clarity. Mitigation then depends on controlling nitrates, smoke sulfates, and soils in the western slope and Sacramento Valley in summer and local wood burning and nitrogen from cars in winter.

Forest Health

The major source of forest damage is ozone, and the ozone is almost entirely from upwind sources during the period when the trees are vigorously growing. Thus, little can be done within the basin. There would need to be limits for summer vehicular emissions (HC, NO) in the foothill Hwy. 50 and I-80 corridors, especially during afternoons in summer. Traffic in the foothills has greatly increased in the past decade. Mitigation would involve such efforts to decrease the traffic as providing alternatives to the car and supporting car pooling.

Human Health

With the successful mitigation of carbon monoxide from vehicles, fine particles, especially $PM_{2.5}$, now appear to pose the major health impact. Because much of the $PM_{2.5}$ is local and is tied to wood smoke, mitigation efforts could include a switch from wood to gas fireplaces and stoves, EPA-

certified low emission wood stoves, cleaner burning hardwood, such as dried fruit wood for existing open fireplaces, and scheduled burn-no burn days in the basin tied to inversions.

These mitigation efforts will be listed roughly in order of the seriousness of the impacts, with the continuing decline in lake clarity driving much of the present concern and research at Lake Tahoe.

Potential Mitigation Strategies for Reducing Airborne Inputs to Lake Tahoe

The strategies listed below each attempt to lower the key components that affect the Lake Tahoe basin. However, without consideration of the cost-benefit analysis essential for intelligent planning, they must be considered merely as a starting point for more complete analyses.

Impact	Key Factor	Potential Controls
Lake clarity	Phosphorous	Control ash effluent from fire places by using chimney screens and EPA-certified stoves, use hardwood fuels, control phosphate-rich ash disposal, reduce roadway dust (see below), prevent wildfires.
	Nitrogen	Control winter nitrates by restricting wood burning, traffic controls (especially on diesels) for NO_x reduction, reduce traffic near lake edge by controlling vehicular flows and moving traffic away to interior roads (e.g., Hwy. 50 to Pioneer trail), prevent wildfires.
	Fine dust	Control condition of roadways (especially in spring), ban leaf and dust blowers, reduce traffic near lake edge by controlling vehicular flows and moving traffic away to interior roads (e.g., Hwy. 50 to Pioneer trail), prevent wildfires.
Air clarity	Local smoke	Limit all types of burning in the Tahoe basin in fall, winter, and early spring conditions of low ventilation; in winter, limit wood smoke from stoves, vehicle exhaust smoke (especially diesels), limit prescribed fire to periods of good ventilation and dry fuel, especially summer, limit smoke from upwind (western slope of the Sierra) in summer, good ventilation conditions.
Regional haze	Sulfates, nitrates, smoke	Control sulfates from Bay Area oil refineries, control nitrates from the Sacramento Valley and Bay Area, reduce agricultural smoke in the Sacramento Valley, limit smoke from prescribed fires on the western slopes of the Sierra Nevada in summer transport conditions.
Forest health	Ozone	Limit summer vehicular emissions (HC, NO) in the foothill Hwy. 50 and I-80 corridors, especially afternoons in summer.
Human health	Fine particles/smoke	Control wood stoves in winter, avoid prescribed fire during inversion conditions (especially fall).

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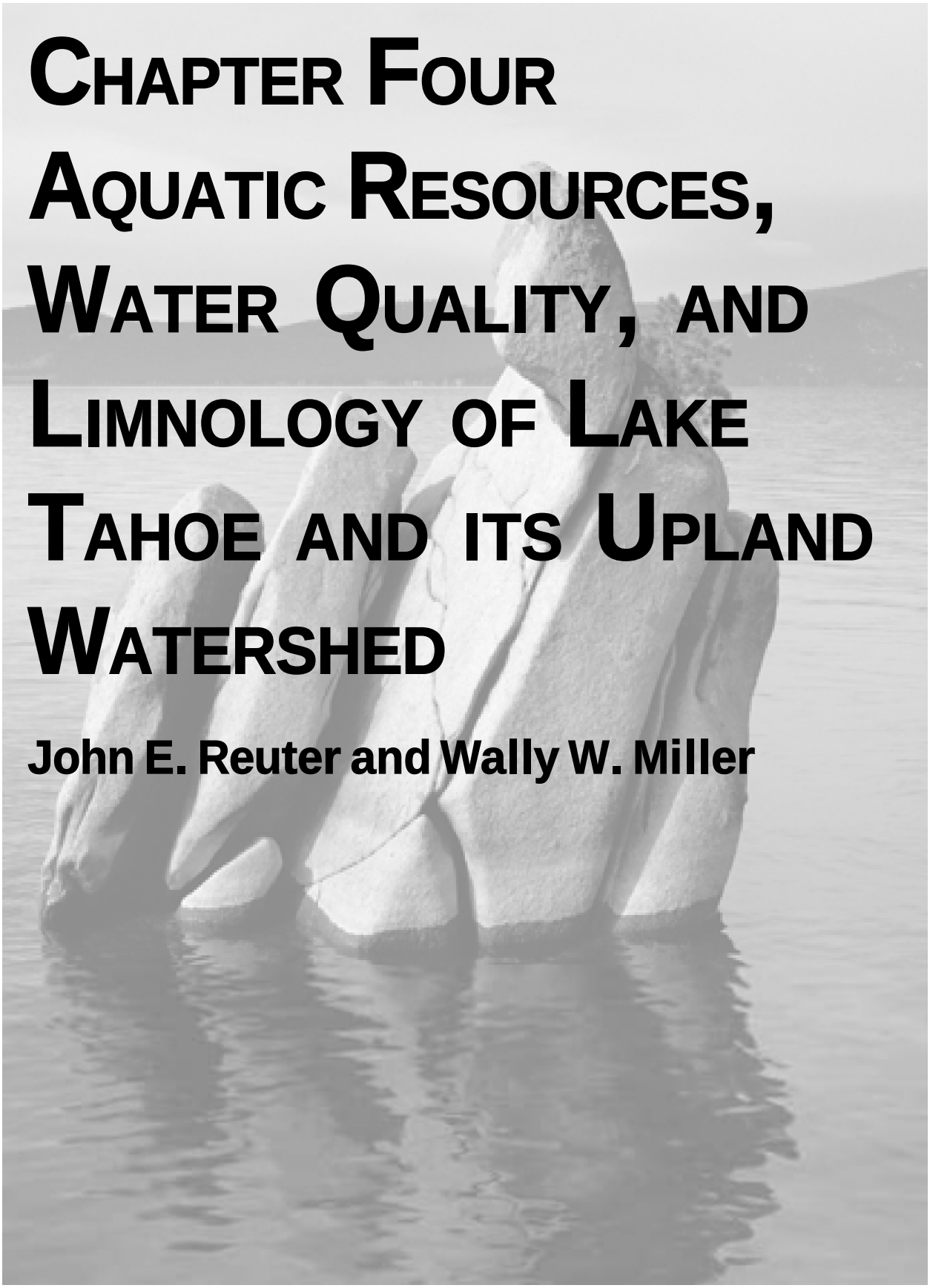
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CHAPTER FOUR AQUATIC RESOURCES, WATER QUALITY, AND LIMNOLOGY OF LAKE TAHOE AND ITS UPLAND WATERSHED

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CHAPTER FOUR

AQUATIC RESOURCES, WATER QUALITY, AND LIMNOLOGY OF LAKE TAHOE AND ITS UPLAND WATERSHED

John E. Reuter and Wally W. Miller

Water quality in Lake Tahoe has been evaluated continuously since the early 1960s, and algal growth has been increasing at a rate greater than five percent per year. Correspondingly, there has been a decline of clarity at an alarming rate of nearly one foot per year. This long-term trend is statistically significant and now can be perceived by even the casual observer. If the loss of clarity continues, it is predicted that the lake will have lost approximately 20 meters of transparency by 2030. The resulting Secchi depth of 12 meters will no doubt be accompanied by a change of lake color and a permanent change in trophic status.

Today, significant portions of the once pristine basin are urbanized. Studies from 1962 to 1999 have shown that many factors, such as land disturbance, habitat destruction, air pollution, soil erosion, and roads, have all interacted to degrade the basin's air quality, terrestrial landscape, and streams, as well as the lake itself. However, some of the same features that maintained the exceptional historical water quality in Lake Tahoe now threaten its future. Once nutrients enter the lake they remain in the water and can be recycled for decades. As a consequence, these pollutants accumulate over time and contribute to Lake Tahoe's progressive decline. The ability of the lake to dilute nutrient and sediment loading to levels where there is no significant affect on lake water quality has been lost.

The Tahoe basin is a complex ecosystem with 63 individual watersheds and numerous intervening areas. Much urbanization is in the intervening areas that drain directly to the lake. It is unrealistic to expect that completing any single mitigation project will have a significant effect on lake water quality. It is clear that future research and monitoring must address such issues as the effectiveness of best management practices (BMP), the potential reduction of nutrient and sediment loading, with its subsequent impact on the nutrient budget and lake response, project design, project monitoring, and priority ranking. This approach is critical to the future of restoration efforts in the basin. Management needs a comprehensive watershed approach. Agencies require technical products to more specifically identify sources of nutrients and sediment, to assess the effectiveness of restoration BMPs, and to help guide erosion control prioritization as project implementation begins to ramp up in magnitude.

While sediments and nutrients are the major problems that must be addressed to meet desired conditions for lake clarity and algal growth, other pollutants also affect aquatic ecosystem processes. These include MTBE and other boat fuel chemicals, toxic organic chemicals, such as pesticides and PCBs, and materials leaking into the ground water from underground storage tanks. The scope of this portion of the watershed assessment focuses primarily on the issue of lake clarity; however, this focus does not imply that these additional water quality issues are not of concern.

The Role of Science-based Decision-making in Adaptive Watershed Management

For effective lake management, understanding is needed of the following:

- What are the specific sources of sediment and nutrients to the lake and what are their respective contributions?
- How much of a reduction in loading is necessary to achieve the desired thresholds or total daily maximum loads (TMDL) for Lake Tahoe (i.e., lake response)?
- How will this reduction be achieved?

The watershed approach taken at Lake Tahoe for many decades recognizes that lake water quality is linked to upland watershed processes and air quality. Natural watershed processes have been affected by the disruption of natural ecosystem processes that treat runoff naturally (e.g., wetlands, ground water infiltration, and vegetation) and a changed landscape that alters hydrology and promotes the accelerated loading of nutrients and sediment (e.g., impervious cover, road network, habitat disruption, and land disturbance). Successfully implementing land, air, and water quality restoration projects is considered the only realistic avenue to arrest further decline in lake clarity. Scientific efforts must be focused on restoration objectives and must be coordinated to obtain information needed for adaptive management.

Hundreds of scientific papers and reports have been written on many aspects of Lake Tahoe, its watershed, and its water quality since studies first began more than 40 years ago. This chapter of the watershed assessment uses a significant portion of this information to answer a series of questions associated with the following three critical issues:

- Issue 1—The need to understand and quantify, where possible, the links between urban and natural features of the watershed landscape and the loading of nutrients and sediments to Lake Tahoe.
- Issue 2—The need to determine the extent to which discharge of sediment and nutrients from basin watersheds can be effectively reduced by management or restoration activities.
- Issue 3—The need to understand how Lake Tahoe will respond to watershed restoration projects.

The goals of this chapter can be summarized by the products it provides, which include:

- A comprehensive review of past studies with the focus of assessing both upland and lake water quality (a review of this magnitude is lacking for the Tahoe basin);
- A focal point that consolidates current and future knowledge;
- A roadmap for future proposed research and monitoring;
- New scientific information on a number of critical issues, including the decline of dissolved oxygen in portions of Lake Tahoe and the effects of fire (prescribed or natural) on nutrient cycling; and
- A review of important hydrologic and ecological processes in the Tahoe basin that require consideration during formulation and implementation of restoration projects and strategy.

The assessment was successful even prior to the publication of this final report in that it has served to galvanize scientific thought in the basin and to reinforce the importance of applying adaptive management at the watershed level.

In the remainder of this summary, the salient findings reported in this portion of the assessment are presented. In particular, focus is placed on those findings with direct and immediate application to restoration and adaptive management. This chapter does not provide a prescriptive formula for restoration; rather it provides key information for science-based decision making. Equally as important, it emphasizes those areas where the existing knowledge is insufficient.

Environmental Setting

Lake Tahoe lies at the crest of the Sierra Nevada at an elevation of 1,898 m within both California and Nevada. The drainage area is 812 square kilometers (km^2), with a lake surface of 501 km^2, producing a ratio of only 1.6. The lake is in a montane-subalpine watershed dominated by coniferous vegetation and nutrient-poor soils. Sixty-three streams flow into the lake. At 505 m, Lake

Tahoe is the world's tenth deepest lake, with a mean depth of 313 m. Its volume is 156 km^3 with a residence time of about 700 years, and the lake is ice-free year-round. The depth of vertical mixing varies from 100 m to >450 m, depending on winter storm intensity. The extent of mixing is directly related to interannual differences in algal growth because of the introduction of nutrient-rich water from the deeper portions of the lake (Goldman and Jassby 1990). The amount of algal primary productivity during the extended summer season is fueled by nutrients that mix up from the bottom waters, enter the lake via surface and subsurface runoff, are loaded by atmospheric deposition to the lake surface, or are recycled by bacteria and other aquatic micro-biota. Lake Tahoe was once classified as ultra-oligotrophic (Goldman 1974); i.e., low nutrient content, low plant productivity, and high transparency. However, because of the ongoing decline in clarity and rise in algal growth rate, its trophic status (level of fertility) has been moving toward a meso-oligotrophic status.

Changing Water Quality

Many of the world's lakes have been subject to cultural eutrophication. The anthropogenic enrichment of waters usually results from nutrients reaching a stream or lake from septic tanks and sewage treatment plants, agricultural and urban runoff, or the disturbance of land during lumbering or urban development. These additional sources typically occur at rates that greatly exceed natural inputs. When nutrient content is too high the resulting dense growth of algae causes a change in the lake's color, reduce light penetration, and lower dissolved oxygen to a point where aquatic organisms can no longer survive. Because of Lake Tahoe's naturally low fertility it historically has been a pristine waterbody. However, extensive research and monitoring has provided clear evidence of the onset of cultural eutrophication in oligotrophic Lake Tahoe (Goldman 1988). Continuous long-term evaluation of lake chemistry and biology since the early 1960s has shown that algal production is increasing at a rate greater than five percent per year, with a corresponding decline of clarity at the alarming rate of approximately 0.3 meters, or 1.2 feet, per year. Not only is the long-term trend of declining clarity statistically significant ($p<0.001$), it is now visually obvious. Secchi depths typically range from >15 to <25 m, depending on season and year.

Lake water clarity is measured using a number of techniques. Most commonly, clarity is expressed as a Secchi depth: the depth at which an eight-inch white disk is no longer visible from the surface as it is lowered into a waterbody. Regular measurements at the UC Davis/Tahoe Research Group Index Station began in 1967 and have been made on average every 12.2 days since then (Jassby et al. 1999). In earlier synoptic studies of lake primary productivity, Goldman found the Index Station to represent whole lake conditions (Goldman 1974). Scientific data shows that Secchi depth is directly related to the amount of suspended matter in the water (Jassby et al. 1999). This suspended matter is composed of both biotic materials and suspended inorganic silt or sediment

Extensive research on the spatial distribution of free-floating algae indicates a marked correspondence between the highest algal growth rates and the most extensive shoreline development. Lakewide studies have shown that the central portion of the lake historically has been characterized by relatively fewer algae, with areas near south and north shore developments exhibiting enhanced production. Similar studies of the attached algae also demonstrate this pattern. The dramatic differences in algal growth on rocks at various shoreline locations are linked to nearby development and are immediately visible to the largely shore-bound populace.

Ironically, some of the same features that maintained the exceptional historical water quality in Lake Tahoe now threaten its health under current conditions of increased nutrient and sediment loading. Tahoe's large depth and volume once acted to dilute pollutants to a level of no significant affect; this is no longer the case. Once nutrients enter the lake they accumulate in the water and are available for use over and over for decades. This phenomenon has crucial implications when the results of watershed mitigation and restoration projects are evaluated.

Research also has shown a fundamental shift of algal growth by nitrogen additions from frequent stimulation to almost exclusive phosphorus stimulation (Goldman et al. 1993). This response of

Lake Tahoe algae to nutrient enrichment has been measured since the 1960s, with the observed shift occurring in the early 1980s. Since phosphorus is typically transported along with sediment, these findings underscore the importance of sediment control and erosion mitigation. Atmospheric deposition of nitrogen from both in-basin and out-of-basin sources is now considered a significant factor contributing to the observed shift in nutrient stimulation (Jassby et al. 1994). Because much of the phosphorus input to the lake is still derived from the watershed, erosion control, acquisition of sensitive lands, and other watershed restoration practices remain an appropriate course of action. The focus of much of the current research is erosion and the transport of sediment and phosphorus to Lake Tahoe.

Another important finding is that Tahoe stream water can stimulate the growth of algae (Goldman and Armstrong 1969; Hatch 1997). Stream water quality data, collected as part of the Lake Tahoe Interagency Monitoring Program (LTIMP) from the Upper Truckee River (the major tributary to the lake, contributing approximately 25 percent of the annual flow) has monitored the magnitude of suspended sediment flowing into Lake Tahoe from this tributary. While the annual load of material varies from year-to-year depending on precipitation and land use, as much as 22,000,000 pounds of sediment can enter the lake in a single year from this river alone (Hatch 1997). Indeed, taking nine intensively studied streams in the basin, the annual amount of phosphorus entering Lake Tahoe from watershed runoff was determined to depend directly on sediment concentration (r^2=0.89, $p<0.001$). Given that annual and instantaneous total phosphorus concentrations in the Upper Truckee River at South Lake Tahoe exceed California state water quality standards, controlling erosion and sediment transport and treating surface runoff are crucial aspects of watershed management at Lake Tahoe.

Deep sediments at the bottom of lakes serve as a reservoir of history within the watershed. A recently completed investigation has shown that the rate of sedimentation has varied over the last hundred years (Heyvaert 1998). In particular, rates increased significantly during the Comstock Silver Mining Era (1850 to 1890), when clear-cut-type logging occurred extensively in the Tahoe basin, and again from 1950 to the present. This latter occurrence is believed to be due to increased population growth, road construction, and general urbanization within the basin. The intervening period, (1900 to 1940), showed a reduction in sedimentation and provides hope that the system may respond to proper management.

Fate of Lake Tahoe's Famous Clarity

If the rate of decline in clarity continues, it is predicted that over the next 30 years Lake Tahoe will have lost over half its extraordinary transparency. In total, the lake will have lost approximately 20 meters of transparency by 2030. The resulting Secchi depth of 12 meters will no doubt be accompanied by a change of water color. A change of this magnitude already has been seen from studies in the polluted regions of Lake Baikal, Russia (Goldman et al. 1996).

Link Between Science and Policy for the Benefit of Lake and Watershed Management

One of the critical cornerstones of watershed management is a comprehensive understanding of hydrologic, atmospheric, and ecological processes and their interactions, real-time assessment of environmental conditions (e.g., air quality, water quality, and forest health), response to anthropogenic and natural disturbance, and the ability to predict environmental improvement based on various management strategies. Indeed, serious concerns regarding ecological condition and long-term environmental protection underscore the need to provide the highest quality science to aid in problem resolution (Goldman 1998). Ecosystem health, sustainable environment, and watershed management are interrelated and support growing view that the fabric of the natural landscape is a complex weave of interacting influences, including physical, chemical, and biological factors. Time after time, valid scientific data, with unbiased interpretation, has provided decision-makers in the Tahoe basin with valuable information and insight. Without a sound scientific foundation, critical discussions are too easily misdirected toward narrowly focused interests.

As evidenced by its special status as Outstanding National Resource Water under the Clean Water Act, Lake Tahoe is unique and must be protected. The agency approach for decades at Tahoe has focused on watershed management to protect water quality; this is clearly stated in the Lake Tahoe Basin 208 Plan and is central to the mission of nearly all basin resource agencies. Indeed, the creation of the Tahoe Regional Planning Agency (TRPA), the USDA Forest Service Lake Tahoe Basin Management Unit (LTBMU), and the California Tahoe Conservancy (CTC) speak to the importance of watershed management. A wide array of public and private institutions now forms an extensive foundation for linking policy to scientific research and monitoring.

A critical component for long-term planning at Lake Tahoe is a water quality model, based on the lake's assimilative capacity to receive and process sediment and nutrients (Reuter et al. 1998a, c). By knowing the level of nutrient loading required to achieve the thresholds, responsible agencies will be able to plan in a more quantitative and progressive manner. Based on previous and ongoing research and monitoring, these types of predictive models are being developed.

Watershed Assessment Focus

The watershed approach that has been taken at Lake Tahoe for many decades recognizes that lake water quality is inexorably linked to upland watershed processes, including nutrient cycling, stream flow, surface runoff, ground water, and direct precipitation (Leonard et al. 1979; Glancy 1988; Sullivan et al. 1996). This largely occurs through the hydrologic and biologic cycles that mediate the discharge of nutrients and sediments to the lake. Those normal cycles have been affected by the disruption of natural ecosystem processes that naturally treat runoff (e.g., wetlands, ground water infiltration, and vegetation) and a changed landscape that alters hydrology and promotes the accelerated loading of nutrients and sediment (e.g., impervious cover, road network, habitat disruption, and land disturbance).

This watershed assessment is intended to serve a number of purposes. First, it allowed scientists to conduct a comprehensive review of past studies with the focus of assessing both upland and lake water quality. Evidence for long-term trends is presented along with information on important ecological and hydrological processes. A review of this magnitude is largely lacking for the Tahoe basin. Second, it provides all agency and university scientists, policy-makers, interested organizations, and the concerned public with a single document that serves to consolidate current knowledge. This assessment is intended to serve as a major and substantive reference resource. Third, the format of the assessment, based on issues and questions, provides a roadmap for future proposed research and monitoring. By its very nature, scientific research depends heavily on the results and lessons from previous investigations. Fourth, the contributors to this section of the document also have conducted a number of new analyses; for example, the decline of dissolved oxygen in portions of Lake Tahoe now has been identified and its ramifications have been considered, and the effects of fire (prescribed or natural) on nutrient cycling have been further quantified. The assessment also has provided the opportunity to develop a nutrient budget for Lake Tahoe, documenting both sources to and losses from the lake. Finally, the assessment process has allowed aquatic scientists to begin the important discussion of aquatic environmental indicators, monitoring, and research in a much more integrated fashion.

While focusing on these three key issues, this assessment did not attempt to review all existing information on pollutants that are not either sediments or nutrients. Prominent examples include PCBs found in lake trout flesh (Datta et al. 1998), MTBE (Allen et al. 1998; Boughton and Lico 1988) and other manufactured organic compounds (Lico and Pennington 1999).

The upland watershed and lake sections of this chapter, issues one and three are intended to assess the current state of knowledge regarding these topics (issues 1 and 3 above). These subjects, the focus of most research and monitoring at Lake Tahoe, constitutes the major portion of this chapter's content. However, on the basis of collective experience and from extensive

conversations with numerous environmental scientists at Lake Tahoe, it is clear that future research and monitoring must address such issues as effectiveness of BMPs used for restoration and water quality treatment, potential reduction of nutrient and sediment loading and its subsequent impact on the nutrient budget, and such factors as lake response, project design, project monitoring, and priority ranking. This approach is critical to the future of restoration efforts in the basin and is discussed as part of Issue 2.

Issue 1: Upland Water Quality In The Tahoe Basin, With Emphasis On Sediment And Nutrient Discharge

With contributions from John Warwick, Lorin K. Hatch, Charles R. Goldman, Scott H. Hackley, Shari Silverberg, Kyle Comanor, Sherman Swanson, Andrew Stubblefield, and Ted J. Swift

What are the current sources and sinks of nutrients to Lake Tahoe? How do these compare to previous periods of disturbance and restoration since the mid-1850s?

Much of the strategy for lake/watershed management has come about in response to long-term decline in clarity and increase in algal growth rate since the 1960s (Goldman 1988; Jassby et al. 1999). For decades, planning, regulatory, and implementation actions have focused on controlling nutrient and sediment inputs to the lake. Examples include, but are not limited to, the acquisition of environmentally sensitive lands, building restrictions, BMP retrofitting, erosion control, BMPs for treatment of surface runoff, permits, and education.

It is now more important than ever that a nutrient budget that quantifies the critical sources and sinks of nutrients and sediment in Lake Tahoe be completed. In simplistic terms, nutrient input (I_{nut}) is equal to nutrient output (O_{nut}) plus nutrient storage in the lake (S_{nut}). To reduce accumulation in the lake, which is a fundamental goal of management, inputs must be diminished or outputs (sinks) must be enhanced. For large lakes such as Tahoe, management strategies for significantly increasing outputs are not feasible. The water clarity model described in this assessment is intended to help predict the consequences of nutrient/sediment control on lake transparency; however, a nutrient budget is needed to identify the most important sources of loading.

Nutrient Budget Components

Reuter et al. (1998a) provided a preliminary nutrient input budget for Lake Tahoe in which five major sources of nutrients to Lake Tahoe were identified: (1) direct wet and dry atmospheric deposition, (2) stream discharge, (3) overland runoff directly to lake, (4) ground water, and (5) shoreline erosion. The major losses include material settling from the water column to the bottom and discharge to the Truckee River outflow. This section provides preliminary estimates for phosphorus and nitrogen loading; however, in order to begin prioritizing and evaluating the potential contribution of planned restoration projects, a much more in-depth analysis of the specific sources of N and P must be performed.

Nutrient Input

Atmospheric Deposition—Jassby et al. (1994) published a paper estimating the contribution of atmospheric deposition of nitrogen and phosphorus to the annual nutrient loading of Lake Tahoe. This study analyzed atmospheric deposition both as rainfall and dry fallout and then compared this to loading from stream inflow. Six sites were equipped to collect dry fallout and precipitation, and data used in this analysis included the period from 1989 to 1992. Although alluded to in a 1985 report to TRPA (Radian Corporation 1985) and again in 1988 (Papadopulos & Associates, Inc. 1988) the Jassby study represented the first published research to conclude that atmospheric deposition provides most of the dissolved inorganic nitrogen and total nitrogen to the annual nutrient load of Lake Tahoe. It was further concluded that atmospheric deposition also contributes significant amounts of soluble reactive-P and total-P (TP) loading but to a less extent. Comparisons of atmospheric loading at the Ward Creek Lake Level location showed that (1) deposition of nitrate and ammonium were similar, (2) wet deposition of nitrate and ammonium

in the forms of snow and rain had approximately twice the loading rate than deposition from dry fallout, (3) conversely, the loading of dry soluble reactive-P was 2.4 times that for wet, (4) the ratio of total-N to dissolved inorganic-N (i.e., nitrate plus ammonium) was 2:1, with dry fallout comprising 64 percent of total-N deposition, and (5) the ratio of total-P to soluble reactive-P was also just over 2:1, with dry fallout comprising 70 percent of total TP deposition.

Annual wet deposition rates for nitrate and ammonium were compared at seven sites in California and one Nevada site close to Lake Tahoe, where the measurements are taken by the National Atmospheric Deposition Program (NADP). The data for Lake Tahoe was judged to be consistent with the two other Sierra Nevada stations located at Yosemite and Sequoia national parks. Note that this database was not sufficient and was it not intended to separate in-basin versus out-of-basin sources. However, Jassby et al. (1994) did hypothesize that nitrogen could have both in- and out-of-basin sources, while soluble-P most likely would have had an in-basin terrestrial source. At this time, P present in wet and dry fallout is hypothesized to result from wood smoke (fires in the forest and wood stove use) and from road dust and aeolian (wind) transport from disturbed land. These conclusions and hypotheses have lead to a more comprehensive exploration of atmospheric nutrient sources, both as part of this assessment and activities of the newly formed Air Quality Modeling Group for Lake Tahoe.

Using these data in concert with other portions of the historic monitoring database and the TRPA isohyetal map for Lake Tahoe (which shows the spatial distribution of precipitation over the entire lake and watershed), loading values for N and P that fall directly on the lake surface were estimated for this assessment. Nutrients deposited on the watershed that are subsequently transported to the lake are included in the calculations of stream discharge, direct runoff, and ground water loading. The database used for calculations in this section includes Ward Valley Lake Level Station, 100 m from lakeshore at an elevation of approximately 1,895 m (1983 to 1992); Ward Valley Bench, 6.8 km west of lakeshore at an elevation of 2,200 m (1983 to 1992); anchored buoys at four lake stations, three forming an east-west transect from Ward Valley to mid-lake and the remaining one offshore of South Lake Tahoe (1986 to 1992); and stations in Glenbrook, Nevada, and Incline Village, Nevada, which were operational only in Water Year 1982.

For bulk deposition (wet plus dry), the estimated rates for both nitrate and ammonium ranged from 250 to 450 $\mu g/m^2$/day, depending on location. Typically, the open water portions of the lake were characterized by concentrations at the lower end of this range. Estimates of bulk soluble reactive-P deposition ranged from approximately 15 $\mu g/m^2$/day along the south shore to 55 $\mu g/m^2$/day near Glenbrook. For TN minus nitrate+ammonium, bulk deposition ranged from 580 to 1,025 $\mu g/m^2$/day; TP minus SRP ranged from 20 to 65 $\mu g/m^2$/day, again depending on location.

Based on the distribution of deposition measurements and the pattern of precipitation denoted by isohyetal contours, the lake was divided into eight regions. Within each region, the deposition rate was multiplied by the area to determine bulk deposition. The data below represent conditions during the period from 1989 to 1993 and can be entered into the lake's overall nutrient budget:

Atmospheric Deposition
(metric tons per year)

	Nitrogen	Phosphorus
Soluble	107	5.6
Particulate	128	6.8
TOTAL	234	12.4

For the entire lake surface area, the contribution of P was an estimated 12.4 MT, where 1 MT = 1,000 kg or 2,205 pounds. Direct N-loading to the lake surface was estimated at 234 MT. This accounts for 27 percent and 56 percent of the annual TP and TN budgets, respectively.

Variability in these estimates is driven by a number of factors, including adequacy of sampling site coverage, year-to-year variability, and coverage of events throughout a single year. Measurements of the nutrient content of atmospheric deposition in the Tahoe basin have been very limited. At this time, only the Tahoe Research Group's (TRG) two sites in

Ward Valley and their mid-lake location are of sufficient duration to estimate interannual variability. The other data used in this analysis represent what is currently available. Despite its potential importance to the lake's nutrient budget, sufficient attention has not been given to establishing additional long-term collection sites elsewhere around the lake. It is difficult to quantify the variability resulting from a limited sampling network; however, based on the available data for the Ward Lake level, Incline Village, Glenbrook, and the four lake stations cited previously, the coefficient of variation (mean÷standard deviation) for bulk nitrate deposition (μmol $N/m^2/d$) is 22 percent. Similarly, the coefficient of variation for bulk ammonium and soluble reactive-P deposition are 24 percent and 36 percent, respectively.

Year-to-year variability also can be analyzed by examining the wet deposition rates for nitrate, ammonium, and soluble reactive-P at the Ward Lake level station from 1983 to 1992 (Jassby et al. 1994). The coefficients of variation for these parameters were 31 percent, 37 percent, and 43 percent, respectively. For each of these parameters, wet deposition from 1989 to 1993 was within 10 to 20 percent of the values found during the longer 1983 to 1992 period.

Stream Loading—The sixty-three streams that drain into Lake Tahoe are characterized by different levels of urban development and disturbance. The LTIMP has been sampling up to 32 sites in 14 streams since 1980. LTIMP is a cooperative program including both state and federal partners, and is operationally managed by the US Geological Survey, The UC Davis/Tahoe Research Group, and TRPA. The following streams are currently monitored and have been monitored since 1988: Trout Creek, Upper Truckee River, General Creek, Blackwood Creek, Ward Creek, Third Creek, Incline Creek, Glenbrook Creek, Logan House Creek, and Edgewood Creek. Note that because of variation in watershed characteristics around the basin and significant "rain shadow" effects from west to east across the lake, no single location represents all watersheds. Flow from these monitored streams totals 50 to 55 percent of the total discharge from all tributaries. Each stream is monitored on 40 to 60 dates each year. N and P loading calculations were performed using the LTIMP flow and nutrient concentration database.

Data from the early 1980s to the early 1990s were used to calculate the stream loads for N and P, as part of two separate studies (Marjanovic 1989; Jassby et al. 1994). The results for annual N-loading were 81.1 MT and 55.2 MT for the beginning and end of this period, respectively. Comparable loading values for total-P were 12.5 MT, and 11.2 MT. Differences between these periods reflect the variation in precipitation and runoff.

The US Geological Survey (USGS), in a cooperative study with TRPA, also provided a very preliminary estimate of nutrient loading to Lake Tahoe from 1990 to 1993 (Thodal 1997). In this latter study, annual nutrient loads associated with streamflow were estimated by multiplying the mean annual volume of surface-water runoff by the mean annual nutrient concentration. Using this simple approach, loading from runoff was reported as 70 MT for total-N and 20 MT for total-P (Thodal 1997). A very early estimate of streamflow nutrient loading by Dugan and McGauhey (1974) estimated 120 MT of total-N and 9.2 MT for total-P. These data are similar to the other estimates, despite being much older and perhaps having been acquired using different methodologies for nutrient analysis. Taking the mean of these values, which represents different periods and consequently different precipitation conditions, loading estimates of 81.6±27.7 (mean±standard deviation) MT and 13.3±4.7 MT were obtained for total-N and total-P, respectively. These accounted for 20 percent and 29 percent of the N and P budgets.

As part of the joint USGS and TRG analysis of the LTIMP stream flow and loading database, scheduled for completion in 2001, these loading rates will be updated and examined for temporal trends, station-to-station variability, relationship to land use, contribution by various chemical forms of N and P, loading of total suspended sediments, and other features of the long-term data set. Part of that effort will be to calculate loading rates for soluble reactive-P (SRP). As a preliminary estimate for this report, SRP accounted for 18 percent of total-P for the ten primary LTIMP streams sampled between 1989 and 1993. This is exactly the mean SRP:TP ratio found for the Upper

Truckee River (South Lake Tahoe site) from 1981 to 1997.

Direct Runoff—The Tahoe basin has 52 intervening zones that drain directly into the lake without first entering streams. These intervening zones generally are found between individual watersheds and, as such, are distributed around the entire lake. These zones range from 0.1 km^2 to 10.5 km^2. The range for covered or otherwise disturbed land within these intervening zone ranges from 0 to 63 percent. The overall ratio of disturbed land to total area is 27 percent, with runoff from the intervening zones accounting for 10 percent of the entire drainage.

Calculations of loading from direct runoff requires quantifying flow and concentration (flow from each of the intervening areas was calculated by Marjanovic [1989]). Data on N and P concentrations in direct runoff are less available than concentrations from other sources because this type of study has not received priority funding in the basin. However, based on a study of urban runoff at south shore in 1983 to 1984 by the Lahontan Regional Water Quality Control Board (RWQCB) (1984), four runoff studies conducted by the TRG between 1993 and 1998 (Ski Run, Pioneer Trail, Upper Truckee Road, and a current study in the 4.3 km^2 intervening area between Ward Creek and the Truckee River outflow), concentration data can be estimated. Clearly, a significant amount of new monitoring that focuses on urban runoff, which is not monitored at the LTIMP stream sites, is still needed.

For the purpose of calculation, an area was considered urban if 25 percent or more of its areas was classified as covered or disturbed. Concentrations representative of urban and nonurban conditions were taken from the field studies cited above and were used in the quantification of loads. Values represent mean±standard deviation and are expressed as mg/L.

	Urban	Nonurban
TSS	238±234	45±28
Total Kjeldahl Nitrogen (TKN)	1.01±0.62	0.33±0.11
Nitrate	0.03±0.02	0.03±0.03
TP	0.43±0.13	0.07±0.03
SRP	0.14±0.05	0.02±<0.01

These concentrations are based on a rather limited database. As discussed elsewhere in this assessment, a comprehensive and well-designed monitoring program for urban and direct runoff must be initiated.

N-loading was calculated at 41.8 MT, or 10 percent of the total-N budget, while P-loading was 15.5 MT, or 34 percent of the total-P budget. Runoff values calculated by Marjanovic (1989) for each intervening zone were used in concert with the measured concentration values. The percent contribution of SRP to TP for direct runoff was estimated at 32 percent, based on the concentration levels. The observation regarding the high contribution of P-loading from direct runoff is particularly important because a significant portion of the urbanization at Tahoe is found in the intervening zones.

Ground Water—Later in this section, a summary of the knowledge of ground water processes in the Tahoe basin is presented; however, quantitative estimates documenting the contribution of ground water discharge to the lake's nutrient budget is limited. The most comprehensive basin-wide effort to date comes from Thodal (1997) as part of a hydrogeology study of the Tahoe basin. Data on the results of a ground water quality monitoring study done from 1990 to 1992 are presented. By multiplying mean nutrient concentrations from their ground water survey (N = 1.0 mg/L; P = 0.074 mg/L) and estimates of total annual ground water discharge to the lake (5.15 x 107 m^3), Thodal calculated "rounded estimates" of 60 MT for N-loading and of 4 MT for P-loading.

This accounted for 14 percent of the TN budget and nine percent of the TP budget. Nitrogen and phosphorus loading was assumed to be in the dissolved form (Thodal 1997).

Shoreline Erosion—The process of shoreline erosion and its quantitative importance to the nutrient and sediment budgets of Lake Tahoe have received very little attention. However, the importance of shoreline erosion has been highlighted in recent years as a result of high lake levels and strong sustained winds that altered some of the west shoreline by many feet. A preliminary estimate of the order-of-magnitude contribution of this process is presented here, with emphasis that additional studies must be performed before any action is based on these rough numbers.

Quantification of the contribution of shoreline erosion to the nutrient budget of Lake Tahoe requires two components: the concentrations of nitrogen and phosphorus associated with shorezone soils and the amount of material lost to the lake. In response to the former need, a pilot study was conducted (Hackley, S. H., B. C. Allen, and J. E. Reuter, University of California, Davis, unpublished data 1998) to determine a first-order estimate of N and P concentrations in backshore and shorezone sediment samples. This work was performed between July and September 1998 at Carnelian Bay, Lake Forest, Homewood, Sugar Pine Point, Pope Beach, and a site near Sand Harbor (TRG, unpublished). Thirty individual sediment sections, ranging from 0 to over 250 cm in depth, were analyzed. This work is ongoing; however, a continuance of this research at the pilot study level is unlikely to be sufficient to calculate adequately nutrient loading from this source.

The amount of shoreline eroded each year has not been quantified nor, even roughly estimated (Smith 1999). With this understanding, a rough estimate that represents a guess may later form the basis for a more comprehensive estimate. This estimate is needed for a number of reasons, including refining the nutrient budget and the extent of shorezone sediment loss. That stated, assuming that 55 percent of the lake's 113-km shoreline is subject to erosion and that on average, a cross-section with an area of 5 cm x 3 cm (0.0015) to 8 cm x 4 cm (0.0032 m^2) is lost from each kilometer of erodable shoreline, then on the order of 100 to 200 m^3 of material may be lost to the lake in a year. Over 10 years this would amount to 1,000 to 2,000 m^3 of shoreline sediment. Using a sediment density of 2.5 g/cm^3, this amounts to 2,500 to 5,000 MT of material during that 10-year period. Furthermore, it was assumed that once every 10 years, a very large erosion event results in an amount of erosion equivalent to that expected in an entire year. Under these circumstances, during this hypothetical 11-year period, there would be [e.g., 2,500 MT + 2,500 MT]/11 years, or approximately 450 to 900 MT of shoreline material eroded per year.

Using the field concentrations measured in the summer of 1998 (see above) the average ratio of TP:TSS was estimated at 0.0007. Concentration of total-P per unit of wet sediment in a single sample ranged from a high of 0.0013 to a low of 0.00003 g TP per g sediment. The mean values for TP per g of wet weight sediment at the sampling sites were within a factor of 2, ranging from 0.00041 to 0.00098. The exception to this was Pope Beach, which was very low in TP, 0.000068 g TP per g of wet weight sediment. Applying a mean TP concentration of 0.00068, a total-P load of 0.3-0.6 MT was calculated.

Sediment total-N concentrations measured by TRG in 1998 ranged from 0.00005 to 0.003 g TN per g sediment, with a mean of 0.0011 g TN per g sediment. TN between locations was more variable than for TP, with a range of 0.00025 to 0.00284 g TN per g of wet weight sediment. Again, the Pope Beach samples were much lower at 0.000084 g TN per g of wet weight sediment. Applying this to the calculation of total-N entering the lake via shoreline erosion resulted in an estimate of 0.5 to 1.0 MT. Note that these calculations depend on estimates of actual erosion shoreline erosion rates, which are extremely rough in this discussion.

Additional Considerations—Three sources of nutrients to Lake Tahoe that deserve special attention include sewage effluent, fertilizer application, and marina dredging. A body of knowledge based on research in the Tahoe basin exists for these three point sources. From a management perspective, these sources are less ambiguous than surface runoff, they can be readily identified and measures can be adopted for their reduction. Indeed, an early success at Tahoe in reducing nutrient loading to the lake was the use of scientific research and monitoring data to justify the cessation of sewage disposal within the basin and to the lake.

With increased population came the

problems of waste disposal. Populated areas first utilized septic tanks and leach fields, then more sophisticated secondary treatment systems, and finally a tertiary waste treatment facility managed by the South Lake Tahoe Public Utility District. As nutrient loading and lake clarity gained in public concern, introducing treated wastewater back into the lake was found to be inadvisable. Hence, sewage began to be exported from the basin beginning in 1968. Initially, some efforts were directed toward wastewater reuse. One pilot program sprayed effluent onto fields near Heavenly Valley. Five years after termination of this program, Heavenly Valley Creek was found to be discharging about 60 times more nitrate into Lake Tahoe than did Ward Creek, which received no effluent irrigation (Perkins et al. 1975; Goldman 1989). Old leaky septic tanks remain an uncontrolled potential source of nutrients that still could be affecting ground water (Loeb and Goldman 1979).

Historical and current use of commercial N and P fertilizers in the basin also is of concern. The fertilizers have been applied predominantly to ski slopes and large turf areas, such as parks and golf courses. Although no longer used to "harden" snow at ski areas, the long-term ramifications of this past practice remain unknown. Nutrient discharge from fertilizing golf courses and other turf areas is largely unknown. However, turf grass has been well documented to be highly efficient in the utilization of N and P. Fertilizer trials were conducted by the University of Nevada, Reno, in the mid- to late 1970s on several Sierra Nevada golf courses, including Incline (Gustafson and Miller, unpublished). Based on these findings, an N application of about 20 kilograms per 1,000 square meters per year of actual N would be sufficient to meet plant uptake without excess application. Properly managed, turf areas should function similarly to wetland and riparian zones in their ability to take up nutrients and to filter sediments. Loeb (1986) estimated that application of fertilizer within the Tahoe basin is significant. Approximately 26 to 28 MT of P are applied to basin soils each year by golf courses, homeowners, and others. These estimates were made on the basis of land use data and, according to Loeb, were similar to projected values made in an earlier study by Mitchell and Reisenaur (1974). While both these studies focus on fertilizer application, a quantitative understanding of effective loading to ground water or surface waters from this source does not take into account the nutrient budget. However, LTIMP sampling by the USGS on Edgewood Creek, Incline Creek, and the Upper Truckee River includes areas of golf course impact. The possible effects of this source will be part of the more detailed USGS-TRG report on the historical LTIMP stream database.

For many years the contribution of marina dredging to the nutrient load of Lake Tahoe was unknown. Hackley et al. (1996) conducted an extensive study of this issue from 1992 to 1994. Highlights from this work include the findings that considerable variability exists in the nutrient content of sediments between marinas, within a single marina, and within different layers of marina sediments. Raw sediment total-N or total-P were not good predictors of the level of soluble nutrients during elutriate tests. On the order of one to six percent of TP released to lake water during the elutriate testing was determined to be biologically available-P (BAP), as determined by chemical testing.

Field monitoring done around a horizontal cutter hydraulic dredge in Lake Tahoe showed that surface plumes were detectable quite a distance from the dredge itself (8-60 m) but that the highest concentrations of turbidity and nutrients were localized within 3-6 m of the dredge. It was not uncommon for concentrations of nutrients and turbidity at the dredge in the lake to be turbidity 10 to 20 NTU, total dissolved-P 10 to 30 μg/L, total-P 40 to >100 μg/L, nitrate 10 to 20 μg N/L, ammonium-N 25 to >50 μg/L, and TKN 200 to 500 μg/L. The mechanical dredging methods (e.g., excavator, clamshell, and dragline) had relatively high sediment resuspension.

The loading of N and P directly to the lake from dredging operations from a given marina was estimated to range from less than a single kilogram to tens of kilograms. These loads are comparable to other inputs from human activities. For instance, release of five kg of TN or TP was calculated to be roughly equivalent to the load in urban runoff from

five acres of medium-developed residential or two to three acres of tourist-commercial property.

Summary of Inputs—The summary values presented below represents an initial estimate at quantifying the nutrient sources to Lake Tahoe. Depending on the amount and form of precipitation, individual water years will differ. Efforts are underway to provide estimates of both interannual and measurement variation to these values (Reuter, unpublished).

Our estimates suggest that approximately 17 MT, or about one-third of the TP load, is in the form of soluble-P and is immediately available for biological uptake. Values of this magnitude are not uncommon in the scientific literature (Reckhow and Chapra 1983; Hatch 1997). While it is important to understand the sources and process that render phosphorus available for algal uptake, it is noteworthy that many of the empirical models developed for lakes to relate phosphorus loading to trophic status or algal biomass are based on total-P (Reckhow and Chapra 1983). Studies are underway, but more are needed to elucidate the factors controlling transformations between the TP and soluble-P pools. This research must look at both watershed and in-lake processes.

The results at this time clearly suggest the importance of direct runoff from urban areas and highlight the need for additional study in this area. As restoration projects are targeted and adaptive management proceeds, it will be very helpful to have more detailed data on the specific sources of nutrients within each of the major categories discussed above. Restoration should give priority to those areas that contribute most to the nutrient loading budget.

INPUTS	**Nitrogen** (MT)	**Phosphorus** (MT)	
	Total	Total	Soluble
Atmospheric deposition	233.9 (56%)	12.4 (27%)	5.6
Stream loading	81.6 (20%)	13.3 (29%)	2.4
Direct runoff	41.8 (10%)	15.5 (34%)	5.0
Ground water	60 (14%)	4 (9%)	4
Shoreline erosion	0.75 (<1%)	0.45 (1%)	No Data
Total	**418.1**	**45.7**	**17.0**

Losses—As discussed in much further detail as part of Issue #3 (Mass Balance Considerations), Heyvaert and Reuter (TRG, unpublished) have found that nutrient sedimentation losses to the bottom of Lake Tahoe are 401.7 MT for total nitrogen and 52.8 MT for total phosphorus. These numbers agree remarkably well with the independent loading estimates given above. This close agreement gives increased confidence that the loading rates are representative.

Characteristics of Nutrient Loading in Lake Tahoe Tributaries, over Daily, Seasonal, Annual and Interannual Time Scales—with Emphasis on Phosphorus

Prior to 1980, tributary nutrient loading was monitored as part of basic research, as part of existing, albeit limited, water quality and streamflow monitoring, or as part of specific project studies, many of which were focused on highway cut-slope and discharge. By the late 1970s, these programs were no longer of sufficient scope or organized in such a manner as to provide the extensive database needed for land use planning and watershed management. In 1979, the LTIMP was established to meet these growing needs. LTIMP now consists of 10 to 15 federal, state, and local agencies.

Nearly 20 years of data from LTIMP has been used for many purposes, including erosion control planning, capital improvement construction projects, environmental policy, community growth planning, and basic research support. State and federal planning and enforcement agencies must base their decisions on data that will withstand the most careful scrutiny. Long-term monitoring of the lake and its tributary streams, as presently accomplished by the LTIMP program, is required as part of the adoption of the Basin 208 Plan.

LTIMP Tributary Monitoring

Sampling Design and Schedule—The basic, long-term tributary monitoring under LTIMP is currently operational on ten of the basin's 63 tributaries at primary sites where sampling is done near the point of inflow to Lake Tahoe. These streams include five in California (Ward Creek, Blackwood Creek, General Creek, Upper Truckee River, and Trout Creek) and five in Nevada (Edgewood Creek, Logan House Creek, Glenbrook Creek, Incline Creek, and Third Creek). However,

LTIMP includes an additional 22 upstream sites on these tributaries, plus First, Second, Wood, and North Logan House Creeks. The reader is referred to excellent summaries of the LTIMP stream monitoring program by Rowe and Stone (1997) and Boughton et al. (1997).

Estimated runoff volumes from each of the 63 tributaries and for each intervening zone is given in Marjanovic (1989). The watershed coverage that drains into LTIMP streams comprises just under 50 percent of the total basin area and slightly greater than 50 percent of the total tributary runoff. The Upper Truckee River alone contributes 24 percent of the total tributary flow. Snow Creek in California was part of the LTIMP sampling design between 1980 and 1985, but it is no longer monitored.

The LTIMP streams are monitored by the USGS and TRG. TRG performs nutrient chemistry, and the USGS analyzes sediment. Field measurements include instantaneous and total discharge, specific conductance, and temperature. Over the period of record, the following forms of phosphorus and nitrogen have been measured: nitrate (+nitrite), ammonium, TKN, dissolved Kjeldahl-N (DKN), SRP, total reactive-P (TRP), total hydrolyzable-P (THP), dissolved hydrolyzable-P (DHP), total dissolved-P (TDP), TP, total biologically available iron (BAFe), and dissolved BAFe. Since 1994, nutrient analysis routinely includes nitrate, ammonium, TKN, SRP, TDP, TP, and total BAFe. Typically, 30 to 50 samples are taken each year representing stream hydrology, precipitation, and surface runoff events. Samples are collected with a depth-integrating sampler and are mixed in a churn splitter. Samples for dissolved P analysis are filtered on-site through 0.45 μm membranes. Water samples for SRP, TDP, and TP raw stream water are stored at 4°C for transport and storage at the laboratory until analysis. Detailed LTIMP laboratory standard operating procedures and quality assurance/control protocol can be found in Hunter et al. (1993). Hatch (1997) provides details on specific methodologies used to measure P concentrations.

Three important milestones exist for the LTIMP tributary monitoring activities. The first milestone was its inception in Water Year (WY) 1980 (October 1979 to September 1980). At that time only Ward Creek, Blackwood Creek, Trout Creek, Upper Truckee River, and Third Creek were sampled. By WY 1981 this was expanded to include General Creek and Snow Creek. The second milestone was in WY 1988 when the number of stations in Nevada was increased as the USGS Carson City extended its activities in the Tahoe basin. By 1991 all of the 10 current stations were in operation. Because of funding difficulties, only Ward Creek, Blackwood Creek, General Creek, and the Upper Truckee River were sampled in WY 1986 and WY 1987. The third milestone was in the early 1990s when the basic LTIMP tributary program was again enhanced to include multiple stations (a total of three per tributary) on Incline Creek, Trout Creek, Ward Creek, and the Upper Truckee River. This multiple station monitoring on these tributaries has been continuous since WY 1991.

Data for the LTIMP nutrient (and sediment) sampling is available from a number of sources. From WY 1980 to WY 1988 the TRG published a series of annual reports, but ensuing LTIMP budgets were significantly reduced, and support was no longer available to produce these reports. In calendar year 1994, the TRG submitted a data report to the Lahontan Regional Water Quality Control Board that summarized stream nutrient concentration and load calculations from WY 1989 to 1993. Since then, the TRPA produces an annual report that summarizes the nutrient loading data calculated by the TRG. The raw concentration data also is published in the water resources data reports issued by the USGS-Nevada. Research papers and technical reports on this topic are available from the USGS, the TRG, and the TRPA.

A Brief Description of LTIMP Watersheds—In addition to the following brief descriptions of the primary LTIMP watersheds, data characterizing all the Tahoe basin watersheds (e.g., drainage area, channel length, elevation ranges, and slope) are available from the USGS (Jorgensen 1978; Cartier et al. 1995).

Ward Creek on the west shore of Lake Tahoe is primarily underlain with volcanic soils scoured by glaciers. The watershed is bound within a steep-walled canyon, with extensive human

development near the mouth. As with the other nine LTIMP watersheds, the Ward Creek watershed experienced heavy logging during the late 19th century (Leonard and Goldman 1982). The upper portion of Ward Creek's north fork contains a recreational ski operation.

The Blackwood Creek watershed (west shore) is primarily underlain by volcanic and surficial deposits. The watershed is largely undeveloped, except for housing within 0.5 km of the lake; however, past disturbance has included logging, gravel excavation from the streambed/streambank, grazing, and fire. Most roads in this watershed are unpaved and subjected to intensive recreational off-road vehicle use.

General Creek (west shore), adjacent to Blackwood Creek, has been considered a "control" watershed because it has remained relatively undisturbed due to its location within a state park. This watershed has the lowest road density of the nine LTIMP watersheds. The upper regions of this watershed are underlain by glaciated granite and are in the Desolation Wilderness Area. Lower watershed areas are primarily underlain by surficial deposits.

The Upper Truckee River (south shore) watershed has the greatest area and stream discharge of all Tahoe watersheds (Dugan and McGauhey 1974). The lower meadowland reaches of the stream are extensively developed with housing, roads, commercial/industrial areas, golf courses, and an airport (Leonard and Goldman 1982). The lower watershed is composed of deep alluvial soils, while the upper undeveloped reaches contain steep granitic soils with some volcanics at the south end.

The Trout Creek (south shore) watershed is immediately to the east of the Upper Truckee River, with two major subwatersheds of Cold Creek and Saxon Creek. The lower reaches of Trout Creek flow through flat meadowlands subjected to extensive human development, but the undeveloped upper watershed is composed of steeper gradients and mixed coniferous forests above 2,800 m (Leonard and Goldman 1982). A large ski resort covers a significant amount of the steeper watershed areas. Trout Creek and Upper Truckee River converge near the lake in the Upper Truckee Marsh, which was disturbed extensively by excavation and construction of a large housing subdivision/marina in the 1960s.

Logan House Creek (east shore) is relatively steep along its entire length. Primarily underlain by metamorphic and granitic rock, this watershed has the lowest road length and the smallest area of the nine LTIMP watersheds. The watershed is largely undeveloped, and, as with other watersheds on the east shore, it typically receives half the precipitation of the west shore due to a "rain shadow" effect.

Glenbrook Creek (east shore) is north of the Logan House Creek watershed and composed primarily of volcanic and decomposed granitic rock. The upper regions are steep and undeveloped, while the middle regions have extensive highway road cuts. The lower watershed area is relatively flat with light to moderate development. Glenbrook Golf Course is within this watershed.

The Incline Creek (northeast shore) watershed consists of mountainous canyons primarily underlain by granitic bedrock with scattered volcanic deposits. The upper parts of the watershed are forested subalpine bowls, while the lower sections are less steep and consist of alluvial wash deposits. Human development is extensive near the lakeshore, including residential and commercial structures, golf courses, and a ski resort.

The Third Creek (northeast shore) watershed is immediately west of Incline Creek and also has been subjected to extensive human disturbance, including two golf courses. Third Creek extends several hundred meters higher in elevation than Incline Creek, with the upper area consisting of a large subalpine bowl. The lower watershed is narrow and relatively steep. The Third and Incline Creek watersheds experienced heavy disturbance in the 1960s and 1970s while Incline Village was being constructed. The mouths of these two streams are less than 50 m apart. Third Creek was the site of a large snow avalanche above Highway 431 in February 1986.

Stream Phosphorus Concentrations and Transport

Phosphorus source/sink behavior is much more difficult to characterize than that for nitrogen. Although phosphate (PO_4^{-3}) is highly soluble and

therefore quite mobile, it has a distinct propensity to become strongly attached to mineral and organic particulates. Consequently its mobility in watersheds is related to sediment transport. Dissolved P moving through the soil is affected by adsorption, desorption, and biological activity. Particulate P levels, on the other hand, changes with the condition of a stream channel and stream discharge. Recent research suggests that P also can form mobile complexes with mineral/organic colloids (Rhea et al. 1996; Harlow 1998).

Relations among Movement of Nutrients, Water, and Sediment

Incline Village Tributaries—Glancy (1988) published a report on streamflow, sediment transport, and nutrient transport at Incline Village from 1970 to 1973. That study was designed to develop a basic knowledge of fundamental hydrologic parameters within the Incline Village study area, to provide some local perspective on alleged or suspected basin-wide problems, to demonstrate the technical and economic feasibility of acquiring certain types of essential hydrologic knowledge, to launch a first approximation effort to obtain data on nutrient transport by streamflow, and to provide databases and knowledge to allow and encourage more detailed and efficient future studies. The discussion below was taken directly from that report.

The nutrient data used in Glancy (1988) came from previously published progress reports (Glancy 1971, 1973, 1976a, b). (A review of the sediment portion of this work is summarized later in this section.) The nutrient data for this study were purposely collected during times of intensive sediment movement to assess conditions during periods of potentially intense erosion. The sampling strategy was not intended to document seasonal or long-term changes. While much of the evaluation focuses on Third and Incline Creeks, data from a similar study for Glenbrook Creek (Glancy 1977) also are analyzed. The studies include a discussion of a number of forms of phosphorus and nitrogen (dissolved, particulate, and total), as well as sediment and hydraulic discharge.

The measured concentration ranges for the three streams were similar, albeit, with a few notable exceptions. Glancy concluded that the "tentative study-period trends of ammonium and ortho-phosphate suggest accelerated nutrient movement during early phases of urban development when effects of land clearing and road construction may have triggered higher-than-normal nutrient releases from freshly disturbed surficial earth materials." He goes on to state, however, that such an implication is tenuous because of insufficient data.

Nutrient movements near the mouths of Third and Incline Creeks were analyzed both graphically and by statistical regression. Plots of nutrient transport rates versus streamflow and sediment transport showed some apparent relationships. This level of analysis indicated that most nutrients moving to the lake tended to increase as flow and sediment discharge increased. However, Glancy noted that the overall poor graphical correlations between most nutrient forms, and either streamflow or sediment transport suggest that nutrient movement may be influenced by other factors.

The statistical evaluations performed were intended to supplement the graphical categorizations. Reliance on the linear regression analyses was downplayed because many of the relationships among nutrient, flow, and sediment transport were curvilinear rather than linear. The correlation coefficients indicated that nutrient movement correlates better with sediment transport than with streamflow. These observations support the widely held contention that erosion and nutrient transport to the lake are related. The fact that the correlations for the less developed Glenbrook watershed were better than for either Third or Incline suggested that the relationship between erosion and nutrient transport is better defined in minimally developed areas. However, as Glancy stressed, the numerically small correlation coefficients suggest that the relations between erosion and nutrient transport are probably quite complex.

Data for Third and Incline Creeks further showed that fine-grained sediment (<63 μm and thus finer than sand) correlates better with nutrients than does coarse-grained sediment (≥ 63 μm) in about two-thirds of the regression analyses. The regression equation exponents were larger for the

relationships between fine-grained sediment and nutrients versus coarse-grained sediment and nutrients, perhaps implying that nutrient transport is more sensitive to the movement of fine-grained material. However, many of the correlations for both coarse- and fine-grained sediment were observed to be only slight, and caution should be exercised in interpreting these results.

Ward Creek—A comprehensive paper on nutrient transport in surface runoff within the Ward Valley watershed was published by Leonard et al. (1979). Along with Glancy (1988), this remains one of the most comprehensive peer-reviewed works on tributaries in the Tahoe basin. These two documents have provided significant background and intellectual guidance for not only LTIMP but for many of the current investigations into discharge, nutrient transport, and sediment transport in Tahoe's tributaries. Below, excepts from the extended abstract and conclusions from the Leonard et al. paper are reviewed.

TRG investigations of nutrient and sediment transport in Ward Valley began in 1971. LTIMP monitoring has been continual since WY 1980 and current UC Davis-TRG hydrologic and sediment transport modeling focuses on Ward Valley (Kavvas et al. 1998). Quantitative data on selected stream water parameters were collected and evaluated by Leonard et al. (1979) for the period from 1972 to 1975 at three stations on Ward Creek, two on the main upper tributaries, and one near the stream mouth. Comparable data were collected at a stream mouth station on adjacent Blackwood Creek in the third year. The parameters were initially selected on the basis of their importance in eutrophication of Lake Tahoe. Sampling schedule and methodologies were similar to the current LTIMP program in that this study served as the precursor to LTIMP.

Sediment and nutrient loading to Lake Tahoe from Ward and Blackwood Creeks reflects a history of soil disturbance and vegetation removal. Logging, fire, and stream channel diversion have been dominant perturbations. Precipitation throughout the watershed during a normal year was primarily snow, but annual patterns varied widely, and rainfall at any time of year can be important in sediment and nutrient transport. Water discharge and the flux of suspended sediments, nitrate, phosphorus, iron, and trace metals was dominated by spring snowmelt runoff from mid-April to mid-June. However, in 1974 heavy fall and summer rains accounted for a large percentage of the annual flux of sediments and nutrients in a total of only 14 days (this phenomenon has been observed in other years since this study but is not common). Spring runoff was characterized by distinct diel water discharge patterns. Similar but not coincident patterns were found to exist for sediments and nutrients, including nitrate but not soluble-P. The Ward watershed has 87 percent of the area of Blackwood but discharged proportionately lower quantities of sediment and nutrients in terms of comparable water yield per hectare. This contrast may be explained in part by the history of greater disturbance in Blackwood Canyon.

The principal source of suspended sediments in Ward Creek was streambank erosion in the lower reaches of the channel. The dominant form of inorganic-N was nitrate derived from precipitation, terrestrial N_2-fixation and the nitrification of organic-N in forest soils. As observed by Glancy for Incline and Third Creeks, organic-N dominated the total-N flux. Phosphorus and iron were almost entirely in particulate form; thus, their dominant periods of flux occurred during high flows and sediment transport.

Five Year LTIMP Review—In 1986, Byron and Goldman issued a report summarizing the first five years of LTIMP. Findings of climatic effects (precipitation and runoff) appeared to have a dominant influence on stream water quality. Variation in water discharge is known to have a confounding effect on studies of long-term changes in stream water quality. The dominance of strong seasonal, storm-related, and year-to-year variation in discharge patterns can result in large fluctuations in volume-weighted concentrations (Byron and Goldman 1986). The results of multivariate statistical techniques to remove the effects of water discharge showed that Blackwood and Trout Creeks had a significantly decreasing nitrate concentration over the period from 1976 to 1985. TP and TSS did not show significant trends over time, but this may have

been related to the shorter data records for these constituents.

The improvement in Blackwood Creek nitrate concentration was attributed to the gradual stabilization of in-channel disturbance. The reduction of nitrate concentration in Trout Creek was a more uniform change from year-to-year. Land disposal of secondary treated sewage occurred in this watershed from 1960 to 1965. With continuous leaching over the years, residual storage of nitrate was hypothesized to be gradually depleted.

Multiple Watershed Scale

While nearly 19 years of data now exist for a few LTIMP streams, many did not enter the program until the late 1980s. The LTIMP stream data set is consistent from WY 1989 to WY 1998 for the nine streams described above. Hatch (1997) examined the LTIMP stream phosphorus database from WY 1989 through WY 1996. One objective of that study was to characterize the LTIMP stream P data set by examining and comparing the P concentration and load databases on watershed. The discussion below comes directly from Hatch (1997). These analyses are helpful in understanding the variability of stream P delivery to Lake Tahoe at different spatial and temporal scales. Identifying watershed characteristics that are potentially influencing P delivery is important to the future management of Tahoe basin resources.

Data Reduction—During WY 1995, TDP was assayed for all stream samples, along with TP and SRP (Hatch 1997). Subtraction of TDP from TP yields particulate P (PP), while subtraction of SRP from TDP yields dissolved organic P (DOP). Phosphate (PO_4^{-3}) is assumed to be estimated by SRP (dissolved inorganic P). These four operationally defined P fractions (TP, PP, DOP, and PO_4^{-3}) were examined only for WY 1995, due to minimal TDP analyses for the rest of the WY 1989 to 1996 period (typically only eight to 12 TDP assays per stream per year). Presentation of the entire WY 1989 to 1996 data set considered TP and PO_4^{-3} only.

The WY 1989 to 1996 period covered five years of drought (WY 1989, 1990, 1991, 1992, and 1994) and three wet years (WY 1993, 1995, and 1996). For comparison, the WY 1981 to 1986 period included two years of drought (WY 1987 and 1988) and six wet years (WY 1981, 1982, 1983, 1984, 1985, and 1986). The representativeness of the WY 1989 to 1996 data (eight years) must be interpreted in light of drought conditions common during this period. It is clear, however, that much of the interannual variability in stream nutrient loading is due to differences in annual precipitation.

Two common methods for calculating annual and monthly concentration means are unweighted and discharge-weighted averaging. Unweighted averaging involves adding all concentrations for a given period and dividing by the total number of samples. Discharge weighting sums the instantaneous concentration-discharge products for a given period, then dividing this number by the sum of all sampling event instantaneous discharges for the same period. Discharge weighting (Yaksich and Verhoff 1983) may be useful to normalize for differences in concentrations due to varying discharges between sampling periods on a single creek and between creeks with highly different discharge ranges. Discharge weighting also gives more importance to high discharge concentrations (Galat 1990). Lewis et al. (1984) assert that for highly variable discharge systems in mountainous areas, discharge weighting best represents the chemical constituents accumulated in proportion to discharge, more accurately reflecting the conditions of the receiving lake. Based on these considerations, the discharge weighting method of mean calculation is used in this study. Standard errors are calculated using the instantaneous concentration values.

P loads (mass per unit time) were calculated using the rating curve method for individual water years as follows:

$$\text{Log}(TP_i * Q_i) = a + b * (\text{Log } Q_i)$$

$$\text{Daily Load (kg)} = (Q_d^b) * (10^a) * 86{,}400 * (10^{-9}) * \exp(2.65 * \text{MSE}).$$

The first equation generates the regression constants a and b along with the mean squared error (MSE) using all TP_i (instantaneous TP concentrations) and Q_i (instantaneous discharges) for a given water year and stream station. The second equation uses a, b, MSE, and Q_d (mean daily discharge for a given day) to generate daily loads.

The daily loading equation uses an adjustment of 86,400 seconds per day and 10^{-9} kilograms per microgram. The "anti-logging" procedure in the second equation is corrected by exp (2.65 * MSE) to account for the fact that anti-logging results in the geometric mean rather than the desired arithmetic mean (Ferguson 1986). This technique was recommended by the USGS in the Tahoe basin to compute stream loads. Daily loads were summed for monthly and annual loads. TP, PP, DOP, and PO_4^{-3} loads for the present study were calculated using this rating curve method.

Annual Variation in Stream Phosphorus Loads and Concentrations--Phosphorus loads were dominated by the particulate-P fraction (PP), which comprised 56 to 94 percent of the WY 1995 TP load for LTIMP streams (Figure 4-1). Maximum PP loads were 6,824 kg/year for the Upper Truckee River, followed by Third Creek (4,618 kg/year), Blackwood Creek (3,569 kg/year), Trout Creek (2,565 kg/year), and Ward Creek (2,465 kg/year). Mean annual WY 1989 to 1996 TP loads (Table 4-1) also were dominated by the Upper Truckee River (3,364 kg/yr), followed by Blackwood Creek (1,927 kg/yr), Trout Creek (1,281 kg/yr), Ward Creek (1,250 kg/yr), and Third Creek (1,120 kg/yr). Mean annual TP loads for the remaining streams ranged from 9 to 560 kg/yr. Annual TP load variation increased as load increased.

With respect to the dissolved P fractions, the DOP contribution to TP load during WY 1995 ranged from three to 29 percent, with the largest DOP loads coming from the Upper Truckee River (1,806 kg/year), Trout Creek (781 kg/year), Blackwood Creek (655 kg/year), and Ward Creek (445 kg/year). PO_4^{-3} comprised three to 17 percent of TP load, with the largest loads from the Upper Truckee River (1,120 kg/year), Trout Creek (598 kg/year), Ward Creek (322 kg/year), and Blackwood Creek (291 kg/year). Annual WY 1989 to 1996 PO_4^{-3} loads were less variable than TP loads, although the relative order of ranking by LTIMP streams was similar (Table 4-2). The Upper Truckee River averaged the highest mean annual PO_4^{-3} load, with 451 kg/yr, followed by Trout Creek (249 kg/yr), Blackwood Creek (158 kg/yr), and Ward Creek (149 kg/yr). The remaining streams contributed 1 to 80 kg/yr PO_4^{-3} per year.

Mean annual, discharge-weighted P concentrations for LTIMP streams were largely present as PP, comprising 58 to 96 percent of the TP concentration in WY 1995 (Figure 4-1). The highest mean PP concentration was 544 μg/L for Third Creek, followed by Incline Creek (146 μg/L), Blackwood Creek (114 μg/L), and Ward Creek (103 μg/L). Standard deviations for PP in WY 1995 were similar in magnitude to the annual means (76 to 133 percent of annual mean). WY 1989 to 1996 TP mean

Table 4-1—Mean annual phosphorus parameters for LTIMP streams, Water Years 1989-1996. All concentration means are discharge-weighted. TP = total P, PO_4 = phosphate. Parentheses: standard deviation for loads, SEM for concentrations.

Stream	TP Load (kg)	PO_4 Load (kg)	TP Conc. (μg L^{-1})	PO_4 Conc. (μg L^{-1})
Blackwood	1927 (1966)	158 (99)	77 (33)	6 (0)
General	324 (262)	63 (41)	24 (6)	4 (0)
Glenbrook	137 (184)	32 (45)	101 (16)	19 (1)
Incline	560 (550)	80 (63)	111 (20)	19 (1)
Loganhouse	9 (11)	1 (1)	33 (4)	4 (0)
Third	1120 (1315)	69 (39)	220 (76)	14 (1)
Trout	1281 (1115)	249 (197)	65 (5)	11 (0)
Upper Truckee	3364 (3010)	451 (372)	61 (5)	7 (1)
Ward	1250 (1261)	149 (116)	63 (40)	7 (1)

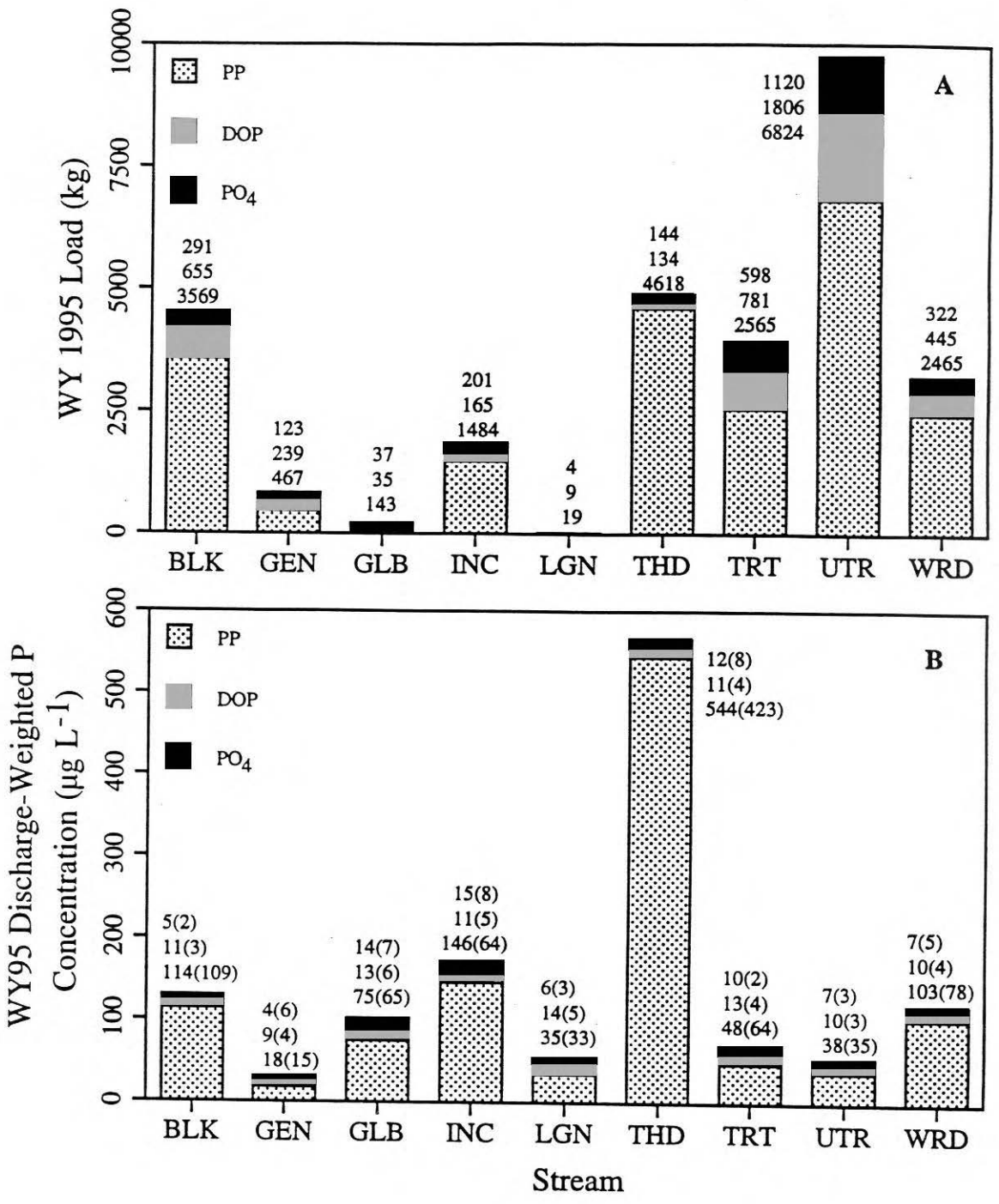


Figure 4-1—Concentration and total for PP, DOP, and PO_4 at LTIMP stream mouth stations during Water Year 1995 (from Hatch 1997).

Table 4-2—Concentration and load rankings for LTIMP streams. Concentrations in μg L^{-1}, loads in kg (Hatch 1997). PO_4 = phosphate, TP = total P, PP = particulate P, DOP = dissolved organic P.

	WY95 Mean Annual Rankings[1]							
Stream	TP Conc. Rank	TP Load Rank	PP Conc. Rank	PP Load Rank	DOP Conc. Rank	DOP Load Rank	PO_4 Conc. Rank	PO_4 Load Rank
Blackwood	3	3	3	3	4	3	8	4
General	9	7	9	7	9	5	9	7
Glenbrook	5	8	5	8	2	8	2	8
Incline	2	6	2	6	4	6	1	5
Loganhouse	7	9	8	9	1	9	7	9
Third	1	2	1	2	4	7	3	6
Trout	6	4	6	4	2	2	4	2
Upper Truckee	7	1	7	1	7	1	5	1
Ward	4	5	4	5	7	4	5	3

	Peak Monthly Mean P Values and Rankings for the WY89-96 Period[2]							
Stream	TP Conc.	TP Conc. Rank	TP Load	TP Load Rank	PO_4 Conc.	PO_4 Conc. Rank	PO_4 Load	PO_4 Load Rank
Blackwood	185	3	713	2	6	6	43	4
General	45	7	114	7	4	9	17	5
Glenbrook	102	5	40	8	16	1	8	8
Incline	147	4	125	6	14	2	16	6
Loganhouse	52	6	4	9	5	8	0.5	9
Third	468	1	329	4	114	3	13	7
Trout	45	7	295	5	9	4	52	2
Upper Truckee	45	7	974	1	6	6	124	1
Ward	260	2	496	3	8	5	46	3

Notes:
[1]Rankings according to values in Figure 2.
[2]Values represent the annual peak mean monthly values.

concentrations (Table 4-1) were also highly variable between the nine streams. Third Creek had the largest annual discharge-weighted TP concentration (220 μg/L), followed by Incline Creek (111 μg/L), Glenbrook Creek (101 μg/L), and Blackwood Creek (77 μg/L). Trout Creek, the Upper Truckee River, and Ward Creek had moderate TP concentrations (61 to 65 μg/L), followed by Logan House Creek (33 μg/L) and General Creek (24 μg/L).

For dissolved P discharge-weighted concentrations, DOP comprised two to 29 percent of the mean annual TP in terms of concentration, with levels ranging from 9 to 14 μg/L for all streams during WY 1995 (Figure 4-1). DOP standard deviations were lower than those for PP, ranging between 27 and 46 percent of the annual DOP mean. PO_4^{-3} contributed two to 14 percent of the TP concentration, with values of 15 μg/L for Incline Creek, 14 μg/L for Glenbrook Creek, and 12 μg/L for Third Creek. The remaining streams had PO_4^{-3} concentrations ranging from 4 to 10 μg/L for annual means. PO_4^{-3} standard deviations were smaller in magnitude than those seen for PP but comprised 20 percent to 150 percent of the mean annual PO_4^{-3} concentration. Annual means and standard deviations for DOP and PO_4^{-3} were similar for WY 1995. WY 1989 to 1996 PO_4^{-3} concentrations (Table 4-1) did not vary between streams on a mean

annual basis (4 to 19 μg/L), and standard errors were small (≤ 1 μg/L). Glenbrook Creek and Incline Creek had the largest mean annual PO_4^{-3} concentrations of 19 μg/L, while General Creek and Logan House Creek had the smallest values at 4 μg/L. In general, annual TP and PO_4^{-3} concentrations for the WY 1989 to 1996 period were very similar to those for WY 1995.

Previous stream studies at Lake Tahoe from WY 1970 to 1973 on Glenbrook Creek, Incline Creek, and Third Creek also found TP concentration to consist of 83 percent, 83 percent, and 69 percent PP for these streams, respectively (Glancy 1977, 1988). Past studies on Ward Creek in the Tahoe basin showed that 84 percent of annual TP load was PP (Leonard et al. 1979), which is similar to the 76 percent value for Ward Creek in WY 1995. Relevant literature data from other high-mountain landscapes is rare. Leonard et al. (1979) found that PO_4^{-3} load comprised 11 percent of TP load for Ward Creek, which is very close to the 10 percent value for WY 1995. Several sources of DOP may be present in Tahoe streams, including periphyton exudates (Perkins 1976), senescing vegetation, streambank roots and fauna, and abandoned septic leach fields. Meyer (1979) argued that decomposing organics on the stream bottom (e.g., leaf litter) are important sources of DOP, while Kaplan et al. (1975) contended that the Ward Creek microbial community is important in breaking down stream organic material.

Monthly Variation in Stream Phosphorus Loads—Mean monthly P concentrations were highly variable for the LTIMP streams (Hatch 1997); monthly P loads, however, were greatest during the spring snowmelt. Using the Upper Truckee River during WY 1995 as an example, 77 percent of the PP load, 70 percent of the DOP load, and 73 percent of the PO_4^{-3} load occurred during the May-July period, while 92 percent of the PP load, 87 percent of the DOP load, and 89 percent of the PO_4^{-3} load occurred during the March-July period (Figure 4-2). During WY 1995, mean monthly PP loads ranged from 3 to 2,470 kg/month, DOP loads ranged

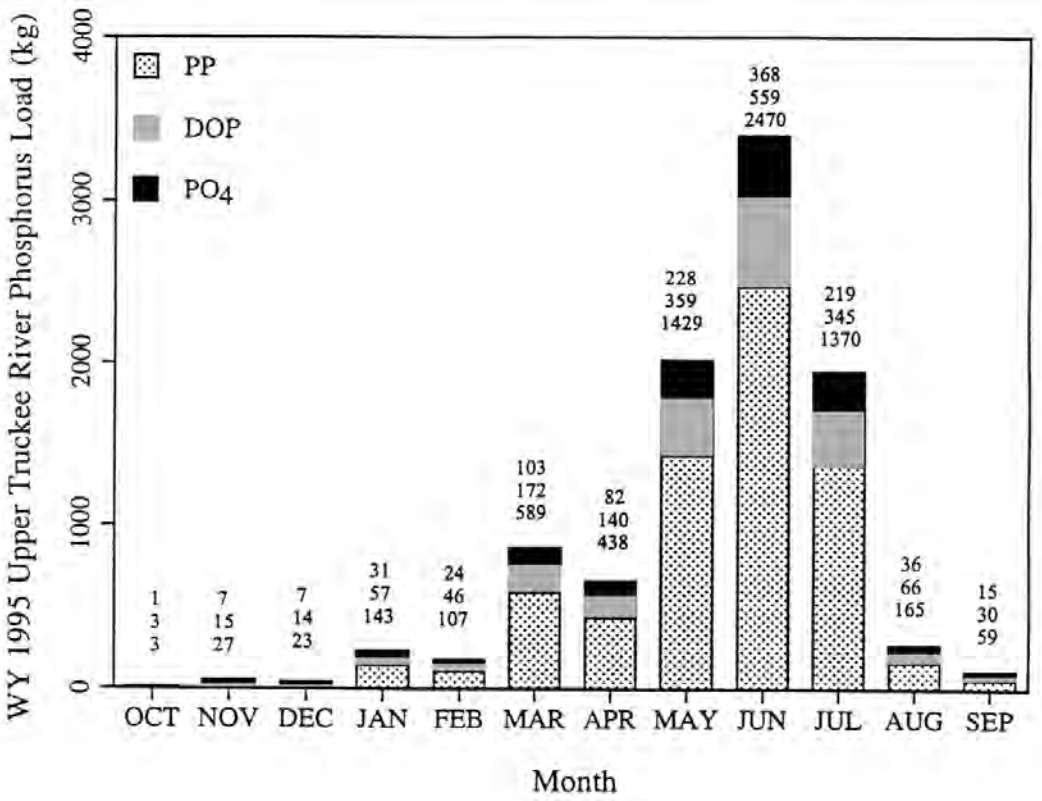


Figure 4-2—Seasonal distribution of PP, DOP, and PO_4 at the mouth of the Upper Truckee River during Water Year 1995 (from Hatch 1997).

from 3 to 559 kg/month, and PO_4^{-3} loads ranged from 1 to 368 kg/month. As expected, mean monthly WY 1989 to 1996 TP loads also peaked at the height of the spring snowmelt (Hatch 1997). Phosphorus and suspended sediment concentrations also have been reported as being higher during the rising stage of stream flow, as the channel is flushed (Drivas 1986).

Concentration versus Load—Examining P concentration-load ranking differences on a monthly basis is best represented by using TP and PO_4^{-3} data from WY 1989 to 1996 (Table 4-2). Peak monthly loads during this period occurred during either May or June. The top three TP concentration rankings were occupied by Third Creek, Ward Creek, and Blackwood Creek. These streams ranked fourth, third, and second for TP loads. The Upper Truckee River, however, was ranked first with respect to TP load, but seventh with respect to TP concentration. The remaining streams ranked lower for both TP concentration and load. Mean annual PO_4^{-3} concentration rankings behaved differently than TP rankings. Although Glenbrook, Incline, and Third Creeks ranked as the top three PO_4^{-3} concentrations for the May/June period, these streams ranked near the bottom with respect to loads (8th, 6th, and 7th, respectively). The streams ranking first, second, and third in peak PO_4^{-3} loads (Upper Truckee River, Trout Creek, and Ward Creek) occupied the middle range of PO_4^{-3} concentration ranks at sixth, fourth, and fifth, respectively. The lowest ranked streams for PO_4^{-3} concentration (Logan House and General Creeks) occupied PO_4^{-3} load rank positions of ninth and fifth, respectively. As seen for the WY 1995 rank comparisons for annual P means, the WY 1989 to 1996 peak monthly mean comparisons also indicate that LTIMP streams with the highest P concentrations do not necessarily have the highest P loads, and vice versa.

Precipitation, Discharge, and Suspended Sediments—Precipitation, discharge, and suspended sediment analyses can be used to help explain the observed P variations in LTIMP streams. Precipitation in the Tahoe basin falls predominantly from October to March. Although most of this precipitation is snow, the large heat capacity of Lake Tahoe, which never freezes, creates a microclimatic effect. Estimates that 90 percent of Sierra Nevada precipitation is in the form of snow (Kattelmann 1990) may not agree with precipitation behavior at the near-lake elevations in the Lake Tahoe basin, which included large amounts of rain.

A significant relationship exists between annual precipitation (over each individual watershed) and annual areal discharge (liters/hectare) in LTIMP streams (Hatch 1997). This relationship occurred for both the inter-watershed WY 1989 to 1996 annual mean ($r^2 = 0.911$, $p < 0.001$, $n = 9$ watersheds) and the individual intra-watershed WY 1989 to 1996 means (all r^2 values ≥ 0.802, all p-values < 0.001, $n = 8$ water years per stream).

The net result of heavy winter precipitation is large stream discharges during the spring snowmelt, as indicated by P loads in Figure 4-2. Hatch (1997) demonstrated that peak monthly discharges during the WY 1989 to 1996 period occurred in May for the Upper Truckee River (211 x 108 L/month), Blackwood Creek (89 x 10^8 L/month), Ward Creek (66 x 10^8 L/month), General Creek (47 x 10^8 L/month), Incline Creek (11 x 10^8 L/month), Glenbrook Creek (3 x 10^8 L/month), and Logan House Creek (1 x 10^8 L/month). June discharge peaks occurred for Trout Creek (57 x 10^8 L/month) and Third Creek (14 x 10^8 L/month).

Suspended sediment is an important substrate for transport of P in stream systems (Logan 1987). There was a strong significant relationship ($p < 0.05$, $n = 7$ water years per stream) between intra-watershed annual TSS and TP concentrations (Hatch 1997) and also for WY 1989 to 1996 annual inter-watershed stream means ($r^2 = 0.84$, $p < 0.001$, $n = 9$ streams). A similar and even stronger correlation was seen between inter-watershed TSS and PP concentrations ($r2 = 0.90$, $p < 0.001$, $n = 9$ streams), although there were fewer measures of PP (approximately 8 to 12 per year per stream) than for TP (approximately 30 to 50 per year per stream). Kronvang et al. (1997) argue that as the proportion of PP to TP increases, there is a stronger association of both PP and TP with TSS. These relationships were also significant for intra-watershed annual means for all nine LTIMP streams, although outliers were present for Incline Creek,

Logan House Creek, and Third Creek (Hatch 1997).

Relationships between TSS and DOP and between TSS and PO_4^{-3} concentrations were very poor, with few significant ($p < 0.05$) relationships for either intra-watershed or inter-watershed comparisons. The general lack of significant relationships between TSS and either DOP ($r^2 = 0.03$, $p = 0.633$, $n = 9$ streams) or PO_4^{-3} ($r^2 = 0.09$, $p = 0.430$, $n = 9$ streams) concentrations is not surprising because dissolved P by definition is not directly bound to particles; i.e., dissolved P passes through a 0.45 μm membrane.

Single Watershed Scale

Justification for Approach—While point sources of phosphorus (P) can be readily identified and sometimes controlled in efforts to halt lake eutrophication, nonpoint sources of P are closely linked to land use and thus are more difficult to quantify due to the physical scale of the problem (Omernik 1977; Correll 1977; Bordas and Canali 1980). In lieu of collecting an unwieldy amount of data on the scale of hundreds of hectares, an effective way to approach this dilemma has been to divide a watershed into several areas of differing land uses. For example, Dillon and Kirchner (1975) found that there was an increase in P export as one moved from forest to pasture to agricultural/urban watersheds. This supports the use of a single watershed as a conceptual framework for studying sources and transport of nonpoint source nutrient and sediment loading.

Hatch (1997) and Hatch et al. (1999) also analyzed the LTIMP database at the watershed scale using concentration and load values for phosphorus collected during WY 1991 to 1996 for Incline Creek (INC), Ward Creek (WRD), Trout Creek (TRT), and the Upper Truckee River (UTR). Three stations were monitored as part of LTIMP on each of these tributaries.

Site Description—Stream station INC3 is above human development, integrating the effects of forested subalpine bowls upstream. Station INC2 is farther downstream, representing the cumulative east branch of the creek. Between stations INC3 and INC2, the stream passes through residential development, a ski resort, and a golf course. Station INC1 is near the stream mouth, a few hundred meters downstream of INC2. The location of INC1 allows one to infer the effects of the west branch of Incline Creek, which passes through residential areas and part of a golf course.

Station TRT3 is high in the Trout Creek watershed, above areas of human development. This station integrates the effects of steep gradients and mixed coniferous forests above 2,800 m (Leonard and Goldman 1982). Station TRT2 is farther downstream, where the effects of human development on the stream first occur. Station TRT1 is in relatively flat meadowlands near the stream mouth within extensive development.

The Upper Truckee River is directly west of the Trout Creek watershed and has the greatest area and stream discharge of all Tahoe watersheds. Station UTR5 is immediately above the first instances of human development on the stream, although a small summer cattle grazing operation occurs several kilometers upstream. Steep granitic soils are present, with some volcanics at the south end. Station UTR3 is downstream of station UTR5 and represents an area under moderate development. Station UTR1 is near the stream mouth and sits on deep alluvial soils. Human development is heavy between stations UTR3 and UTR1 and includes housing, roads, commercial/industrial areas, golf courses, and an airport. The Upper Truckee River and Trout Creek converge near the lake in the Upper Truckee Marsh, which has been disturbed extensively from the development of a large residential marina.

Within the steep-walled Ward Creek watershed, station WRD3A is below the confluence of the two major upstream bowls, with minimal effects of development (one back bowl of a ski resort). Station WRD7A is farther downstream just below the last tributary confluence. Station WRD8 is near the lake within a region of significant human development.

Data Reduction Techniques—Using topographic divides for delineation, each stream was divided into three subwatersheds according to water quality station locations. Areal P loads for each subwatershed represent that area contributing P to a given gauging station. For example, the INC2

subwatershed includes all the area below station INC3 and its drainage but above the area that drains solely into station INC1. Areal loads (kg P/ha/yr) were calculated by subtracting upstream loads (kg/yr) from downstream loads (kg/yr), then dividing by the area of the watershed draining solely into the downstream gauging station.

Station Differences on the Annual Time Scale

The LTIMP data on multistation streams from WY 1991 to WY 1996 allow examination of P trends on an annual scale. This period was composed of below-average, average, and above-average precipitation years (Tahoe City precipitation [1931-1994 WY mean = 81 cm/yr]: WY 1991 = 58 cm, WY 1992 = 48 cm, WY 1993 = 105 cm, WY 1994 = 42 cm, WY 1995 = 154 cm, WY 1996 = 124 cm). Mean annual discharges increased in the downstream direction for each stream due to the cumulative contributions of tributary and ground water sources (Figure 4-3). Incline Creek stations had the lowest discharge values, with larger values for Trout Creek and Ward Creek. The Upper Truckee River had the greatest mean discharge.

P Concentration—Within-stream TP behavior was not the same for the four LTIMP streams (Figure 4-2C). TP concentrations increased downstream for Incline Creek, although INC1 and INC2 were not statistically different ($p>0.05$). Conversely, Trout Creek TP concentrations decreased in the downstream direction. The UTR1 TP concentration (43 μg/L) was statistically different from UTR3 (33 μg/L), but UTR1-to-UTR5 and UTR3-to-UTR5 TP concentrations were not statistically different. Despite the statistical difference between UTR1 and UTR3, the absolute magnitude of this difference was not great and may be of little practical significance. WRD7A and WRD3A had the same mean annual TP concentration, both being approximately half that recorded at the most downstream station at WRD8.

Analysis of TDP for the multistation streams during WY 1995 facilitated the calculation of PP, DOP, and PO_4^{-3} concentrations and loads. Particulate-P concentrations were not statistically different for INC2 and INC3, but both these stations were less than INC1. There were no statistical PP concentration differences between the three Trout Creek stations. There were also no statistical PP concentration differences between the two upper stations for the Upper Truckee River and Ward Creek, but the two upper stations were different from their respective stream mouth stations.

Mean annual PO_4^{-3} concentrations were quite similar for stations on the same stream. Incline Creek had the highest PO_4^{-3} values, ranging from 12 to 15 μg/L. Trout Creek had relatively intermediate concentrations at about 8 to 10 μg/L, while Ward Creek and the Upper Truckee River showed the lowest values at approximately 5 to 7 μg/L.

The WY 1995 data show within-watershed differences for DOP and PO_4^{-3} were minimal and most likely of little ecological significance in the streamflow. In Incline Creek, PO_4^{-3} concentrations were a few μg/L higher than DOP (11 to 15 μg/L vs. 10 to 12 μg/L), while just the opposite was recorded for Trout Creek. DOP for the Upper Truckee River and Ward Creek were noticeably higher than PO_4^{-3} (9 to 12 μg/L vs. 4 to 7 μg/L).

P Load—TP loads and PO_4^{-3} loads for the WY 1991 to 1996 increased in the downstream direction for all four streams. This condition reflects the fact that discharge, a major component of load calculation, always increased in the downstream direction. WY 1995 PP, DOP, and PO_4^{-3} loads also typically increased in the downstream direction for all streams. In general, the greatest loading increases occurred between the upper and middle stream stations for all three P fractions for each stream. For example, PP load increased greatly between TRT3 (649 kg) and TRT2 (2,078 kg), with a smaller increase between TRT2 and TRT1 (2,551 kg). An exception was the change for PP load between UTR3 (2,533 kg) and UTR1 (6,816 kg).

Subwatershed Phosphorus Characteristics—Stream P loads, not concentrations, are what actually affect Lake Tahoe phytoplankton as a whole. Adjusting stream loads by basin area assigns P loading values to specific areas of land. Because direct comparison of subwatershed areal

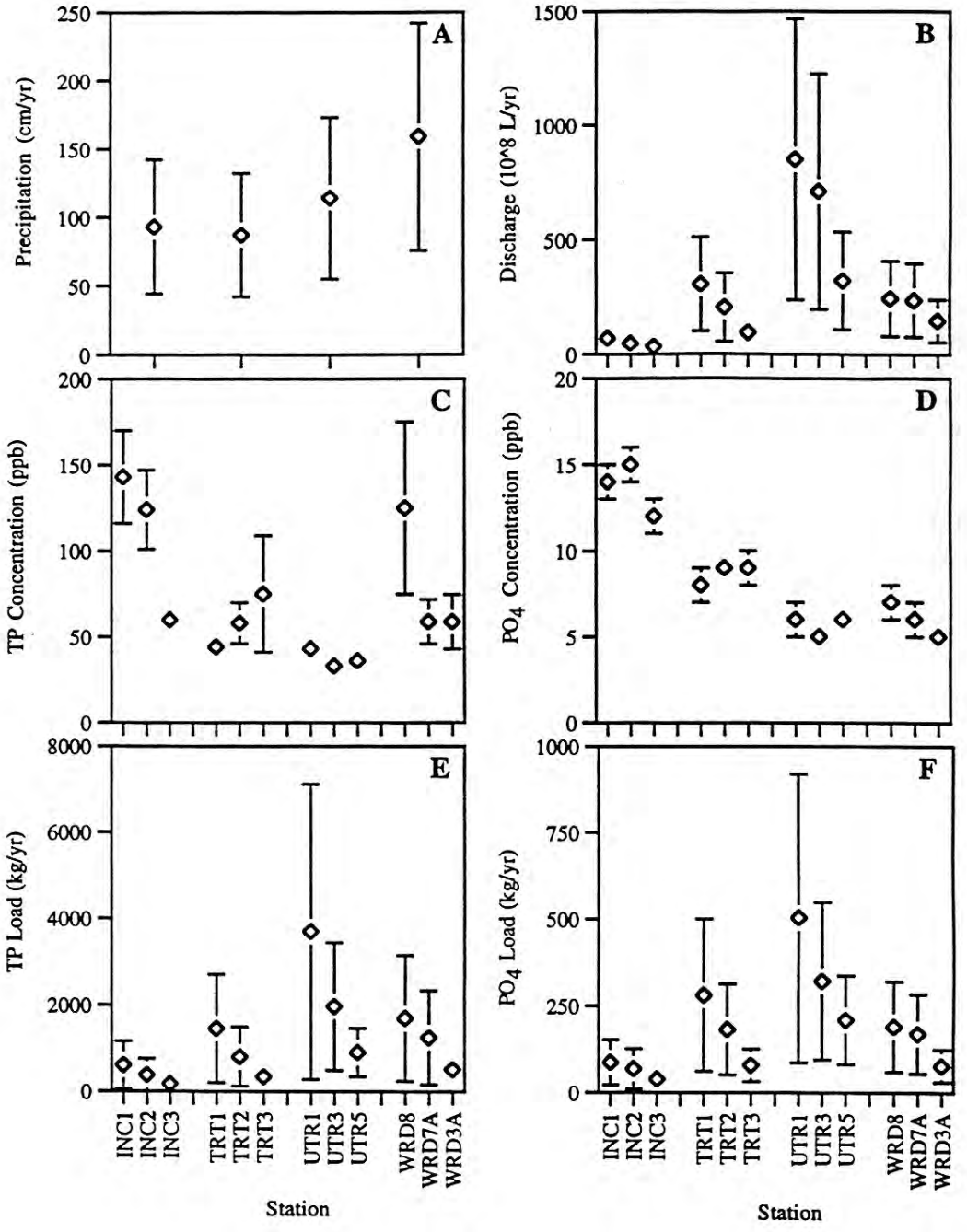


Figure 4-3—Annual precipitation, discharge, and phosphorus fractions for the multistation LTIMP creeks from Water Year 1991 to 1996 (from Hatch 1997).

P loads (kg/ha/yr) and discharge can result in spurious correlations due to a strong discharge-load relationship, it is more appropriate to compare areal P loads with precipitation.

Areal TP loads generally increased with increasing precipitation for the four LTIMP streams during the WY 1991 to 1996 period (Figure 4-4; note differences in axis ranges between creeks). The WRD3A (i.e., most upstream) subwatershed areal TP loads did not increase greatly with precipitation levels. Differences in areal TP loading between

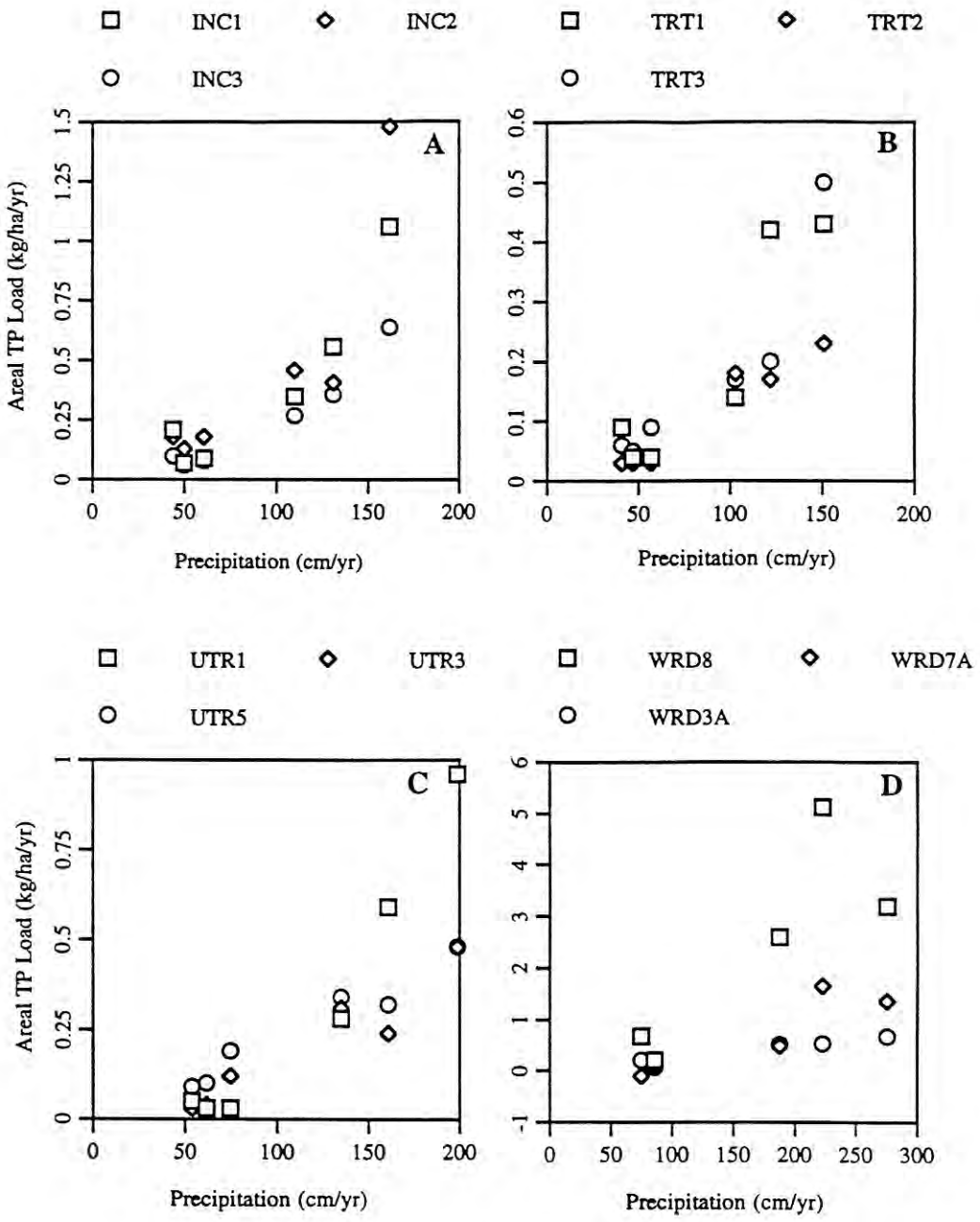


Figure 4-4—Relationship between areal TP load and precipitation for the subwatersheds defined by the multistation sampling design on four LTIMP creeks (from Hatch 1997).

subwatersheds on the same stream were minimal during relatively low precipitation years, but during high precipitation years obvious contrasts existed. For example, Incline Creek's areal TP loads were quite similar among the three subwatersheds when precipitation was around 50 cm/yr . However, at precipitation levels greater than 150 cm/yr there was a large difference among the three stations. This "threshold" precipitation value of approximately 150 cm/yr was similar for the Upper Truckee River and

Ward Creek but slightly different for Trout Creek (approximately 110 cm/yr).

There also appeared to be threshold precipitation values at which areal PO_4^{-3} load differences emerged between subwatersheds, but these values occurred at a lower level of precipitation than those seen for areal TP loads. Subwatershed areal PO_4^{-3} differences began occurring around precipitation values of 125 cm/yr for Incline Creek, 50 to 100 cm/yr for Trout Creek, 75 to 125 cm/yr for the Upper Truckee River, and 100 to 175 cm/yr for Ward Creek. Future data will most likely fill in the precipitation gaps and allow greater delineation of these precipitation thresholds.

According to Hatch (1997), instream and near-stream processes undoubtedly influence the P behavior observed in the four study streams. Stream PP sources, due in part to association with sediment particles and TSS, have been linked to streambank erosion. Leonard et al. (1979) suggested that streambank erosion in the lower reaches of Ward Creek was responsible for the large increase in PP between the mid-watershed and lower-watershed sampling stations. Work done on adjacent Blackwood Creek implies that 70 percent of stream TSS came from streambank and streambed erosion in low order channels, with the majority coming from the main channel and a much less amount coming from sheet/rill erosion next to stream channels (Nolan and Hill 1987).

Variation in Daily P Transport

Missing from stream studies at Lake Tahoe has been an assessment of how daily P transport varies, especially during the temperature-driven spring snowmelt cycle. In a study by Hatch (1997) and Hatch et al. (1999), P variability was assessed by conducting 24-hour sampling studies (once monthly) on three Incline Creek stations from May 1995 to March 1996. This analysis was necessary to understand the real-time variation of P because the hydrologic events that drive the movement of sediment-associated P from Tahoe streams to the lake occur on an hourly to daily time scale (Leonard et al. 1979).

Data Collection—Twenty-four hour (diel) monitoring took place during the first week of each month, from May 1995 through March 1996. Stations included INC3 (above human development), INC2 (representing the cumulative east branch), and INC1 located near the mouth (Figure 4-5). Sampling times for the sites during each diel study were at 11AM, 3PM, 6PM, 9PM, 12AM, 7AM, and 11AM. At each site the stream stage was determined by reading the staff gauge at the USGS gauge house. Sampling occurred during temperature-driven snowmelt and low-discharge conditions; no rain-on-soil or rain-on-snow events were sampled. A three-liter grab sample was taken in the main stream current. Particulate-P associated with different particle sizes was determined as sand-sized fraction of particulate-P (PP_{sand}), and silt- and clay-sized fraction of particulate-P (PP_{s+c}). Quality assurance procedures consisted of duplicates and spike recoveries, which were performed on 10 percent of the samples for a given analytical run. All sample analyses were within the LTIMP quality assurance tolerance limits (Hunter et al. 1993). Six P fractions were examined: TP, PP, PP_{sand}, PP_{s+c}, DOP, and PO_4^{-3}.

Station Differences on the Daily Time Scale

Diel Changes in P Concentration—The annual snowmelt runoff season was covered quite well by the Incline Creek diel studies. The effect of increasing discharge as one moves downstream from station INC3 to INC2 to INC1 was evident, as were the typical high discharges in May, June, and July.

Daily and seasonal diel behavior for the three Incline Creek stations indicates that the largest daily TP fluctuations coincided with the largest mean daily discharge (in WY 1995 this occurred in June). However, high mean daily discharges also occurred in July but without corresponding large values for TP. Hatch reported this behavior as indicative of the seasonal "first flush" phenomenon. Large quantities of P-bearing sediment appear to have been flushed from the stream during the initial high discharges of June, leaving less material readily available for transport in July.

PP was the dominant form of phosphorus during periods of high discharge. Mean monthly diel

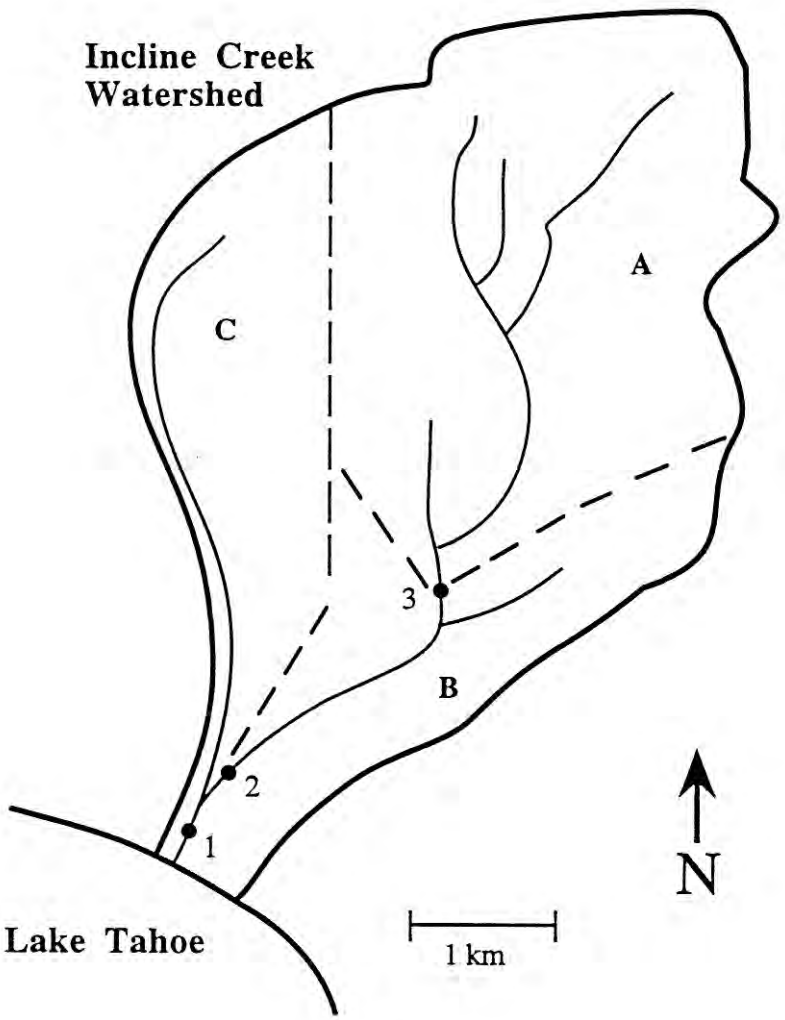


Figure 4-5—Diagram of Incline Creek watershed denotes location of three sampling stations and corresponding subwatershed drainages.

PP typically comprised 49 to 83 percent of the TP concentration at that time. PP concentrations for the June 1995 diel study fluctuated from 75 to 350 μg/L for INC1, 55 to 326 μg/L for INC2, and 40 to 210 μg/L for INC3. Peak PP concentrations were higher for both INC1 and INC2 than for INC3 during the May, June, and July studies, but PP values were similar for all three stations the remainder of the year (within 5 μg/L of one another). Leonard et al. (1979), working in Ward Creek, found that PP concentrations peaked around 250 ppb during May/June but remained below 10 ppb for the rest of the year.

The fluctuations in DOP concentration were not as great as those for PP, and the largest daily variations did not occur until August and September. At that time, mean diel DOP was 37 to 44 percent of TP. Peak DOP values at all three stations were nearly identical, at 10 to 30 μg/L. Throughout the study, never more than a 4 μg/L monthly mean DOP difference was found among the three Incline Creek stations. The elevated DOP levels in late summer and early fall are most likely due to peak summer production of stream periphyton exudates (Perkins 1976) and/or leaf-fall and in-stream litter processing.

Peak PO_4^{-3} concentration fluctuations were relatively small, with values ranging from 8 to 15 μg/L during the period of maximum discharge (i.e., June). PO_4^{-3} concentrations were greater than either PP or DOP during the November, January, and February studies, comprising 37 to 58 percent of mean diel TP concentrations. For each month from August 1995 to March 1996, PO_4^{-3} as a percentage of TP decreased in the downstream direction. This behavior was the opposite as that seen for PP, which increased its contribution in the downstream direction.

Relationship of P Concentration to Daily Discharge Cycle—The June 1995 diel study allowed for a more detailed examination of the relationship between P concentration and the daily snowmelt-driven discharge cycle. Peak discharges in Incline Creek at that time were observed at 9PM for INC1 (2,038 L/s), 6PM for INC2 (1,442 L/s), and 9PM for INC3 (1,333 L/s) (Figure 4-6). Although the exact time of peak discharge was probably not sampled, peak discharge was inferred to have occurred in the early evening during spring runoff as snowmelt water from upper portions of the watershed reaches the monitoring stations downstream (Hatch 1997). However, this conclusion may be valid for only Incline Creek. For example, peak snowmelt discharges for the Upper Truckee River generally occurs around 3AM due to the large watershed size and resultant time-to-concentration for discharge (Rowe 1999).

Maximum PP concentrations occurred prior to the observed peak in discharge at the mouth and upstream stations. At station INC2, both discharge and PP concentration peaked simultaneously at 6PM. INC1 displayed the largest changes in PP during the daily rising and falling hydrograph limbs, with INC2 and INC3 displaying smaller changes. PP appears to depend highly on discharge during the spring snowmelt for all three Incline Creek stations.

DOP concentrations ranged from 20 to 30 μg/L during the June diel study and were an order of magnitude lower than the observed PP concentrations. DOP concentrations were quite similar among the three stations, differing no more than 7 μg/L. Unlike PP, DOP concentrations continued to increase during the falling limb of the daily discharge cycle. Hatch et al. (1999) tentatively concluded that DOP did not directly depend on discharge. Ground water increases following the surface discharge peak may be possible sources of the increasing DOP, although ground water was not monitored.

PO_4^{-3} concentrations were quite similar among the three stations during June at approximately 10 μg/L. PO_4^{-3} remained relatively constant throughout the 24-hour period, implying independence from discharge.

Size Fractionation of Particulate P—Further insight into the large diel concentration fluctuations seen for PP during the period of maximum discharge was obtained by examining the behavior of PP_{sand} (particulate P associated with particles > 63 μm) and PP_{s+c} (particulate P associated with particles > 0.45 μm but < 63 μm, i.e., silts and clays). PP_{sand} displayed behavior similar to that of PP, with peak values occurring at 6PM (158 to 259 μg/L). Peak values for PP_{s+c} (54 to 83 μg/L) were much lower than those for PP_{sand} and were observed later in the diel period at 9PM. Peak concentrations increased in the downstream direction for both PP_{sand} and PP_{s+c}.

Stream hysteresis (changing relationship between phosphorus and flow over the diel period) varied according to P size fraction. For example, a counter-clockwise hysteresis was inferred for DOP concentration since DOP continued to rise as discharge decreased in the early morning hours. Walling and Webb (1980), using specific conductance, reported both clockwise and counter-clockwise hysteresis loops along different stretches of the same English stream system. These authors argued that this varying behavior was the result of differing source area chemical composition. Diel movement of hydraulic discharge and associated nutrients through the melting snowpack via ice lenses also may influence the hysteresis behavior of dissolved stream ions (Caine 1992) .

The differing hysteresis behavior for the PP_{sand} and PP_{s+c} fractions in Incline Creek may be explained by considering the physical conditions necessary to mobilize each fraction and the source of each fraction. Hatch et al. note that sand-sized particles require a higher velocity and shear stress

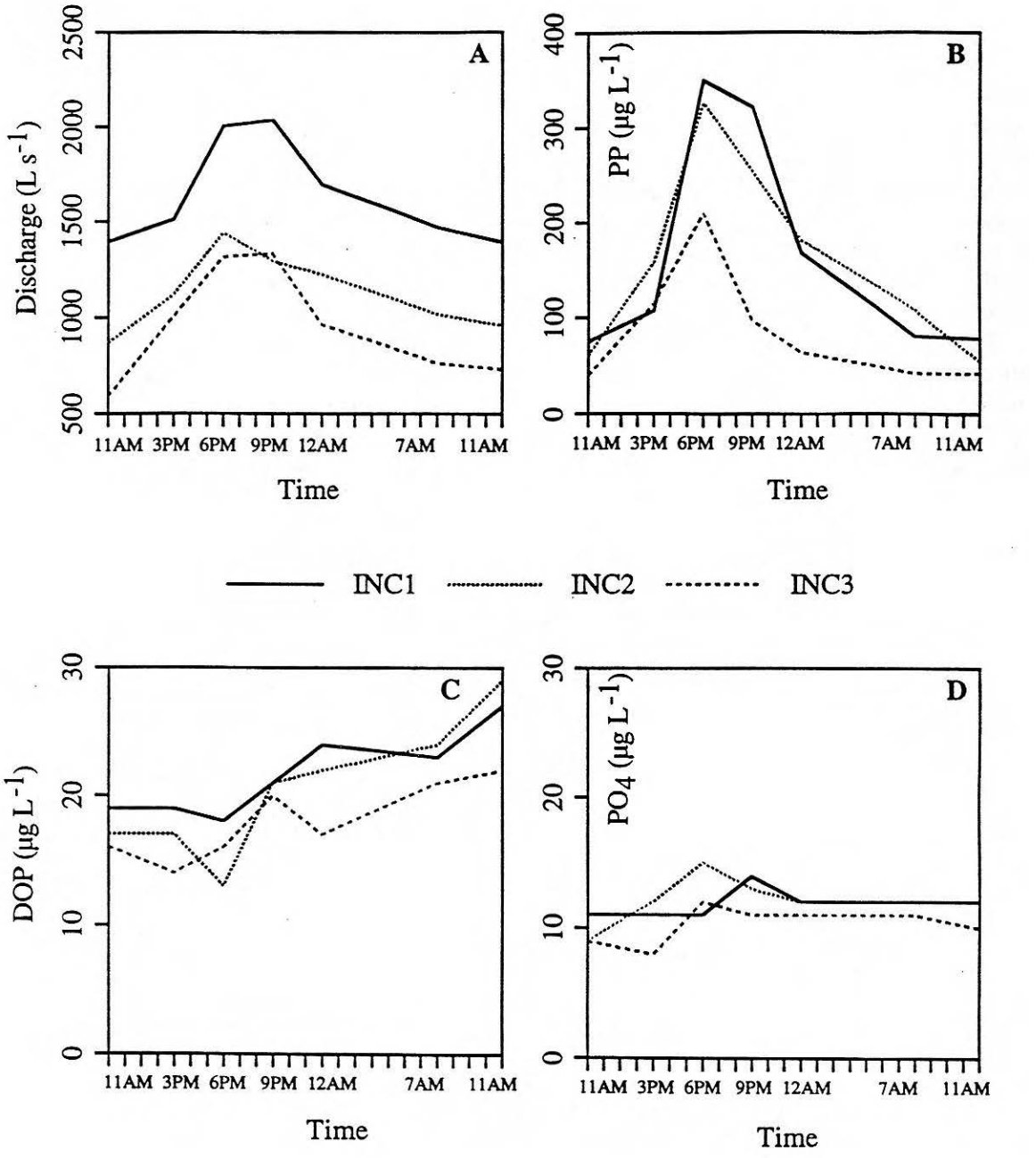


Figure 4-6—Diel pattern of discharge and phosphorus concentration at three stations on Incline Creek, June 1995 (from Hatch 1999).

to become entrained in flow than smaller-sized particles. Hence a threshold-like behavior in which significant amounts of sands are mobilized once a certain discharge is reached; may be displayed. For stations INC1 and INC2 this threshold appears to occur around 1,000-1,500 L/s. Once the flow threshold is reached and the sediment flushing occurs, significant sources of sand-sized particles may be exhausted, resulting in lowered sediment levels for a given discharge during the falling hydrograph limb (i.e., clockwise hysteresis).

Silt- and clay-sized particles require lower

shear stress to become entrained in the flow. It is possible that the shear stress required to suspend and entrain these smaller particles in Incline Creek is present at all hours of the day during the daily snowmelt cycle. There was little fluctuation in PP_{s+c} over the 24-hour period, and PP_{s+c} increased with rising flows even at low rates of discharge. The counter-clockwise hysteresis seen for PP_{s+c} also may be the result of a nonstream channel source, possibly subsurface (Loeb and Goldman 1979). Very small particulates may move within the coarse soil matrix of the Tahoe basin (Rhea et al. 1996), so it is possible that the heightened PP_{s+c} levels seen on the falling hydrograph limb are due to subsurface sources of P, which reach a maximum after the peak stream discharge occurs.

Hatch et al. concluded that instream and near-stream processes both influence the P behavior observed in Incline Creek. Stream PP sources, due in part to association with sediment particles and TSS, have been linked to streambank and streambed erosion. Dissolved P concentrations in Incline Creek are most likely the result of equilibrium processes between stream water, stream suspended sediments, and stream bottom/bank sediments (Meyer and Likens 1979). Incline Creek showed relatively small changes in PO_4^{-3} between stations. The extent to which stream bottom and suspended sediment P retention is influencing these similarities is unknown. Downstream subwatershed dissolved P contributions plus dissolved P from the upstream monitoring station may be offset by stream bottom P and suspended sediment buffering, resulting in similar dissolved P concentrations for the three Incline Creek stations. Stream bottom retention of dissolved P also was reported in Ward Creek (Perkins 1976; Leonard et al. 1979).

Colloids and Their Potential Importance to Nutrient Water Chemistry

Colloid nutrient transport also can play a significant role in organic and inorganic nutrients migrating to stream and lake ecosystems (Ryan and Gschwend 1990; Chin and Gschwend 1991; Qualls and Haines 1991; Backhus et al. 1993; Rhea et al. 1996). Lake Tahoe research in this regard is in its infancy. Rhea et al. (1996) investigated the presence and behavior of colloidal N and P in a Lake Tahoe subbasin before and after the application of a 10 cm/h one-hour artificial rainfall event. Colloidal rather than inorganic nutrient species were the dominant forms present in soil water extracts taken both before and after the artificial event (figures 4-7, 4-8, and 4-9). As a result of their findings, it is now apparent that colloidal nutrient forms must be considered a potential source of mobile nutrients in soils of the Sierra Nevada.

At the watershed scale, a number of factors, including geology, vegetation, and extent of erosion may affect the form and magnitude of phosphorus contained in tributary discharge. Harlow (1998) conducted a study in an undisturbed portion of Incline Creek to investigate the leachability of P from undisturbed soil cores taken from upland and riparian plant communities. No significant differences among plant communities for leachable inorganic ortho-phosphorus or dissolved organic/colloidal P were identified. Furthermore, no correlation was found between inorganic or dissolved organic/colloidal P concentrations in the leachate and any other soil properties, including oxalate extractable iron and aluminum. The median ratio of dissolved organic/colloidal P to PO_4^{-3} was 0.38, lower than that reported by Rhea et al. (1996). Although this study did not collect data on TP, several studies have indicated that the TP levels (which include both the digested and inorganic fraction) are typically significantly higher than the dissolved fraction alone (Leonard et al. 1979; Byron and Goldman 1989; Vaithiyanathan and Correll 1992; Hatch 1997). This is likely the case for the Incline Creek watershed as well. Harlow (1998) also identified a "delayed" inorganic phosphorus peak (figures 4-10 and 4-11) during leaching that was consistent with the findings of Marcus et al. (1998). Unlike other nonconservative nutrients, such as nitrate-N, the delayed phosphorus release could be significant when considering nutrient transport during longer duration snowmelt runoff events versus brief summer precipitation events. The transport of P through the riparian corridor and into the stream is in need of further investigation.

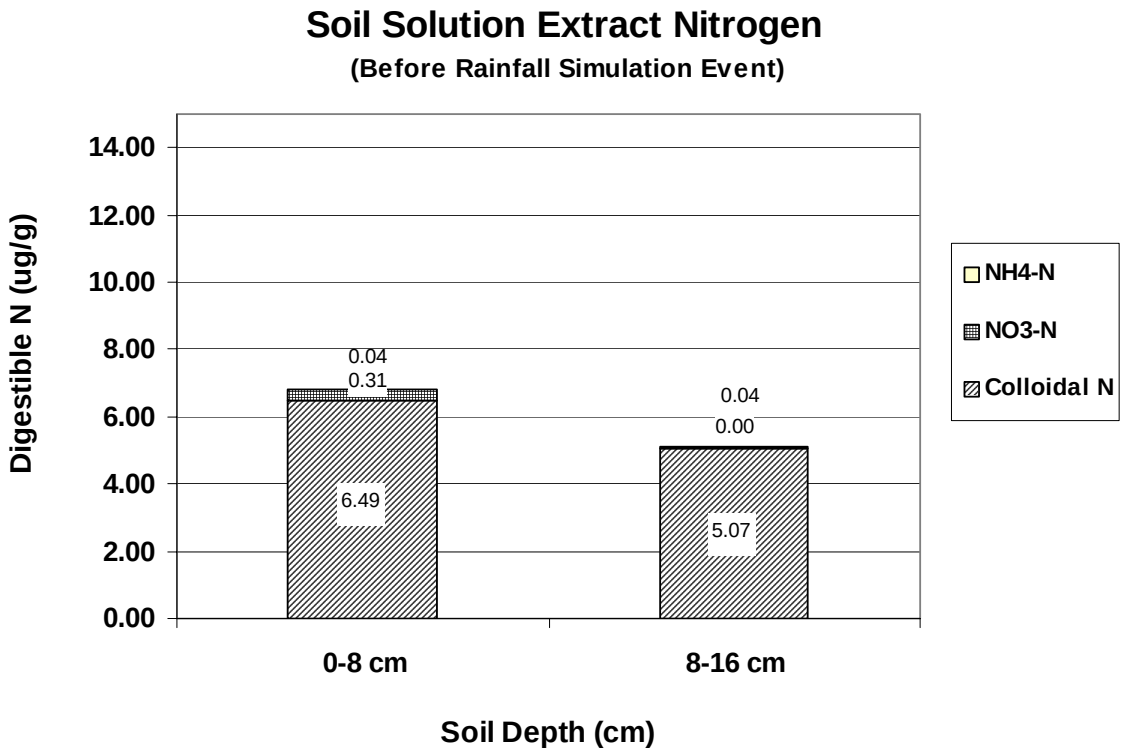


Figure 4-7—Water extractable inorganic and colloidal nitrogen from soil before artificial rainfall (from Rhea et al. 1996).

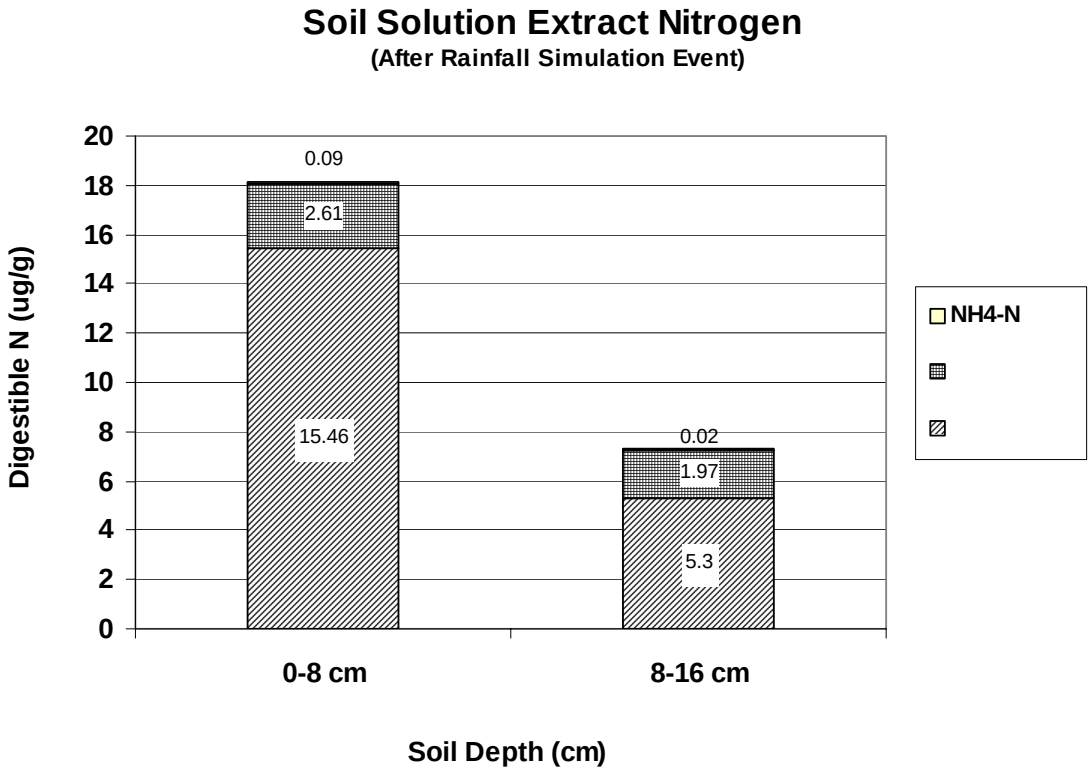


Figure 4-8—Water extractable inorganic and colloidal nitrogen from soil after artificial rainfall (from Rhea et al. 1996).

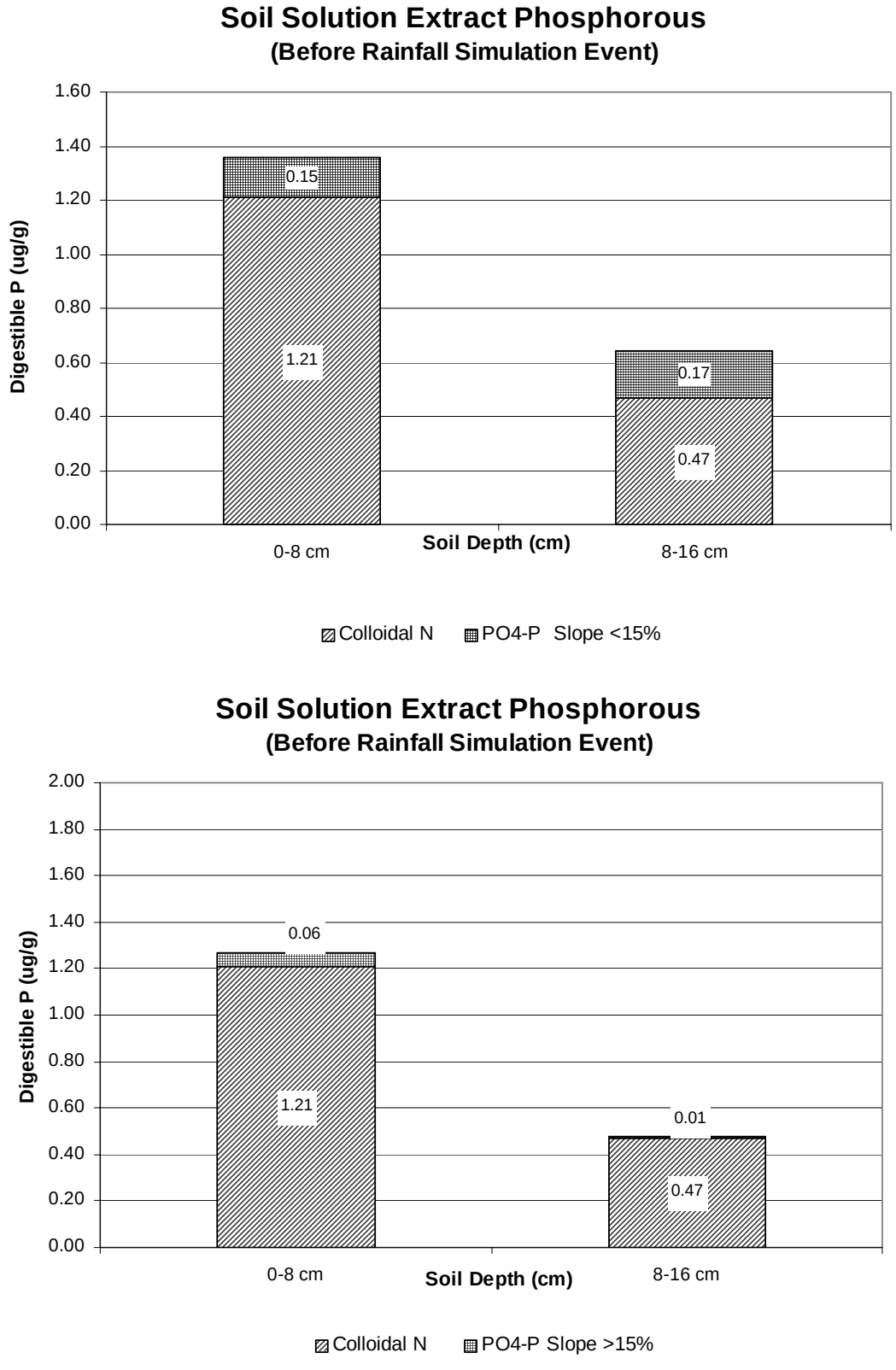


Figure 4-9—Water extractable inorganic and colloidal phosphorus from soil before and after artificial rainfall (from Rhea et al. 1996).

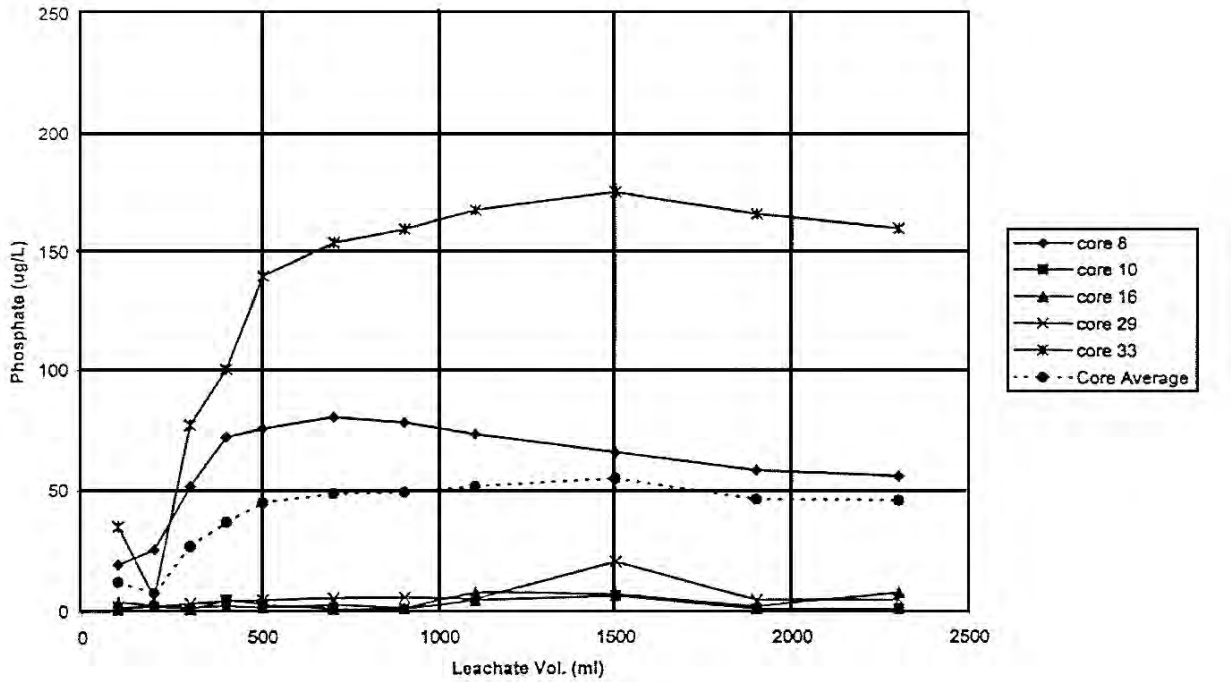


Figure 4-10—Phosphorus release during leaching of undisturbed soil cores from upland forested sites (UPFOR) (from Harlow 1998).

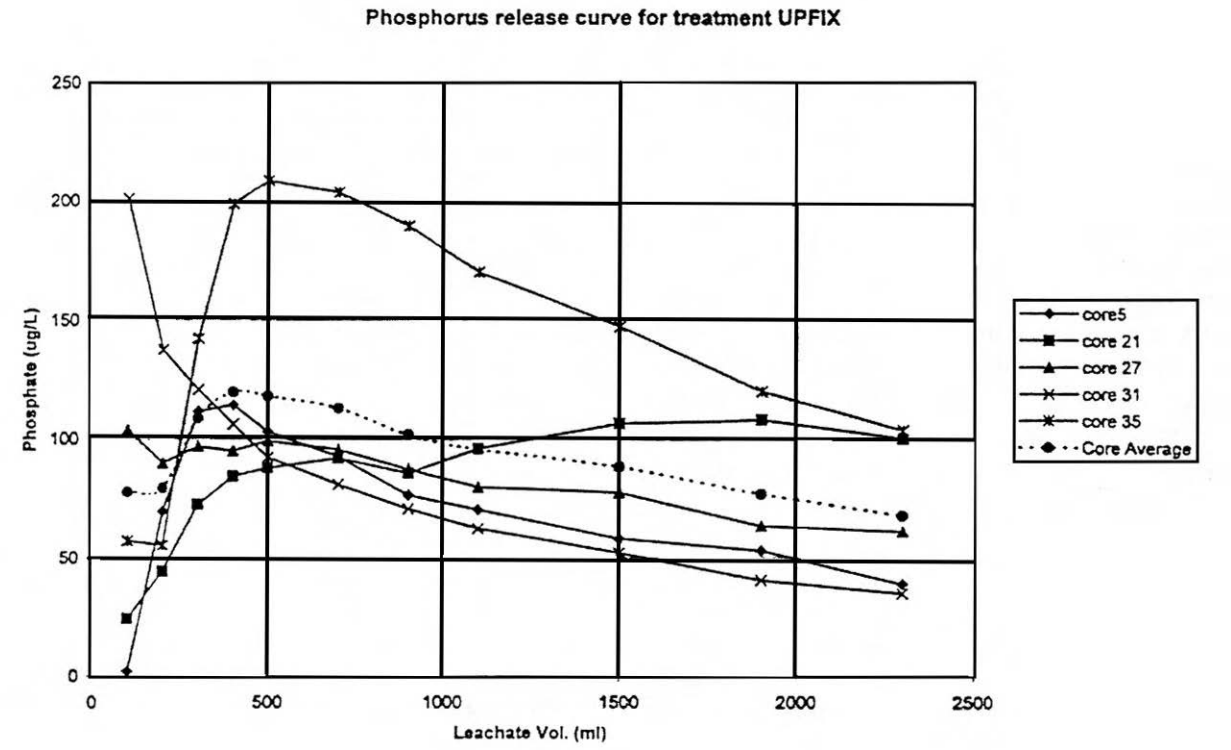


Figure 4-11—Phosphorus release during leaching of undisturbed soil cores from upland sites with nitrogen fixing vegetation (UPFIX) (from Harlow 1998).

Comparison to Background Concentrations and Water Quality Standards

Table 4-3 provides the average annual flow-weighted total-P concentrations for the nine LTIMP streams. Accompanying these concentrations are the numeric water quality standards and objectives established by California and Nevada. For California, each creek is identical with a desired concentration of 15 μg/L. This concentration was exceeded in each of the ten years from WY 1987 to WY 1996. For most of the LTIMP creeks, it was exceeded by a factor of two to four times; however, in Ward and Blackwood Creeks during WY 1995 and WY 1996, the 15 μg/L was exceeded by four- to eight-fold. Only General Creek approximated the water quality objective with average annual TP in the range of 17 to 31 μg/L. This observation supports the use of General Creek as an indicator of "control" conditions. The California objectives are particularly stringent, they are aimed at restoring historical or better water quality. The Nevada value of 50 μg/L is based on data collected during the more recent period WY 1988 to WY 1995 and consequently reflects more current rather than historical conditions. Even so, Incline Creek always exceeded this value, while Glenbrook Creek does so about half the time. With a range of 21 to 42 μg/L, TP in Logan House Creek was relatively low, again reflecting its undeveloped nature.

In their analysis of land use and water quality in streams tributary to Lake Tahoe, Byron and Goldman (1989) used the y-intercept from plots of disturbed, low, and high hazard land versus TP as representative of control conditions, i.e., those with little or no human disturbance. At the time of their analysis adequate data was only available for streams on the north, west, and south sides of the lake; monitoring of the eastside creeks was not yet fully underway. They found that the predicted TP concentration without disturbance was in the neighborhood of 12 to 15 μg/L, which supports the California water quality objective of 15 μg/L (representing historical conditions).

Table 4-3—Mean annual total phosphorus (P) concentrations (μg/L) in each of the monitored streams in the Tahoe basin. Values were obtained by dividing total P load by annual discharge. Each year 30-50 samples are taken for chemical analysis from each stream as part of the Lake Tahoe Interagency Monitoring Program (LTIMP). A Water Year (WY) extends from October 1 to September 30. LTIMP streams include TC = Trout Creek, UT = Upper Truckee River, GC = General Creek, BC = Blackwood Creek, WC = Ward Creek, TH = Third Creek, IN = Incline Creek, GB = Glenbrook Creek and LH = Logan House Creek. Combined these account for approximately 50% of the annual inflow to Lake Tahoe, ND denotes that data is not available.

Station/WY	87	88	89	90	91	92	93	94	95	96	Nevada[1]	California[2]
TC	ND	ND	42	42	32	34	44	36	58	49		15
UT	48	40	43	32	37	23	40	28	53	44		15
GC	24	23	18	21	21	17	23	17	28	31		15
BC	43	33	35	34	51	31	57	27	71	126		15
WC	33	31	33	34	35	33	55	39	67	101		15
TH	ND	11	160	75	241	119	164	100	345	60	50	
IN	ND	ND	98	81	74	68	81	76	131	67	50	
GB	ND	ND	70	42	48	33	ND	60	78	74	50	
LH	ND	ND	32	34	26	21	28	20	42	30	50	

Notes:
[1]Nevada Requirements to Maintain Existing Higher Quality (RMHQs) are based on the 95th percentile using the WY 1988-1995 data set.
[2]California numerical objectives based on 90th percentile values for historical (often pre-1975) water quality.

Directly differentiating between the natural and the human impact contribution to P delivery is difficult because there is no adequate database for predevelopment water quality conditions in the LTIMP watersheds. However, as noted above, the General Creek watershed can be considered as relatively undeveloped because it is in a state park. If one characterizes P transport in General Creek and applies these relationships to a more developed watershed nearby, one can get a glimpse as to what P transport would be like if that nearby watershed were not subject to human disturbance. This technique enables a preliminary differentiation between natural and human-influenced P delivery. Of the monitored watersheds adjacent to General Creek, Ward Creek is the best candidate for comparison. Housing subdivisions and roads are the major human influences in Ward Valley. General and Ward Creeks have approximately the same precipitation amounts, vegetation types, and basin area; however, they are not identical with respect to all aspects of geomorphology. For example, the General Creek watershed consists primarily of a granitic geology, whereas the Ward Creek watershed contains significant portions of volcanic material. In addition, channel morphologies in the lower reaches of the main stems are different (Norman 1999).

In his analysis of this situation, Hatch et al. (1997) presented a simplistic "model" of TP loading in which annual areal TP load is significantly related to annual discharge for General Creek. This model is intended only for problem-solving purposes. Assuming that current hydraulic discharge in Ward Creek would be characteristic of undeveloped conditions, the discharge for Ward Creek was substituted into the equation generated from the General Creek model. The results of this extrapolation indicated that Ward Creek areal TP loading would be much lower during high precipitation and discharge years (Figure 4-12) if the watershed had no development. Ward Creek's actual measured load exceeded the predicted load during above-average precipitation years, suggesting that Ward Creek responds to the effects of human development primarily during high-discharge years. The model estimated that human development increased areal TP loading over background levels by 73 percent in WY 1983, by 39 percent in WY 1984, by 74 percent in WY 1986, by 33 percent in WY 1993, by 58 percent in WY 1995, and by 144 percent in WY 1996. That actual measured loading from Ward Creek was similar to predicted loading based on the General Creek model during low precipitation/low flow years but was greater during high precipitation/high flow years supports the observation mode by Hatch (1997) that TP loads did not increase greatly with precipitation levels until a certain threshold level of precipitation was reached.

Nitrate Transport

Coats and Goldman (1993) published a study on nitrate transport in subalpine streams in the Tahoe basin. LTIMP data from Ward Creek, Blackwood Creek, General Creek, the Upper Truckee River, Third Creek, and Snow Creek were used to develop a linear model relating nitrate-N concentration to two discharge variables. The data set comprised >3,100 mean daily discharge and nitrate concentration values representing 45 watershed years. The goal was to compare the relative contribution to nitrate concentration of two dominant water types: short flow-path water, which occurs during storms and snowmelt, and long flow-path water, or base flow.

The first variable was a reciprocal function of discharge, derived from a mixing model for both water types in an open system. The second variable used either cumulative water discharge or cumulative nitrate load for the water year. Stepwise linear regression was used to fit model parameters to the data. Both independent variables made a highly significant contribution to explaining the concentration variance. Values of R^2 ranged from 0.22 to 0.45. For one catchment, the model was fitted to data for eight separate water years; it explained up to 80 percent of the variance in nitrate concentration. The results of this study indicated the Coats and Goldman model can be used to distinguish anthropogenic nitrate sources from the ion pulse associated with early snowmelt and can be developed into predictive models for estimating total N load.

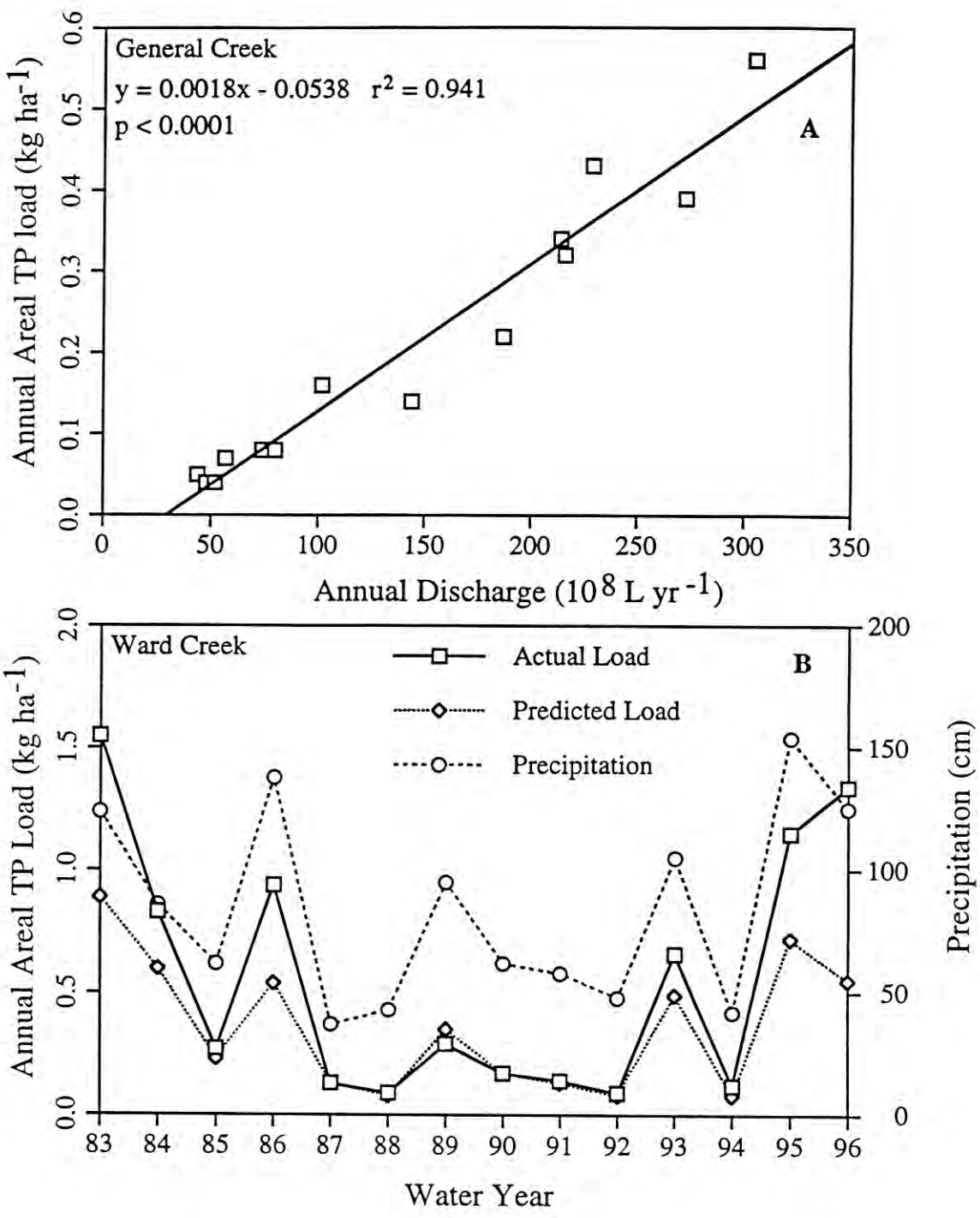


Figure 4-12—Discharge versus areal TP load relationship for General Creek used to predict areal load from Ward Creek under similar land use conditions. This undisturbed value is compared to actual measured loading from Ward Creek under current conditions of development in the watershed (from Hatch 1997).

Current Projects

Two projects of significance are in the planning or pilot study stages. The first is an integrated and comprehensive focus on nitrogen, phosphorus, and suspended sediment contribution from urban runoff and runoff from intervening zones. As suggested in the nutrient budget at the beginning of this chapter, these may be very important sources of phosphorus to Lake Tahoe and are areas where restoration/abatement may be successful. A more detailed understanding of nonpoint source loading within these regions is critical. Based on discussions at the 1998-1999 Tahoe Science Symposia, deliberations of the Tahoe Water Quality Working Group, and planning with basin agencies, efforts are now underway to coordinate the monitoring and research in this area.

The second project that commenced in the Spring of 1999 is an evaluation of the historical LTIMP stream discharge and water quality database. Among other things, this study evaluated the long-term data for trends in changing water quality conditions; identified the influence of climate, precipitation, and runoff on stream water quality; further evaluated sources of nutrient and sediment within LTIMP watersheds in a more statistically robust manner than previously used, and examined the differences among watersheds to determine the influence(s) of natural geomorphic characteristics and human land use patterns on stream loads and concentrations.

In summary, understanding phosphorus dynamics within the Tahoe basin will require much more in the way of research effort. For example, the long-term changes in phosphorous loading are unknown. Actual transport mechanisms, including colloid transport, also need further investigation, given the apparent association between P loading and the loss of lake clarity.

What is the evidence linking tributary sediment and nutrient loading to land use and watershed geomorphologic characteristics?

Numerous previous studies in the Tahoe basin suggest that, on a localized scale, land use can have a large effect on the water quality of surface runoff. Examples include Glancy (1969, 1982), Dugan and McGauhey (1974), Goldman (1974), Kroll (1976), Leonard et al. (1979), California Department of Conservation (1969), Perkins et al. (1975), Coats et al. (1976), California Tahoe Conservancy (1987), Garcia (1988), Loeb (1990), Woyshner and Hecht (1990), Reuter et al. (1990), Reuter and Goldman (1992), Lowry et al. (1994). No attempt is made here to summarize all the data available on this topic.

Because the basin does not contain many activities with point source discharges, watershed management of nonpoint source pollution has been adopted as the necessary approach for protecting lake water quality and clarity. Currently, more than 30 state, federal, and local agencies and legislative groups are active in the basin. Based on the principle that environmental disturbance accelerates the delivery of nutrients and sediments to Lake Tahoe, such management actions as the following have been initiated:

- Lake Tahoe Basin 208 Plan;
- TRPA Compact;
- Formation of the USDA Forest Service's LTBMU;
- Creation of the California Tahoe Conservancy for the purpose of administering erosion control and land restoration projects;
- Passage of the Santini-Burton Act by Congress;
- Formation of LTIMP;
- Adoption of environmental thresholds by TRPA;
- Establishment of Water Quality Working Group;
- Numerous Erosion Control Technical Advisory Committees;
- The Lake Tahoe Federal Legislative Agenda;
- The IPES Program;
- The Presidential Forum Deliverables;
- The Tahoe Bonds Acts in Nevada; and
- The Environmental Implementation Plan (EIP).

Below, three of the most comprehensive analyses of land use and stream water quality are summarized. Most of these use LTIMP data as the basis for their evaluation.

Multiple Watershed Comparisons

Early Studies—The Upper Truckee, Incline Creek, and Ward Creek watersheds were studied in 1970 to evaluate the potential effects of residential and commercial development on tributary water quality (Lake Tahoe Area Council and United States Federal Water Quality Administration 1970). Although no baseline data were available, the study provided a "real time" comparison between the discharge water quality from a well-developed watershed (Upper Truckee), an actively developing watershed (Incline), and a relatively undeveloped watershed (Ward). Incline Creek water quality was consistently more turbid and contained a higher nutrient concentration than either of the other watershed tributaries, followed by the Upper Truckee and then Ward Creek, the undeveloped watershed. Because the streams did not have equal discharge flow volumes, the data cannot be quantitatively compared. However, the Ward Creek nutrient variation was seasonal, while the other two watersheds exhibited concentration peaks at times when human activity was greatest.

Sediment Yield—Hill and Nolan (1990) presented the results of a study intended to assess those factors that might affect variations in average annual suspended sediment yields of streams tributary to Lake Tahoe. The relative importance of natural and land use-related factors were considered using regression analysis to examine empirical relationships between selected independent variables and suspended sediment yields.

To include a wide range of flow conditions, Hill and Nolan used LTIMP data collected between 1981 and 1985. which included the Upper Truckee River and General, Blackwood, Ward, Snow, Third, and Trout Creeks. This period included two very wet years, which was important because sediment yields are greatly affected by high flow conditions. The authors point out that although none of the streams were on the east side of the lake, where geologic and climatic conditions are different, this analysis included approximately 80 percent of the Lake Tahoe basin.

Drainage density (total length of stream channels in a watershed divided by total watershed area) and road miles were selected to represent channel erosion and land use, respectively; however, because a wide variety of drainage-basin characteristics can affect sediment yield, Hill and Nolan considered additional independent variables. These variables included channel gradient, ground slope, main channel length, basin area, relief, relief ratio, elongation ratio, hypsometric analysis index, percent of watershed in high, moderate, and low erosion hazard rating, road miles, road density, drainage density, geologic composition, and average precipitation.

Drainage density was by far the most important variable in explaining variations in sediment yield during the period of record; i.e., an r^2 value of 0.77. The importance of drainage density as possibly controlling sediment yield for the entire basin is less clear because sediment yields are low but drainage densities are high on the eastside of the lake. Other independent variables that explained variation in sediment yield included percentage of basin area underlain by metamorphic rocks (r^2=0.42), average annual precipitation (r^2=0.41), and average ground slope (r^2=0.40).

Individually, road miles and road density (road miles per unit watershed area) accounted for little of the observed variability in suspended sediment yields. However, they did help improve the explanation of variability when used in concert with drainage density and precipitation in multiple regression analysis. Drainage density and road miles together explained 83 percent of the variation in sediment yield, while drainage density, road miles, and precipitation accounted for 89 percent of the variation over the period of record. Hill and Nolan point out that while previous studies have indicated that land use disturbances can increase sediment yield within individual watersheds by an order of magnitude (Glancy 1982), the large differences between physiographic features appear to account for most of the observed variability of suspended sediment yields.

The correlation between percent land use and average discharge sediment concentration in Tahoe basin tributaries also is the subject of current research of Comanor et al. (unpublished). Land use information was derived for seven Tahoe basin tributaries using the TEGIS database. Four buffer zones were defined adjacent to each stream

encompassing distances of 50 m, 100 m, 250 m, and 500 m, with a fifth scenario that considered the total watershed as a whole. Discriminant analysis was used to verify the study approach. Within ARC/VIEW, percent cover was calculated for five land use types (residential, commercial, natural, recreational, and miscellaneous) for each of the buffer zones and for the entire watershed. Only natural surfaces exhibited a negative correlation with sediment discharge. All other defined land uses exhibited a positive correlation. Natural land use demonstrated a maximum negative correlation within the 100 m buffer zone. In other words, the greater the amount of natural undisturbed conditions within 100 m of the stream, the lower the average amount of sediment discharge. Maximum correlation (r^2=0.79) for recreational use was within the 50-meter buffer zone, indicating that the greatest adverse impact from recreation activity would occur within 50 meters of the stream. For commercial land use, the correlation increased with increasing size of the buffer zone. This suggests that the impact is more related to the degree of commercial land use than it is to location relative to a given tributary. Correspondence analysis indicated that the overall pattern of land use among the seven tributaries did not significantly differ. Multiple regression models of percent land use and average sediment discharge concentration for each of the buffer zones (r^2=0.81) also indicated a significant cumulative effect from all land use types. Interpretive assessment thus far clearly illustrates that zoning for land use planning must consider both existing and proposed land use types, as well as the respective distance from the stream. However, because of the probable role that the road network plays in conveying runoff, streamside buffer strips are most likely to have an impact on a local scale and not at the watershed level.

Nutrient and Sediment Concentration—Byron and Goldman (1989) evaluated the relationships between land use and water quality in 10 Tahoe basin watersheds. The water quality parameters used in this study were TSS, TP, and nitrate. The land use characteristics considered were the disturbance level and coverage by impervious surface of various land use categories.

This analysis combined data sets from LTIMP and USDA Forest Service stream water chemistry and TRPA land use data. The LTIMP streams included the Upper Truckee River, Trout Creek, General Creek, Ward Creek, Snow Creek, and Third Creek (75 to 100 samples each, per year). The USDA Forest Service streams were Saxon Creek, Meeks Creek, Big Meadow Creek, and Grass Lake Creek (15 samples each, per year). As with the Hill and Nolan evaluation, adequate data from eastside streams were not yet available. The nutrient concentrations used in this analysis were the flow-weighted averages of four annual values for WY 1981 to 1984. Byron and Goldman (1989) noted that these flow-weighted concentration values encompassed normal, drought, and high-water years and thus provided a representative flow regime. In addition, they noted that because nutrients and sediments may be variably stored within watersheds during dry years and flushed out during wet years, this multi-year average is a better method for comparing watersheds than an analysis based on data from a single year.

They developed two land use classifications for each watershed. The first was termed disturbed or covered low hazard land (DCLH), which represents that portion of each watershed assigned to disturbed or covered land (impervious) capability classes 4 through 7, as defined by the Bailey (1974) system. Classes 4 through 7 have a gradient ranging from 0 to 30 percent and are rated as slight to moderate erosion and runoff potentials. They are lands that are relatively less sensitive and may be allowed future development. These classes were considered least likely to yield high amounts of sediment and nutrients through the disturbance associated with construction activities. The second classification, disturbed or covered high hazard land (DCHH) represents that portion of the watershed assigned to disturbed or impervious covered land capability classes 1 through 3. These classes have gradients of nine to >50 percent, are rated as having relatively high or moderate erosion potentials, and are restricted from future development. In the Byron and Goldman analysis, DCHH included stream environment zones. That portion of DCHH characterizes watersheds on the basis of their relative

disturbance to their most erodable areas. Land use mapping was considered fine enough to allow the authors to differentiate watersheds with a range of only six percent in total disturbance and coverage. Nutrient and sediment concentration values were linearly regressed against both DCHH and DCLH to evaluate the potential effect of land disturbance on runoff water quality.

It was determined that under conditions of little or no human disturbance in which DCLH and DCHH were equal to zero (i.e., representative of control conditions), the concentrations of soluble reactive-P and nitrate-N would be predicated at 5 to 7 μg/L each, 12 to 15 μg/L for total-P, and 10 to 15 mg/L for TSS. Under conditions of increasing human disturbance (DCLH or DCHH≥0), the magnitude of cumulative disturbance within a watershed was usually significantly related to runoff water quality. Nitrate-N and TSS showed significant regression coefficients to DCHH but not to DCLH. TP showed significant relationships with both, but the slope of the DCHH equation was 50 percent greater, suggesting a higher level of sensitivity to P transport from the high hazard lands. Similar patterns were seen for nitrate-N (DCHH 125 percent greater slope) and especially TSS (DCHH 250 percent greater slope). The mere presence of high hazard lands within a watershed did not appear to have a significant effect on nutrient or sediment yield. Byron and Goldman observed that when the 10 watersheds were compared on the basis of the total area made up of high hazard lands (i.e., regardless of the proportion of human disturbance or coverage), there were no statistically significant relationships to the water quality parameters.

This study indicates that the long-term average nutrient flux originating from nonpoint sources closely reflects the intensity and location of disturbance in the watershed. As time proceeds and as watersheds move toward a state of equilibrium among natural processes, recovery, and disturbance, the exact nature of these relationships may change.

Goldman (1989) has reported water quality to be more sensitive to land use than to geomorphology or soil type. He found higher nutrient loading of both nitrogen (N) and phosphorus (P) in areas where there has been documented land disturbance, whether natural or anthropogenic. Soil disturbance reduces both vegetative cover and soil stability. Reduced vegetation causes reduced nutrient uptake and diminished soil stability, which increases erosion, sediment transport, and the discharge of sediment-associated P. For example, although Blackwood Creek contains little residential development, it exhibits relatively high levels of phosphorous loading. In addition to a significant fire history, the creek was mined for gravel beginning in 1960. As a result, sediment and debris have washed into the lake, forming a large spit at the creek mouth. The creek is still suffering from continued erosion (Goldman 1989; Tahoe Regional Planning Agency 1996).

Phosphorus Concentration and Load

Multiple Watershed Analysis—Most recently, the task of relating watershed parameters and stream water quality parameters was engaged by using an 11-by-21 matrix of mean annual P indices and watershed parameters for each of the nine LTIMP watersheds (Hatch 1997). The discussion below comes directly from Hatch's recent doctoral dissertation. Most watershed parameters are fixed geologic or morphologic features. Even the road and development categories can be assumed to be constant because there were no new roads built during the WY 1989 to 1996 period and because development coverage has been strictly regulated since 1987. After linear univariate regressions were performed, parameter associations with $p < 0.05$ were considered for additional analysis. Watershed characteristics included drainage area, precipitation, main channel length, main channel gradient, drainage density ground slope, aspect elongation ratio, relief ratio percent high, moderate, and low hazard land, geologic composition, total road mileage, road density, road coverage and development coverage. Many of these features were taken from Hill and Nolan (1990).

While some important watershed variables influencing discharge, P loads, and P concentrations may have been overlooked, it is interesting to note that many of the listed watershed parameters did not correlate well with P-related variables in LTIMP streams (Hatch 1997). These results were somewhat surprising because the literature indicates that watershed geology can strongly influence water quality (Dillon and Kirchner 1975; Keller and Strobel 1982; Grobler and Silberbauer 1985; Molot et al. 1989). However, a lack of significant associations between catchment and water quality parameters also has been noted by Dillon et al. (1991) and Svendsen et al. (1995). The LTIMP data for inter-watershed discharge were associated positively with basin area and main channel length but were negatively associated with channel gradient and basin relief ratio. Positive associations also existed among discharge and road length, road coverage, and development coverage. Inter-watershed PO_4^{-3} loads and TP loads were associated with the same parameters as discharge, which is not surprising considering that loads are fundamentally linked to discharge. Inter-watershed areal discharge (liters/ha) had similar associations as seen for discharge but also was linked to precipitation. Areal loads (kg/ha), however, lost many of the associations seen for loads (kg), suggesting that basin area exerts a strong influence on PO_4^{-3} and TP loads in LTIMP streams. Inter-watershed TSS and TP concentrations (and by association PP concentrations) were associated with percent surficial deposits, which are located primarily adjacent to stream channels. Inter-watershed PO_4^{-3} concentrations were correlated with drainage density and road density.

Hatch (1997) suggested that the general lack of significant correlations may indicate several things. First, correlational analysis for the types of variables chosen may not be appropriate. Water quality variables in the Tahoe basin are truly variable, changing significantly from year to year. Using mean (or even modal) values may mask the true variability of the hydrologic system, especially when one compares water quality to nonvariable watershed parameters. Also, as suggested by Hill and Nolan (1990), the relationships under investigation may not be linear. Second, it may be the case that despite their seemingly broad range of characteristics, the LTIMP watersheds are quite similar in their hydrologic behavior. Significant relationships between water quality and catchment parameters are seen in the literature where both the independent and dependent variables have a broad range (i.e., large axes spreads), which are associated with more regional/global data sets. The significant correlations that did exist in the LTIMP data set suggest that discharges and stream P loads are strongly associated with precipitation, basin area, and basin steepness. The values of these variables may appear quite different when compared on the scale of the Lake Tahoe basin, but may appear quite similar when compared to a data set from a more regional, national, or global scale. Finally, as indicated earlier, it may be the case that streambank erosion is the primary variable driving sediment and P transport in the LTIMP streams. If indeed a significant portion of the TSS and supposedly phosphorus is derived from streambanks, direct contribution of these materials to the streams via surface and subsurface flow may not be as important as the contribution of runoff water, which would have a direct impact on streambank processes. Quantification of sediment movement from this source would rank the significance of the contribution of streambanks to the overall transport of stream sediment and P to Lake Tahoe.

The process of snowmelt water reaching Tahoe streams by either ground water or overland flow has been altered by human activities. The amount of artificial impermeable surface coverage was significantly correlated with discharge, TP load, and PO_4^{-3} load, but this does not necessarily mean causation. In addition to discharge and loads, basin area was also a strong predictor (positive relationship) of main channel length ($r^2 = 0.884$, $p < 0.001$), road length ($r^2 = 0.843$, $p < 0.001$), road coverage ($r^2 = 0.965$, $p < 0.001$), and development coverage ($r^2 = 0.766$, $p = 0.002$). Thus the relationship of impermeable surface with discharge and loads only might be a statistical one, with all these variables (discharge, loads, channel length, road length, road coverage, and development coverage) related directly to basin area and not each other. Again, correlational analysis may not be the most appropriate method of statistical analysis for

this type of data. However, there are sound reasons why road and development coverage can affect stream discharge and loads.

First, as urbanization increases, so does the amount of impervious coverage (Beaulac and Reckhow 1982). Road coverage can influence stream discharge by not allowing surface water to infiltrate the ground water. The runoff water either flows onto bare ground next to the impermeable coverage where it can erode soils, or the water is channeled into storm drains that eventually lead to streams or the lake. Stormwater runoff not only carries debris and nutrients, but it also causes heightened storm hydrograph pulses. Stormwater pulses to streams occur because road and storm drain systems focus water into a relatively small area much more quickly than most natural systems. These pulses create higher water velocity and water quantity conditions than those in which natural stream systems have evolved (Beaulac and Reckhow 1982), increasing the potential for erosion higher up on streambanks.

Roads also can influence nutrient movement indirectly via exposure of roadcuts. The steep terrain and extensive subdivision developments in the Tahoe basin result in large areas of roadcuts; these bare surfaces can be eroded, and the liberated sediment and nutrients can be transported to nearby streams. However, Glancy (1977) argued that roadcuts in the Glenbrook watershed were not significant to the overall TSS load. Because the probability of sediment reaching a stream is in part proportional to distance from the stream, only roadcut sediment draining to stream areas will influence stream TSS loads.

Unpaved logging roads can be a significant source of nutrient export. Megahan (1987) asserts that such roads have on-site impacts, such as reduced forest productivity and increased runoff and erosion, and off-site impacts, such as altered streamflow, water quality, and channel morphology. Montgomery (1994) argues that logging roads increase the effective length of the channel networks, implying that roads can act as routes of sediment transport, not unlike streams. While these risks occur in association with the salvage logging that currently occurs with the Tahoe basin, commercial logging of the type cited in Montgomery's study has not occurred within the basin for over 30 years. Current salvage operations proceed under very strict rules that are likely to limit erosion (Unsicker 1999).

Managers also need to be aware of the distinction between historic logging roads, such as remnants from the Comstock logging period of the late 1800s, and current logging operations. Many of the historic logging roads now appear as drainage channels or swales. Over the last 100 years, channel morphology has been modified, and in many cases vegetation has been established (Lindström, Chapter 2 of this document). No comprehensive reports on these old logging-roads, as sources of sediment or nutrients have yet been uncovered.

Overland flows have not been observed frequently in the Sierra Nevada (Skau et al. 1980). Rarity of overland flow in forested catchments also has been demonstrated in New Hampshire (Meyer and Likens 1979), in other areas of the eastern United States (Beaulac and Reckhow 1982), and in Japan (Chikita 1996). Coarse sandy soils and thick layers of forest duff (partially decayed organic matter) in the Tahoe basin most likely allow water to easily percolate into the soil. Much precipitation probably reaches Tahoe streams via ground water (subsurface quickflow), implying that in forested catchments the major sediment/nutrient sources to streams come from channel or near-channel sources (Walling 1983; Dedkov and Moszherin 1992; Svendsen et al. 1995; Chikita 1996).

Streambank erosion has been cited as the main source of TSS in Tahoe basin streams in several studies (Leonard et al. 1979; Hill and Nolan 1990; USDA Forest Service 1994). Mountain stream bottom sediments have been shown to come from streambank erosion (Chikita 1996), often as course particulates (Fenn and Gomez 1989), which can be deposited and re-deposited several times along the course of a stream (Walling 1983). Heavy armoring and stair-stepping in mountain streambeds dissipates much of the energy caused by steep stream slopes, greatly limiting the amount of sediment originating from stream bottoms (Skau et al. 1980). Stream PP sources (by association with TP and TSS) are closely

tied to streambank and streambed erosion (Svendsen et al. 1995).

The Influence of Subwatershed Characteristics on Phosphorus Loading—Areal P loading is a direct measurement of how watershed processes influence P movement to streams. The subwatersheds on the same Tahoe stream behave similarly with respect to areal P loading during low precipitation, and hence low discharge, years. However, the subwatersheds displayed differing behavior during relatively high precipitation years. What is causing the observed changes in areal P loading as one moves downstream in LTIMP watersheds during high precipitation years? Water Year 1995 offers an excellent opportunity to examine this question. Hatch (1997) addressed this question using the LTIMP database for Incline Creek, Trout Creek, the Upper Truckee River, and Ward Creek. Three stations are monitored on each stream as part of the LTIMP monitoring. Location descriptions are the same as those presented above in the discussion of nutrient loading from Lake Tahoe tributaries.

Using data for PO_4^{-3}, DOP, and PP collected in WY 1995, Hatch reported that although the INC2 (middle to lower portion of the more extensive east fork of Incline Creek) subwatershed produced greater areal P loads than the other Incline Creek subwatersheds, none of the land use parameters considered appeared to explain intra-watershed differences. The INC2 subwatershed had the lowest gradient and shortest channel lengths for Incline Creek, which might imply that the physical energy to move sediments and nutrients and the stream channel P sources would be low. However, the INC2 subwatershed contains portions of a golf course, a ski resort/parking lot, and residential development, which may be contributing large amounts of P to the stream between stations INC3 and INC2. Although the other lower elevation, subwatershed (INC1) also contains residential development and part of a golf course, its areal P loading rates were less than those for INC2. Hence the ski resort/parking lot areas in the INC2 subwatershed may contribute to the enhanced areal P loading rates observed there in WY 1995.

Areal DOP and PO_4^{-3} loading rates of all three Trout Creek subwatersheds were very similar in WY 1995, suggesting that similar processes are taking place with respect to dissolved P transport from the subwatersheds. Watershed parameters are similar for the three areas, except for decreasing slopes and increasing road lengths/densities in the downstream direction for Trout Creek stations. The relatively low areal PP loading for TRT1 during WY 1995 may be a result of a relatively low stream and subbasin slope but may also be due to the presence of a wetland area along a tributary stream in this downstream portion of the watershed. Cold Creek enters the main stem of Trout Creek between stations TRT2 and TRT1. The Cold Creek watershed is completely contained in the TRT1 subwatershed and supplies over 50 percent of the discharge. However, just prior to its confluence with Trout Creek, Cold Creek passes through a large (10.5 ha) newly restored wetland (former Lake Christopher). Although Cold Creek is confined to its main channel during low discharge periods, during the high discharges of spring snowmelt the creek spreads out over the wetland. This behavior most likely removes large amounts of sediment and PP, hence could result in a lower areal PP loading in the Cold Creek subwatershed than would be expected without the presence of the wetland. The overall effect may be to cause Cold Creek to contribute relatively PP-dilute water into Trout Creek, and thus the TRT1 subwatershed had a lower areal PP loading rate than either the TRT2 or TRT3 subwatersheds during WY 1995.

DOP and PO_4^{-3} areal loads were quite similar for the three Upper Truckee River subwatersheds, indicating the presence of similar dissolved P loading mechanisms. The UTR1 subwatershed, however, exhibited relatively high areal PP loading rates. This subwatershed is characterized by relatively low slopes, high percentages of surficial deposits, low percentages of glaciated granite, and high road densities in comparison to the UTR3 and UTR5 subwatersheds. Surficial deposits, located primarily along stream channels, may be contributing PP to the Upper

Truckee River through unstable streambank erosion (Hatch 1997).

The lower subwatershed (WRD8) had much higher areal PP and PO_4^{-3} loading rates than either of the upstream areas. High percentages of surficial deposits and very high road densities may combine to create enhanced loading conditions in this area. An explanation for the net loss of DOP between Ward Creek stations WRD7A and WRD8 may lie in how human activities have altered the watershed. Because there are no tributary inputs between stations WRD7A and WRD8, most discharge and dissolved P must be entering the stream via ground water or overland flow. Beaulac and Reckhow (1982) argue that urbanization increases will result in increased impervious surface area, which in turn will create increased annual surface runoff and decreased ground water recharge. If ground water recharge is being reduced in the WRD8 subwatershed due to high housing densities, subsurface processing of soil and rhizosphere DOP sources (Leonard et al. 1979) also may be reduced. The net result may be a large reduction of ground water DOP inputs to the stream between stations WRD7A and WRD8. This outcome, along with the potential of stream bottom sediments and vegetation to absorb DOP (Meyer 1979), may partially explain the net loss of DOP in the lower reaches of Ward Creek. Details of phosphorus chemistry in the Lake Tahoe tributaries are not well known at this time. The extent of such transformations as those between inorganic-P and organic-P and between particulate-P and dissolved-P require study before unambiguous conclusions can be made.

According to Hatch (1997), an important point to note is that certain areal P loads from the upper subwatersheds in Incline Creek (INC3: DOP and PO_4^{-3}), Trout Creek (TRT3: all P forms), and the Upper Truckee River (UTR5: DOP and PO_4^{-3}) were equal to or greater than their respective downstream subwatersheds (INC1, TRT1, and UTR1). Because the upper watersheds for these streams are considered undisturbed due to their relatively low levels of human activity, their higher P loading rates suggest that such natural factors as slope are a dominant influence. Much smaller slopes may lead to relatively lower loading rates in the lower watersheds, but greater levels of human development in the lower watersheds may lead to higher loading rates than would be expected under undisturbed conditions.

The overall results of this study indicate that although P concentrations may increase, decrease, or remain constant in the downstream direction, P loads will always increase in the downstream direction. Reduction of areal TP loads should focus on the lower subwatersheds where sources and loading are the greatest. Future research should address the question of how dissolved P (both PO_4^{-3} and DOP) is absorbed/adsorbed/desorbed and transformed (e.g., into PP) along the course of a single stream. Knowledge of the interaction rates between stream sediment P and stream water P will give an idea of whether Tahoe streams can continue to buffer human-enhanced P fluxes into the future.

Effects of Site Condition on Soil Permeability and Sediment Yield

Erosion potential is linked with amount and type of runoff, as well as disturbance. Guerrant et al. (1990, 1991) evaluated the runoff and site-specific erosion potential of the Cagwin soil (common to the Tahoe basin). This work was intended to examine soil's ability to be infiltrated under conditions of excessive artificial precipitation. Study sites consisted of undisturbed forest soils with natural duff (P1), undisturbed without natural duff (P2), disturbed without natural duff (P3), and disturbed with natural duff removed (P4). Artificial rainfall was applied to measure runoff and infiltration parameters on each site.

The P2 site demonstrated a very high apparent infiltration capacity (due to the very high storage capacity of the duff layer), and what little runoff there was contained little sediment. The P2 condition had the highest percent runoff and P4 had the lowest, at final infiltration. The P4 condition had the lowest runoff but also had the highest sediment loads. The disturbance and removal of duff enhanced the infiltration capacity but also the potential for sediment transport. Disturbance and particle detachment at the soil surface caused individual mineral particles to be more easily transported by a small amount of runoff. This was especially apparent on the steeper slopes (Table 4-4),

however, the interrill erosivity (that is, the erosion that occurred among very small brooks) was found to decrease with time for all sites. Slope gradient had a positive effect on the amount of interrill erosion. Although this study demonstrated which site conditions (disturbed/undisturbed, duff/no duff) were more likely to erode, application to other Tahoe basin soil types of different erosivity classification cannot be directly inferred.

Guerrant et al. (1991) also noted that only interrill erosion was examined and not rill erosion, which may be a greater source of sediment discharge on some soils. A subsequent University of Nevada, Reno (UNR) study focused on sediment discharge from four different plot conditions on Meeks Creek (Naslas 1991). The conclusions were similar to those of Guerrant et al. (1991) in that soil disturbance and slope were identified as the greatest predictors of sediment transport. The highest sediment came from the wooded disturbed site without duff, and the least from the wooded natural site with duff intact. The open natural and open disturbed sites produced erratic sediment discharge, while the wooded disturbed site demonstrated decreasing erosivity with time. The sites with duff showed an increase in infiltration with time as the water repellency decreased.

Sullivan et al. (1996, 1998) conducted a study to quantify and delineate spatial variations in surface infiltration and to estimate infiltration parameters used in computer models for simulating runoff quantity following summer rainstorms from a small watershed (Incline Creek) in the Tahoe basin. Field tests that give the infiltration parameters of sorptivity and hydraulic conductivity, two parameters found in the Philip infiltration model, were performed in the watershed with the use of a disk permeameter. These field data were combined with coverages in an existing GIS database and field observations of surface attributes (soil type and vegetation), that are known to contribute to variation in infiltration rates. Statistical tests performed on

Table 4-4—Cumulative runoff (CR) and cumulative interrill erosion (CIE) from experimental plots after 1 h of simulated rainfall[1].

	Plot Condition					
	P2		P3		P4	
Slope	CR	CIE	CR	CIE	CR	CIE
%	L	g m^{-2}	L	g m^{-2}	L	g m^{-2}
0-15	18.8	79.4	12.8	171.3	11.3	136.3
15-30	11.2	301.3	15.7	244.5	14.6	37.6
>30	15.2	634.2	13.5	285.9	13.5	1,083.8

	Significance Matrix											
	Slope						Plot Condition					
	P2		P3		P4		P2		P3		P4	
	CR	CIE	CR	CIE	CR	CIE	CR	CIE	CR	CIE	CR	CIE
0-15	a[2]	a	a	a	a	a	a'	c'	b'	a'	b'	b'
15-30	a	b	a	b	a	b	a'	a'	b'	b'	b'	c'
>30	a	c	a	c	a	c	a'	b'	b'	c'	b'	a'

Notes:
[1]Values calculated from model estimation of field data.
[2]Significance of slope on cumulative runoff and cumulative interrill erosion is compared by column only and letters a, b, and c. Significance of plot condition on cumulative runoff and cumulative interrill erosion is compared by row only and letters a', b', and c'. CR and CIE followed by the same letter are not significantly different at $P = 0.01$.

field test data indicate that the only surface attribute that influences variations in infiltration rates in this watershed (owing mainly to limited variations in soil type) is vegetation. Further, time-to-ponding calculations, which indicate when and if runoff might occur following the start of a precipitation event, indicate that for most precipitation events likely to occur in this area during the summer, infiltration in all but nonforested areas is unlikely.

Tahoe basin roads act as pathways for sediment transport. If left unpaved, roads and trails also are a source of sediment. Studies on Trout Creek and the Upper Truckee River (California Department of Conservation 1969) have reported that roadways were responsible for 48 percent of the suspended sediment found in Tahoe basin stream flows. Unpaved logging roads transport fine particles mobilized by logging operations. Even when logging is not currently active, the roads still exist as a source of sediment and nutrients and for easy transport to the streams.

Nutrient loading also is affected by hydrologic discharge. For undeveloped watersheds, early snowmelt discharges the largest pulse in stream water N. During freeze-thaw cycles, the nitrogen becomes concentrated, resulting in an initial flush when the snow melts. Indeed, Coats and Goldman (1993) reported that the first 50 percent of surface runoff accounted for approximately 75 percent of the nitrate-N load during the 1980 water year.

An undisturbed subwatershed of Clear Creek near the Tahoe basin was studied in 1982 and 1983 (Rhodes 1985). The forested area had no development, had never been logged, and therefore was considered representative of a natural state. The soils (primarily acidic Cagwin series) were very permeable. Winter precipitation generally infiltrated through the vadose zone (i.e., above the ground water), to the ground water, and then to the discharge tributary. Any nitrate entering the stream would have come from direct meltwater. The site was found to be extremely effective at removing nitrate. Although during the summer and fall, vadose zone nitrate concentrations were elevated, ground water sampling showed nitrate concentrations an order of magnitude below that contained in natural precipitation. Denitrification was suggested as the primary nitrate removal mechanism. The findings of this study are believed to have characterized N behavior in tributary discharge from pristine watersheds on eastern slopes of the Sierra Nevada.

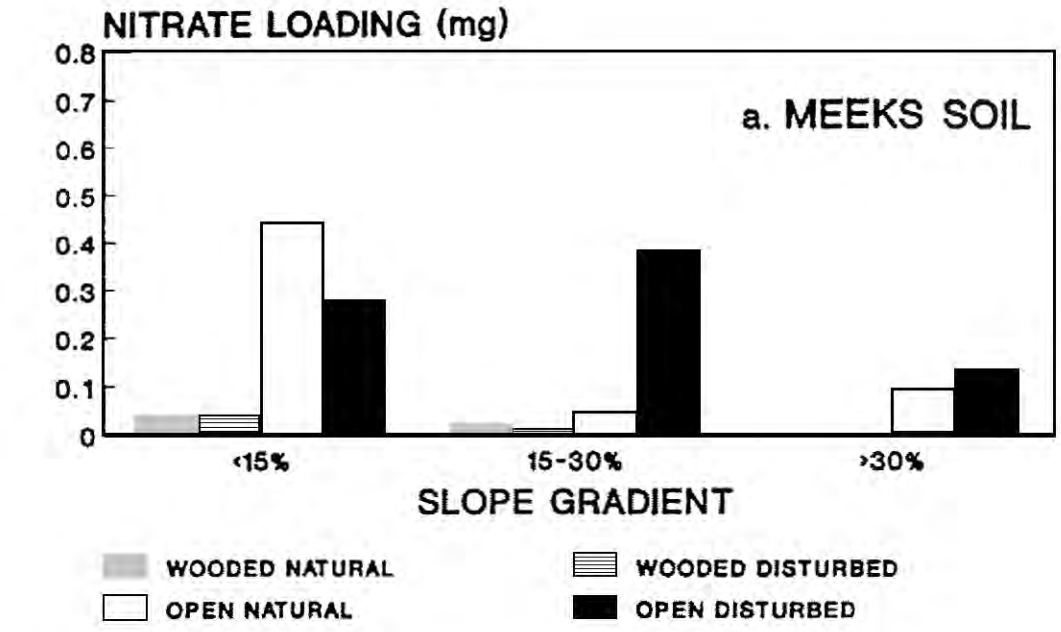
Surface runoff is a primary nutrient transport mechanism, so it is important to understand what areas are most vulnerable. Nitrate content in runoff from open areas has been found in greater quantities than in surface runoff from wooded sites (Figure 4-13). In contrast, conifer stands in the Tahoe basin have been found to be efficient at removing nitrate from precipitation (Naslas et al. 1994; Coats et al. 1976). When a wooded site was disturbed through litter removal or soil raking, the nitrate discharge increased, but not to the level of the open sites. Soil type was also significant in predicting nitrate levels but not as important as plot condition. On all sites, the early stages of runoff produced the highest levels of nitrate (Naslas et al. 1994). Summer rainfall and runoff also are a source of nutrients to Lake Tahoe. Sullivan et al. (1996, 1998) found that although total loading from summer precipitation may not be great, the runoff nutrient concentrations are often quite high. Construction or other disturbances should be scheduled to avoid periods of snowmelt runoff or summer storms to minimize nitrogen loading to the lake.

What is the effect of nutrient cycling in the watershed on transportable carbon, nitrogen, and phosphorous? How does system hydrology interact with nutrient cycling to influence nutrient loading?

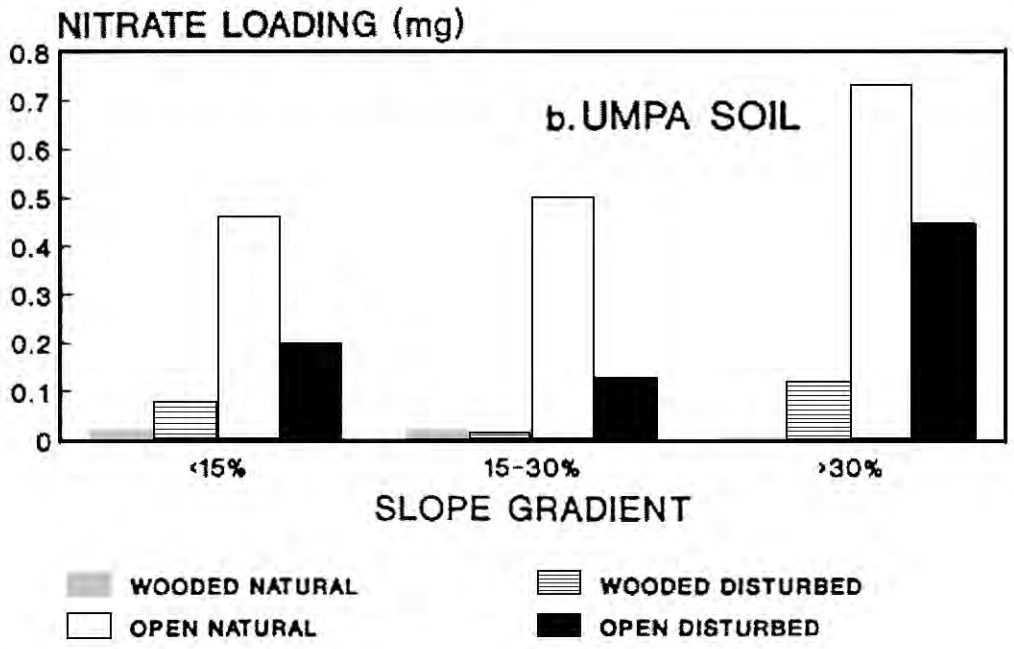
Nutrient Reservoirs in the Terrestrial Watershed

There are several ecosystem components that serve as reservoirs (nutrient pools) for water and nutrients, such as carbon, nitrogen, and phosphorus. These can be broadly grouped into five categories:

- Vegetation—forest, shrub understory, meadow, riparian and, nitrogen-fixing/non-nitrogen-fixing plants;
- Forest floor—litter, duff, humus;



LSD .05=0.203; LSD .01=0.301



LSD .05=0.203; LSD .01=.301

Figure 4-13—Nitrate loading in surface runoff from Meeks and Umpa soils during one hour of artificial rainfall application (from Naslas et al. 1994).

- Soils—granitic, volcanic, upland, riparian;
- System hydrology—soil water, streamflow, surface runoff, ground water, terrestrial/aquatic interface (hyporheic zone); and
- Stream sediments—primarily bedload, which moves a rate slower than that of channel flow.

Each of these reservoirs plays a key role in the cycling (source/sink interaction) of watershed nutrients. When linked with dynamic watershed processes, these reservoirs in conjunction with hydrologic response ultimately determine discharge water quality.

The terrestrial watershed nutrient pool in soils is generated and resupplied from both internal and external resources. When internal resources are inadequate for plant nutrient supply, nutrients are commonly imported from external sources, such as inorganic and organic fertilizer. Internal nutrient resources, however, are derived from within the ecosystem itself, be it a forest, a watershed, or a home. These resources include processes of mineral weathering, biological nitrogen fixation, acquisition from atmospheric deposition, and internal recycling from plant and animal residues.

Nutrient cycling is affected by temperature, vegetation, soil type, and presence of bacteria, organic matter, and soil oxygen (Hixson 1989). It affects the availability of nutrients for plant uptake and the nutrient reservoir available for transport and discharge. The transport of nutrients, particularly N and P, to Lake Tahoe unquestionably is an important cause of enhanced algal growth and decreased clarity.

Watershed Processes Affecting Nutrient Cycling and Transport

The Ward Creek watershed contributes only six percent of the annual surface runoff to the lake but is the fourth largest of the 63 watersheds in the basin. Its soils are derived primarily from andesitic and basaltic rock sources. Vegetation consists of conifers, meadow plants, and mountain alder. Coats et al. (1976) studied Ward Creek to evaluate the effect of soil disturbance on nitrogen concentrations in tributary discharge water. At the time of the study the watershed was relatively undeveloped, but logging and road construction had disturbed large areas. The study considered seven plots: unlogged, newly logged, red fir, old logged, alder, meadow, and an readability plot that had been raked and whose vegetation had been removed through herbicide application. All sampled areas were approximately 10^4 m^2. Their results showed that organic N content was consistently higher in the A soil horizon than the subsurface C horizon for all plot conditions. Furthermore, soil disturbance was found to increase the variability of organic N levels within a stand. The newly logged plots yielded more organic N in soil water extracts than did the study plots.

Precipitation collected throughout the winter in three separate meadows was analyzed for N content, thus N input from precipitation was determined. The unlogged plot removed almost all NO_3^--N added from the snowmelt. Soil water extracts from the undisturbed control plots contained little NO_3^--N. Those from beneath newly logged red fir and meadow plots, however, contained higher NO_3^--N. In older logged plots (eight years prior), there was a net release of NO_3^--N from the surface layers, but little was derived from the deeper C horizon. Soil water extracts from beneath the mountain alder plots contained very high levels of NO_3^--N. This was attributed to the N_2 fixation. NO_3^--N levels in the A and C horizons were positively correlated; when high in the A horizon it was also high in the C horizon. Tree basal area and C:N ratio correlated inversely with log (NO_3^--N). This shows that a heavy conifer stand with N-poor litter both strips the NO_3^--N from snowmelt water and inhibits nitrification.

Soil samples were perfused with either ammonium sulfate or distilled water for 30 days to determine if the addition of NH_4^+-N increased nitrification. It was found that the nitrification potential was high in the disturbed erodibility plot and low in the undisturbed unlogged plots. In the disturbed plots litter disturbance and vegetation removal may have created conditions favorable for heterotrophic mineralization. This would have increased the supply of NH_4^+-N available for biological nitrification and the release of NO_3^--N.

Even so, Coats et al. (1976) reported NO_3^--N loading into the lake from Ward Creek to be fairly small. It would appear that release of NO_3^--N from such disturbances as home construction can be mitigated fairly rapidly with prompt revegetation of the site.

Leonard et al. (1979) conducted a study similar to that of Coats et al. (1976). Their focus considered sediment nutrient flux into Lake Tahoe from Ward and Blackwood Creeks. Blackwood Creek is the third largest watershed in the basin and is similar in geology but substantially less vegetated than Ward (50 percent sparse or no cover for Blackwood versus 31 percent for Ward). Estimated inorganic N inputs to the watershed via atmospheric deposition in 1973 and 1974 were one to two kg/ha, based on measurements taken at Ward Valley (Leonard et al. 1979) (not equivalent to direct deposition on the lake surface, as discussed above for Lake Tahoe's nutrient budget). Estimated nitrogen fixation contributed 10 to 20 kg/ha.

Summer and early winter stream NO_3^--N levels were very low in the absence of rainfall. Later, during winter and spring, NO_3^--N in tributary discharges were higher in response to snow and snowmelt. In areas of mountain alder vegetation, there was a steady flux of NO_3^--N into the stream water during fall and early winter. The flux, however, is believed to change depending on the amount of rainfall received earlier in the year. Given enough rainfall, NO_3^--N would flush early into the stream water with baseflow. Concentration and flux patterns were similar. NO_3^--N was transported into the streams during periods of heavy spring runoff, and most of the annual load entered the stream from a single storm. It is interesting to note that NO_3^--N flux did not correlate with streamflow volume. This suggests that flux was controlled by the release of NO_3^--N from soil to stream water, as well as from direct runoff.

In this study (Leonard et al. 1979), organic N analysis was not performed, and NH_4^+-N levels were below detection (<5 μg/L). However, other studies have reported higher levels of NH_4^+-N in various tributaries of the Tahoe basin (Glancy 1973). LTIMP data collected between WY 1989 and 1993 show that NH_4^+-N concentrations are typically less than 10 μg/L, but they can reach 20 to 50 μg/L and occasionally even greater than 75 μg/L. Leonard et al. (1979) believed that the unreliability of analytical methods was reflected in the variability of organic N levels in Tahoe tributaries in the literature existing at that time. Since the mid-1980s, the LTIMP data for dissolved Kjeldahl-N has been very reliable relative to those much earlier measurements.

Dissolved organic/colloidal nitrogen fractions recently have been reported to be the major N form discharged from the leaching of intact soil cores taken from the Incline Creek watershed (Harlow 1998). Further study is needed to estimate accurately the mobility of colloids throughout the Tahoe basin. Although Marjanovic (1989) also reported high dissolved organic-N loading rates, it is as yet unclear what fraction of the total nutrient budget is affected by colloid transport or what mechanisms may affect their transport and bioavailability. This study (Harlow 1998) examined only the leachate mobility of nutrient-bound colloids and not the potential for colloids to actually reach the lake or to enhance the growth of algae.

Wetlands, artificial or natural, traditionally have been considered to function as a sink for sediment and nutrients. Settling basins or wetlands (natural or artificial) are designed to remove coarse sediment (sand and silt), initially through sedimentation and filtration and ultimately through vegetative uptake. Vegetation is also particularly effective at lowering the flow velocity such that particulate settlement is facilitated. Nitrogen removal is generally very efficient. Wetland plants with associated bacteria provide a site for the rapid uptake and removal of N, primarily through denitrification. Denitrification also can function as a primary sink for nitrogen. In an undeveloped headwater area on eastern slopes of the Sierra Nevada, denitrification was found to remove almost all of the available nitrogen (Brown 1987; Melgin 1985). Another meadow near Lake Tahoe demonstrated denitrification rates twice that of the input rate from rainfall (Greenlee 1985). The most important factor in nitrogen removal was found to be residence time. The slower the flow and the longer the residence time, the more efficient the N removal.

The influence of such physical factors as

channel morphology on hydrology adds opportunity for denitrification because of the increased expanse and temporal extent of saturate soils within the root zone or riparian vegetation. Decaying roots provide the carbon source that supplies energy to denitrifying bacteria that thrive where water tables fluctuate slightly but frequently. The abundance of available water for riparian vegetation adds to the opportunity for plant growth and nutrient uptake. At Lake Tahoe, Morris et al. (1980) found that as tributary flow, which was nutrient-rich, passed through an undisturbed wetland/stream riparian zone, 74 percent of the total-N, 86 percent of the total-P, 72 percent of the total iron, and 84 percent of the suspended sediment was removed.

In the late 1980s, an artificial wetland was constructed near Lake Tahoe to receive runoff from a fertilized athletic field (Reuter et al. 1992). During WY 1988, the wetlands received 873 m^3 of surface runoff. Water samples were collected at points of inflow and outflow to evaluate the removal of sediment and nutrients, and TKN was sampled during periods of high and low runoff. At low runoff (December 1987 and April-May 1988), TKN in the inflow was greater that the outflow because of the longer residence time. TKN was removed during low runoff but was discharged during high runoff. TKN was exported when inflow concentrations were less than 500 μg N/L, but above that level the wetland functioned as a sink.

The wetland was very efficient at removing nitrate from the inflow runoff. Removal efficiency (in concentration) was 93 percent and 85 percent in both winter and summer, respectively. Final discharge concentration was close to that found in Lake Tahoe (<10 to 15 μg N/L). Ammonium was not removed, and the wetland often acted as a source. This may have been due to the immature state of the vegetation. The root systems may not have been established enough to give proper O_2 levels for nitrification to occur. Low nitrification rates would increase the inefficiency of removal of both ammonium and TKN.

Presumably the rate of nutrient capture relates inversely to the rate of water transport. As a sediment detention basin fills up, the rate of water transport through a pond increases. Eventually it will become sufficiently full that vegetation will encroach onto the deposited sediment. Then it will act more as a stream with an accessible floodplain. Thus the export of the sediments and their stored nutrients may not be a big hazard, but the decreased functionality of it for nutrient capture is. If there is a mechanism for stored sediment and nutrient export, that ought to be described.

Reuter et al. (1992) found that particulate P was well removed by the artificial wetland. Since particulate P and sediment are commonly associated, it is not surprising that suspended sediment and turbidity also were greatly reduced. Percent removal for suspended solids ranged from 85 to 89 percent. Even at low flow rates, however, clay-sized particles in complex with particulate P can remain in solution. These finer particles are the most difficult to remove from solution. Consequently, particulate P, soluble P, and sediment levels need to be continually monitored in artificial wetland systems because it is not clear how these wetlands will respond with age.

Recent research (Rhea et al. 1996; Harlow 1998) suggests that natural riparian zones can, in fact, function as a source of N and P as a result of nutrient cycling processes. For example, a newly constructed sedimentation pond initially might be quite effective in removing particulate nutrient forms, such as P. Once overgrown with vegetation, however, biotic nutrient cycling processes may well contribute rather than remove N and P. A sediment and nutrient analysis on wetland discharges would be most helpful in determining if wetlands actually reduce nutrient loading on a long-term basis. Finally, accumulated sediments and associated P would be vulnerable to extreme upper watershed events. High flow discharges could easily flush accumulated sediment and nutrients directly into the lake. Project protection and maintenance are essential.

Johnson et al. (1997) studied nutrient fluxes in Little Valley and Sagehen Creek, in the eastern Sierra Nevada. They found that organic N fluxes were generally greater than inorganic fluxes. Inorganic N and P from snowpack under a canopy was immobilized in the soil, with a flux of only 1 to 15 percent of the input. Decomposition under

snowpack is responsible for a pulse of nutrients during snowmelt. NO_3^--N stream water pulses occurred during the winters of low snowfall years in both Little Valley and Sagehen Creek watersheds. Soil solution NO_3^--N was low during snowmelt, indicating that the NO_3^--N did not pass through the soil. In years with average precipitation, no stream water increase in NO_3^--N would be expected at these two sites.

On the other hand, mineralization and nitrification do not appear to be large contributors of N to stream water from forest watersheds in the Tahoe basin. Nitrification occurs in forest soils, but it is generally limited by pH, the natural supply of NH_4^+-N, and decomposing litter (Coats et al. 1976). On the other hand, mineralization and nitrification can be significant in areas that have been disturbed or are covered with logging slash (Leonard et al. 1979). Other localized sources of N are related to N_2 fixing vegetation such as mountain alder trees (Goldman 1961).

Nutrient cycling occurs on a localized scale. This makes it difficult to predict the effects of nutrient cycling on basin-wide nutrient loading. Nitrogen transformation processes are well understood but highly variable. Phosphorus cycling also is highly variable but less well understood. No information was found on transportable carbon, and dissolved/suspended colloidal transport should be studied further. This is a potentially significant method of nutrient transport and could pose a real barrier to nutrient management in the Tahoe basin.

Lake Tahoe Basin Ground Water Quality, Nutrient Loading and Evidence of Land Use Impacts

The difference between stream and ground water discharge lies in the method of Lake entry. Streamflow discharge is rapid, and initially spreads out into the Lake, primarily as a result of discharge turbulence. Ground water discharge is comparatively slower, and enters the Lake in a much more diffuse manner. This ground water flow is more likely to have an effect on the littoral (shore) zone sediments, stimulating benthic growth. Ground water also can enter a stream as baseflow. Depending on the level of ground water discharge, baseflow contributions can be a significant component of tributary nutrients loading (Woodling 1987).

Several studies have been completed that add to the knowledge of ground water quality and nutrient loading in the basin (Loeb and Goldman 1979; Loeb 1987; Thodal 1995, 1997; Tyler and Ramsing 1998). These studies have indicated that elevated levels of nutrients are present in some ground waters and that ground water may contribute significant nitrogen and phosphorus to the lake. The following focuses on the results of these studies with particular emphasis on evidence that links land use to ground water quality and nutrient loading.

Ward Valley—In 1975, Loeb and Goldman (1979) did geophysical studies and ground water nutrient monitoring in the Ward Valley watershed along the west shore in order to estimate the total ground water flow and associated nutrient loading into Lake Tahoe. They estimated the amount of ground water flow to be 410×10^7 L/yr, which was about 16 percent of the flow carried by Ward Creek and 10 percent of the total precipitation in the watershed. Well chemistry data collected from four wells in the watershed indicated that the average ground water nitrate concentration was 162 μg/L and that the average soluble reactive-P concentration was 73 μg/L, while ammonium concentration was below the level of detection (<15 μg/L). Based on these values, the amount of nutrient loading from ground water into the lake was calculated. Ground water nitrate loading from Ward Valley was estimated to contribute 49 percent of the total watershed nitrate loading to the lake and 44 percent of the soluble reactive-P loading. This study indicated that while the volume of ground water entering the lake may be small relative to other sources (e.g., stream water), the amount of biostimulating nutrients entering the lake may be substantial.

Loeb and Goldman (1979) also found much higher levels of nitrate in two wells than could be accounted for by stream or precipitation sources. They speculated that the additional nitrate probably came from urban development in Pineland (about 200 homes), where, until 1970, all the houses leached their sewage into the permeable soils and substrata.

They speculated also that the impact of ground water nutrient inputs on eutrophication of the lake could be significant. Streams enter the lake at discrete points, with stream water and associated nutrients rapidly extending out into the lake; in contrast, ground water from Ward Valley enters Lake Tahoe at a much lower velocity and over a wide sediment-lake interface. The movement of ground water and associated nutrients would enrich the littoral benthos, stimulating the productivity of the benthic algal and bacterial communities.

Upper Truckee River and Trout Creek—Loeb (1987) did a more intensive study of ground water quality in three major basin aquifers: the Upper Truckee River, Trout Creek, and Ward Creek. Geophysical studies of aquifer characteristics and wellwater monitoring were combined with studies of seepage and algal growth to estimate nutrient loading and to determine whether an association between ground water inputs and nearshore algal growth could be demonstrated. The results from well water monitoring showed an association between ground water nutrient levels and land use. Water quality data was collected from 49 wells and springs within the three study aquifers. In Ward Valley, nitrate concentrations in ground water increased two to 10 times as it flowed toward Lake Tahoe through the developed (Pineland) portion of the watershed. In the Upper Truckee River and Trout Creek aquifers, higher nitrate concentrations were similarly found nearer the lake and developed areas than at sites upgradient in the watershed. The highest average nitrate concentrations in the south shore aquifers were observed in the developed area in the vicinity of the "Y" where highways 50 and 89 join. These findings led to the conclusion that ground waters were being contaminated with nitrate as they moved toward Lake Tahoe through developed or disturbed areas of the watershed.

Interestingly, chloride concentration showed similar trends as nitrate in the Upper Truckee River and Trout Creek aquifers; that is, samples with high nitrate also had high chloride. However, concentrations of ammonium and phosphate did not show similar trends as nitrate. Ammonium concentration was very low in all three aquifers, and phosphate was low in the south shore aquifers and only slightly higher in the Ward Creek aquifer. Loeb (1987) identified several potential sources for high nitrate and chloride, as follows:

- Fertilizers and increased nitrification following land disturbance or land with impervious surfaces are sources of nitrate;
- Exfiltration from sewer lines or old septic leach fields could contribute both nitrate and chloride; and
- De-icing salt used on highways in the winter is a source of chloride.

Ground water flow modeling indicated that discharge from the ground waters of the Upper Truckee River and Trout Creek aquifers to Lake Tahoe was approximately 170 x 10^7 L/year. Ward ground water flow calculated by Loeb and Goldman (1979) was 410 x 10^7 L/year. Therefore, Ward ground water flow was estimated to be 2.4 times the amount of ground water flowing into the lake from the Upper Truckee River and Trout Creek aquifers combined.

Ground water nitrate N and soluble reactive P loading to the lake were estimated to be 525 kg N/year and 185 kg P/year from Ward Creek and 799 kg N/year and 26.64 kg P/year from the Upper Truckee River and Trout Creek aquifers. The amount of nitrate and soluble phosphorus contributed by ground water could be a significant proportion of the total watershed input (stream plus ground water) of these forms. Nitrate loading from Ward Creek ground water was estimated to be about 60 percent of that from ground water and streams combined, while the contribution of nitrate from the Upper Truckee River and Trout Creek aquifers was estimated to be 20 percent of the watershed nitrate. Ground water phosphorus loading was 44 percent of watershed loading (stream water plus ground water) in Ward Creek but only two percent of loading in the Upper Truckee River-Trout Creek watershed.

Nutrients carried by ground water into Lake Tahoe become focused into the nearshore region of the littoral zone. It has been in this region of the lake that visible signs of differential nutrient availability and accelerated eutrophication have been observed in the form of increased amounts of attached algae

(periphyton) (Loeb 1980; Loeb et al. 1986). Loeb (1987) monitored attached algal growth in the nearshore zone adjacent to the aquifers to see whether impacts of ground water flow on algal growth could be detected. Seepage meters were used to try to determine ground water flow rates at the sediment-lake interface, and sediment interstitial water was measured to estimate quality of ground water seeping into the lake. Seepage flow rates and quality then were compared with in-lake measures of algal growth to determine whether an association existed. Loeb also did periphyton and phytoplankton bioassays, which tested algal response to nitrogen, phosphorus, seepage, and well waters.

It was difficult to demonstrate definitively a direct association between algal growth in the lake and ground water input; however, the results did provide evidence for such an association. Only limited success was achieved by directly measuring seepage because the flow rates were near the limit of detection for the method and because of methodological difficulties. The amount of algal growth was not found to be correlated with seepage or seepage nutrient loading. However, this was due, at least in part, to the confounding influence on algal growth of differential stream inputs of nutrients at the sites. An increased growth of periphyton for at least one site (Pineland, which is adjacent to the Ward Creek aquifer) was thought to have been due in part to ground water inflow. At Pineland elevated levels of periphyton growth were found, along with positive seepage of ground water containing elevated N and P concentrations. Bioassays showed that Pineland interstitial water was stimulatory to periphyton growth. In addition, nutrient enrichment bioassays showed that periphyton growth was highest when nitrogen and phosphorus were added in combination rather than singly. Increased periphyton growth at this site was probably due, in part, to seepage of ground water containing both nitrogen and phosphorus. Loeb (1987) indicated that ground water inputs, along with other important sources, such as streams and nonchannelized runoff, are significant in regard to nearshore algal production. The effect of nutrients entering through this ground water pathway was thought to be an increased production of periphyton in the littoral zone.

The results from Loeb (1987) also demonstrated the water quality variability of ground water systems that may interact with Lake Tahoe. Due to the diversity of geologic and physiographic settings and the different degrees of development and types of land use, extrapolation of results from studies of individual aquifers to other parts of the basin may not be appropriate (Thodal 1995). Moreover, in order to evaluate the ground water component of the nutrient budget for Lake Tahoe, it is necessary to characterize the hydrogeologic setting of the entire basin and to identify the features that are related to the distribution of nutrients in ground water (Thodal 1995).

Hydrogeology of the Lake Tahoe Basin—From 1985 to 1987, a study was done to determine the quality and nutrient content of ground water and to characterize the hydrogeologic setting of the Tahoe basin (Thodal 1995). Concentrations of nutrients in the aquifers were found to be generally low, but certain areas that had particularly high nutrient concentrations were identified. Anthropogenic sources were possible at these sites, but a definitive link could not be made. Dissolved nitrate concentrations at least two orders of magnitude greater than concentrations reported for Lake Tahoe were measured in samples from wells on golf courses and near an abandoned septic tank system. However, historical data indicate that there were comparable nitrate-nitrogen concentrations in these areas as early as 1961, predating the golf courses. According to Dr. J. Unsicker (1999), several factors may have contributed to this finding. The riparian areas that became golf courses probably were used for livestock gazing, and livestock waste may have entered the ground water. Alder trees or other nitrogen-fixing species may have contributed. Analytical techniques for nitrate measurements have changed significantly and now have lower limits of detection.

Concentrations of organic nitrogen and ammonia nitrogen greater than 1 mg/L were measured in ground water in the vicinity of a resort that historically relied on a septic tank system for wastewater disposal and that also has a riding stable. This area also is underlain by carbonaceous alluvial deposits that could contribute these species of nitrogen to the ground water system.

Orthophosphate was generally low and not distinguishable as associated with particular land uses. For nonmacronutrient species, chloride concentration was elevated in three wells near US Highway 50, indicating ground water quality may be locally affected by leachate from road salt.

Thodal (1995) also estimated ranges of annual nutrient loads possibly transported to the lake through three aquifers that extend along 1.3 miles of the 19 miles of shoreline in the study area. A wide range in potential loading of nitrogen, phosphorus, and iron was found, which was a result of uncertainty associated with aquifer geometry and hydraulic properties and local variability in concentrations of nitrogen and iron. Nevertheless, the nutrient loading estimates indicated that ground water is a plausible pathway for solutes to enter the lake.

With a need for information on the overall contribution of ground water to the nutrient budget of Lake Tahoe, from 1990 to 1992 the USGS, in cooperation with TRPA, initiated a basin-wide ground water monitoring program to evaluate the role of ground water in processes of nutrient loading to the lake. Historical data describing ground water flow and quality were reviewed and a ground water quality monitoring network was designed and operated to provide information on the relative significance of ground water to the nutrient budget of Lake Tahoe. The results of this study are presented in Thodal (1997).

Thodal (1997) found that nitrate-N was the dominant form of nitrogen in ground water samples, that it represented 100 percent of nitrogen at 17 of 31 sites, and that it averaged about 85 percent of measurable nitrogen. A large range in filtered nitrogen concentrations was observed (<0.020 to 12 mg/L), and several sites had very high soluble nitrogen suggesting contamination associated with land use. Five well sites contained nitrate concentrations higher than 1 mg/L, up to a maximum of 12 mg/L (Nevada Maximum Contaminant Level is 10 mg/L). Two sites with high filtered nitrogen are in the South Lake Tahoe urban area and downgradient of an area historically used for spray-disposal of treated sewage effluent. Other areas of high nitrogen included two observation wells on golf courses and an observation well near a resort that historically relied on a septic tank leach field system for domestic waste disposal. Concentrations of phosphorus and iron did not range as much as nitrogen concentrations, and no relation to land use was apparent from the data. Tritium activity in samples of well waters indicated many of the aquifers had been recharged since 1952. Relationships between recharge dates and nutrient concentrations need to be examined.

This study also looked at ratios of nitrogen isotopes in samples of ground water from several of these high-nitrogen sites in an attempt to determine their sources. Variation in the ratio of isotopes of nitrogen ($^{15}N/^{14}N$) have been used in other studies to determine sources of nitrogen in the hydrologic cycle (Heaton 1986) and to distinguish ground water contaminated with fertilizer N from that contaminated from human or animal wastes (Exner and Spaulding 1994). The results of these analyses were in general not conclusive, they indicated that N ratios in high nitrogen areas were within a range characteristic of oxidized soil nitrogen; however, one of the golf course well sites was in the range that could indicate a synthetic fertilizer source. Elevated concentrations of soluble nitrogen suggest that mechanisms capable of accumulating soil nitrogen may exist at these sites. Possible mechanisms include nitrogen fixation or evaporative concentration of nitrogen, or alternatively the soil nitrogen could be from a combination of N sources, such as from synthetic fertilizer and sewage effluent.

The mean cationic composition of the ground water was 46 percent calcium, 27 percent sodium, 23 percent magnesium, and four percent potassium. The mean anionic composition was 81 percent bicarbonate, 11 percent chloride, four percent sulfate, three percent nitrate plus nitrite, and one percent fluoride. These values are based on a relatively small number of samples, and the results were variable from well to well. The median nitrate-nitrogen concentration was 0.14 mg/L in ground water, but 0.014 mg/L for Lake Tahoe. Nitrate accounted for approximately 85 percent of the total nitrogen in the samples, while organic nitrogen and

ammonium was 10 percent and five percent, respectively. Total P from filtered water samples ranged from 0.021 to 0.40 mg/L, with a median of 0.058 mg/L. Approximately 55 percent of total P was orthophosphate, and 42 percent was organic P.

Thodal (1997) used a combination of approaches to estimate ground water discharge to the lake for the entire basin. Ultimately a figure of 40,000 acre-ft/yr (from the top 50 feet of saturated basin fill deposits) was used as a first approximation of discharge. Nutrient contributions from ground water then were estimated by multiplying the mean concentrations of nutrients by the estimated volume of water discharged. This approach indicated that the ground water contribution of nutrients to the lake was 60 tons/yr of nitrogen, four tons/yr of phosphorus, and two tons/yr of soluble iron (see section on Lake Tahoe nutrient budget). Thodal underscored that there is a considerable degree of uncertainty in such estimates of mass loading, due to the small amount of available information on geologic boundaries, hydraulic gradient, and hydraulic conductivity. Assumptions that a mean concentration is representative for the entire basin is an additional uncertainty, especially considering that the number of sample sites were relatively small (32) and appeared to contain several polluted wells. Continued study related to these factors will help refine loading estimates and identify links to land use. However, these estimates do indicate ground water is a potentially significant source of nutrients to the lake.

Factors Affecting Mobility in the Shallow Subsurface Environment

Many soils of the Tahoe basin exhibit preferential infiltration and subsurface water flow. Preferential flowpaths can act as a shortcut to the ground water; as such, nutrients tend to bypass direct contact with the soil matrix, which generally would enhance nutrient removal from the percolate. Water-repellent soils tend to exhibit greater preferential flow during drier seasons. Furthermore, predominant preferential flow paths (Figure 4-14) are especially evident in finer textured soils of the Sierra Nevada (Burcar et al. 1994). Under conditions of preferential flow, nutrients are more likely to enter baseflow in forested areas immediately adjacent to tributaries and the lake itself. Nitrate was found to be more mobile in granitic soils than volcanic soils under conditions of normal matrix flow. Preferential flow paths in finer-textured volcanic soils could be responsible for more rapid transport of nitrate to the ground water.

In a study of stormflow source in a small mountain watershed, McGraw (1998) employed a combination of artificial rainfall observations and computer modeling to develop an understanding of potential subsurface flow from the riparian zone to the Upper Incline Creek. Results indicated that for events with wet antecedent soil conditions the estimated subsurface contribution ranged from eight percent to 36 percent of the total streamflow increase (i.e., due to subsurface water flux), while for those events with dry antecedent conditions the subsurface contribution ranged from 32 percent to 72 percent of the total streamflow.

Colloidal nitrogen and P were studied in Incline Creek to determine their role in subsurface nutrient transport. Rhea et al. (1996) created artificial rainfall to collect surface runoff and subsurface infiltrate on gentle (<15 percent) and moderate (>15 percent) slopes. The dominant water extractable N and P forms contained in soil extracts were colloidal rather than inorganic. Colloidal N increased in the soil following precipitation, indicating mobility. Colloidal P decreased following winter at the upper watershed locations but not at lower locations.

Marcus et al. (1998) examined leached soil nutrients from three classes of vegetation. Leachability of the organic matter showed that colloidal organic matter is significant in nutrient transport. Riparian sites were found to contain the most inorganic and colloidal nitrogen from soil extracts compared to forested and nonforested sites (Figure 4-15). Nitrogen-fixing mountain alder may have contributed to the higher nitrate levels on the riparian site. The elevated inorganic and colloidal nitrogen probably reflects the depositional nature of the site under the influence of riparian vegetation

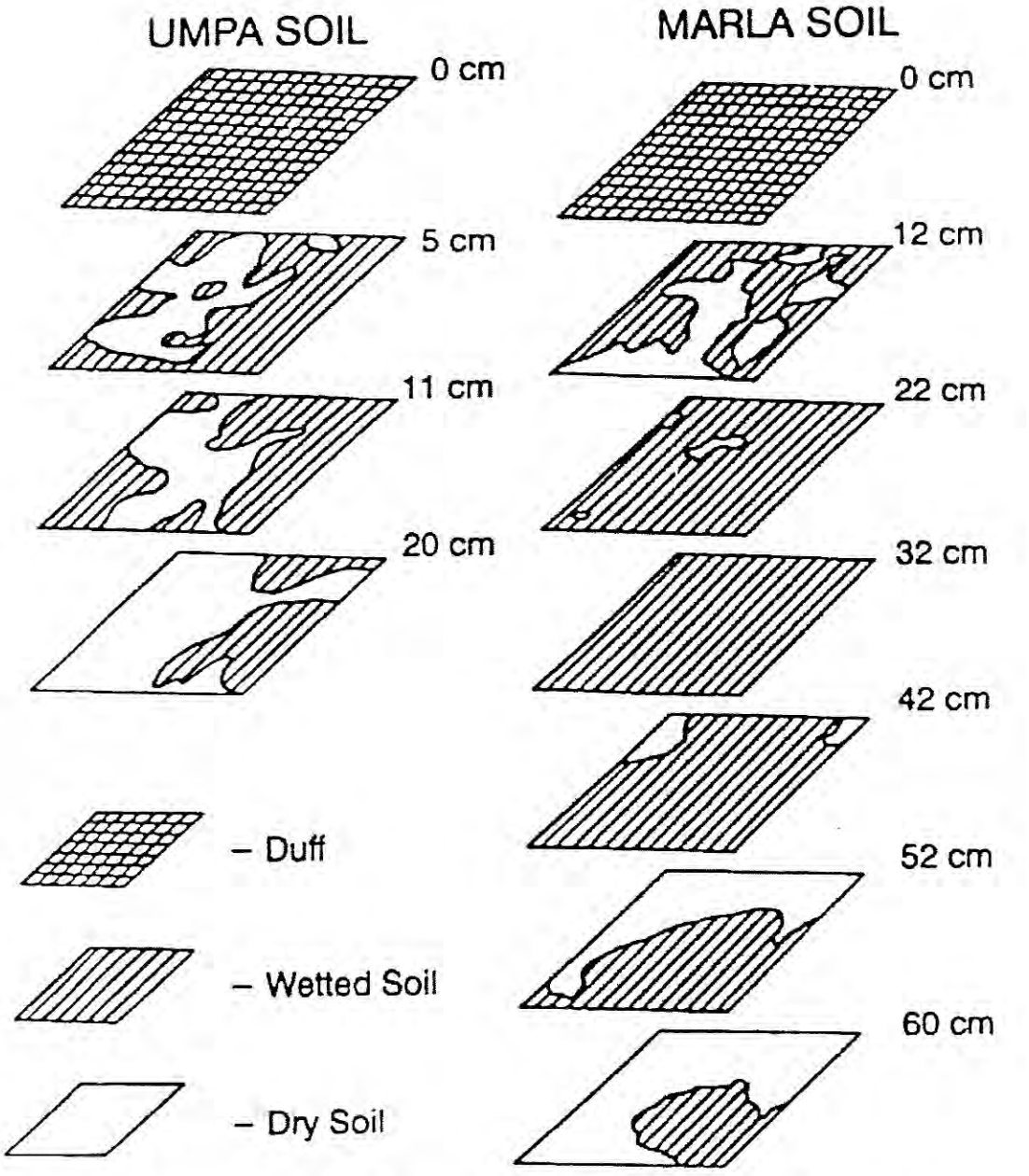


Figure 4-14—Preferential flow patterns observed in Umpa and Marla soils following artificial rainfall application (from Burcar et al. 1994).

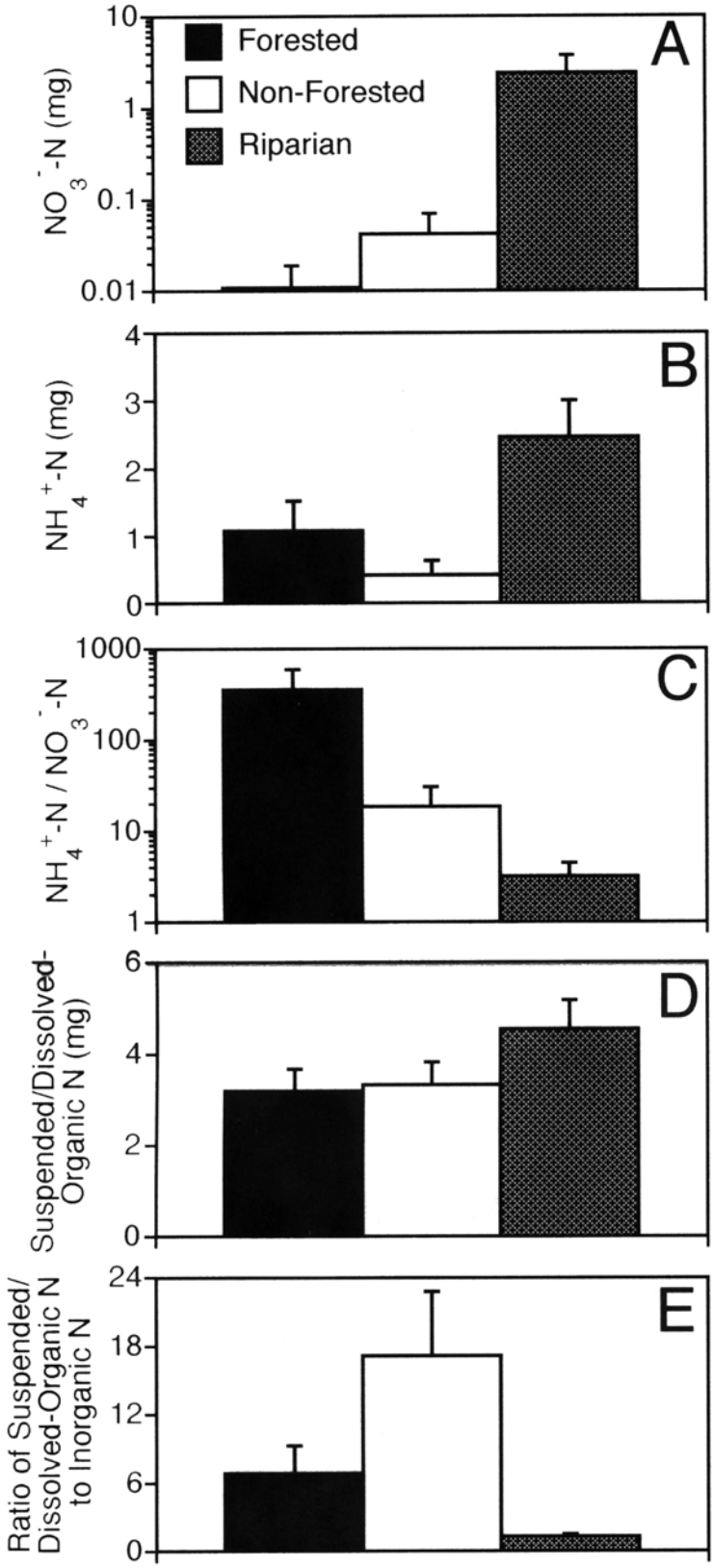


Figure 4-15—Cumulative inorganic and dissolved organic nitrogen in leachate from undisturbed forested, nonforested, and riparian soil cores (from Marcus et al. 1998).

and flood energy dissipation over deposited sediments and the history of vegetative uptake.

Harlow (1998) also found that local vegetation has an effect on the nutrient leachability. Sites near nitrogen-fixing mountain alders were examined to determine local increases in nitrogen. The alder did contribute nitrate to the soils, and the colloid forms were mobile in samples taken during leaching experiments. Transport of these colloids is a potentially serious but poorly understood mechanism. Colloidal N did not correlate with percent organic matter in the soil, indicating that the colloids are associated with nonorganic material.

While nitrogen fixation by alder would be an addition of N to the Lake, loss of N via denitrification in or near saturated soils would be a subtraction. Riparian woody vegetation is needed in some situations to provide channel roughness to reduce velocity and soil binding or coarse woody debris to keep soil in place where it is critical for stream hydraulics and hydrology. Although some other woody plants could provide these functions at some levels and in some places, alder is clearly adapted to this role quite well. Removal of woody riparian vegetation obviously would have serious consequences for water quality immediately and for decades to come.

MTBE in Lake Tahoe Ground Water and Drinking Water Wells

One of the most dramatic examples of the sensitivity of basin ground waters to contamination from human activities has been the recent finding of methyl tertiary butyl ether (MTBE) in several public water supply wells in the South Lake Tahoe area (Fogg et al. 1999). Eight of the South Tahoe Public Utility District's (STPUD) 34 wells have been shut down following detection of MTBE in water samples, and four additional wells have been shut down due to proximity of MTBE plumes to the wells. MTBE is a highly soluble fuel additive that has been labeled a possible cancer-causing agent. Significant sources of MTBE ground water contamination are leaky underground fuel storage tank systems and spills around fueling facilities. Once introduced into the aquifer MTBE moves freely with the ground water and can persist for long periods. The use of MTBE in fuels apparently began to grow in 1990 as a result of federal Clean Air Act amendments, and the first well closures as a result of MTBE contamination occurred in 1997. Unlike nutrients in ground water, for which specific sources may be difficult to pinpoint, MTBE can be traced directly to sources of fuel leakage in the watershed overlying the aquifer.

Continuing Studies

Studies of ground water in the basin are continuing. The University of Nevada Reno is studying ground water hydrology, ground water quality, and seepage to the lake in the Incline Creek watershed. This study included ground water monitoring in the vicinity of golf courses, as well as in the nearshore area, among other sites. Tyler (1998) discusses aspects related to hydrology. The results related to ground water quality should be available in a thesis in progress by F. Ramsing (Tyler 1999). The hydrogeology and ecology of Pope Marsh recently were studied by C. Green at the University of California at Davis (Green 1998). Changes in water inputs into the marsh have occurred probably as a result of surface water diversions around development, and data also suggest that ground water pumping affects water levels in certain areas of the marsh during drought. These changes can exacerbate the affects of drought on the marsh. While his study focused on hydrology, Green also collected some samples for ground water quality analysis, including from an area below a controlled burn. Interestingly, he found elevated levels of nitrate in these samples and observed an algal bloom in the burn area. This suggested that the burn area was the source; however, because no preburn ground water data were available, it is difficult to definitively attribute high nitrate concentrations to the burn (Green 1998). Finally, USGS is continuing its ground water studies in the basin, including studies of interactions between ground water and tributaries (Thodal 1997). These studies should further greater understanding of the ground water component of the watershed.

Summary

The information gathered so far in several ground water studies has provided evidence that human activities and land use practices within the

basin can increase the levels of nitrogen or other contaminants in the ground water. This evidence has included the following:

- Findings of higher nitrate levels in well waters in more heavily developed sections of the basin;
- Findings of high nitrogen in wells located near suspected sources of anthropogenic nitrate, such as abandoned septic tank systems, areas where treated effluent was sprayed, and golf courses where fertilizers are used;
- Evidence of elevated levels of chloride in wells near US Highway 50, which is suspected to have originated from highway de-icing; and
- Recent findings of MTBE in several South Lake Tahoe wells from leaking underground storage facilities or from surface spills.

Additional information is needed to relate ground water impacts (and magnitudes of impact) to specific sources and land uses.

There are indications that ground water indicate ground water is a potentially significant source of nutrient loading to the lake. When considered in the annual budget of nutrient loading to the lake, ground water may contribute 14 percent of the nitrogen and four percent of the phosphorus. If most of the ground water phosphorus is loaded in a dissolved form, its relative contribution to biologically available phosphorus will be much higher. Much of the impact from ground water is likely focused in the nearshore area of the littoral zone. Bioassays have indicated that algal (phytoplankton and periphyton) growth is stimulated by the addition of ground waters that contain nitrogen and phosphorus. Ground water inputs, along with such other important sources as streams and nonchannelized runoff, are likely to be significant in regard to nearshore algal production. Continued study related to such factors as geologic boundaries, hydraulic gradients, and hydraulic conductivity will help to refine loading estimates and to identify links to land use.

What are the major characteristics of sediment transport in tributary flow to Lake Tahoe? What is known regarding the important sources of this material?

Perhaps the most significant factor connecting watershed land use and geomorphology hydrology to water quality is the change in peak flow events that comes with such changes to land use as urbanization (Hammer 1972; Booth 1990). These changes frequently upset natural dynamic equilibria in stream reaches and lead to drastic alteration of stream channel morphology, such as channel incision. "Regardless of whether the incision is caused by external or internal controls, the presence of the incision indicates a threshold of stability that has been exceeded" (Schumm 1977). This is especially true in alluvial streams where the connection to a floodplain is critical for energy dissipation, watershed hydrology, and nutrient capture and storage. Once incised, the stream is very likely to export stored nutrients as its energy becomes unleashed to rapidly erode banks that are decreasingly protected by riparian vegetation (Zonge and Swanson 1996). This sets in motion a chain of events that has been described by many (e.g. and Schumm et al. [1988], Harvey and Watson [1986], Van Havern and Jackson [1986], Swanson and Myers [1994], Pritchard et al. [1993, 1998], Rosgen [1994, 1996], Simon [1989]), including Butt et al. (1998), for work in the Tahoe basin.

"The causes of incision are highly variable but the response of incised channels, regardless of scale, follows a very similar pattern, which suggests that their evolution can be predicted" (Schumm 1977). Using the stream classification metrics of Rosgen (1997), one could easily envision a stream cross section becoming approximately 20 times larger after crossing a threshold of incision and before recovering. However, the relative magnitude of incision depth, and therefore crosssection enlargement, will vary with substrate, distance upstream from effective base level, and sometimes the rate of channel widening. Channels that are straightened at the time of incision tend to deepen

more than channels that remain sinuous because the steeper gradient increases velocity and cutting before reaching a new gradient controlled by downstream base level. Once initiated, the degree of incision and the rate of channel widening often have little to do with on-site management until the enlarged channel width allows for the reduction of shear stress sufficient for a floodplain and riparian vegetation at the new lower level.

Incised channel widening represents considerable export of stored alluvium and the incumbent nutrients. Alluvial lands have been forming as floodplain depositional material, often with the influence of wetland or riparian vegetation; therefore, much of the stored sediment, especially in surface horizons, is fine grained. The increased nutrient concentration and bioavailability represented by fine grained and organic material, and the capture of soluble nutrients by vegetation often causes these soils to be quite fertile. Loss of this stored alluvium and its store of plant nutrients represents both on-site degradation and downstream eutrophication. Butt et al. (1998) provides more detailed information about the riparian focus areas of many Tahoe basin watersheds, including Big Meadow, Blackwood, Burke, Burton, Cold, Marlette, Meeks, Slaughterhouse, Taylor, Third, Trout, Ward, Watson, and Zephyr Creeks, and the Upper Truckee River. They found problems with channel incision in all but Burke, Meeks, Taylor, Watson, and possibly Zephyr Creeks.

Fortunately, the process of incised channel widening leads back to the opportunity for sediment deposition and nutrient retention under the influence of riparian vegetation and energy dissipation across the new floodplain and with increasing sinuosity (Harvey and Watson 1986; Rosgen 1997; Swanson and Myers 1994; Prichard et al. 1998).

Early Field Studies

One of the most comprehensive investigations of sediment source in the Tahoe basin was performed by Glancy (1988) at Incline Village. He measured streamflow and sediment loading for the five principal tributaries of Incline Village, a drainage area of 17.8 square miles. From 1970 to 1973, 31,000 tons of sediment was transported to the lake, 75 percent of which was gravel and sand, 15 percent was silt, and 10 percent was clay. Glancy found a poor relationship between fine sediment load and discharge. Most of the sediment was transported during snowmelt. The sediment yield was three to 930 tons per square mile for undeveloped regions and 26 to 5,000 tons per square mile for developed regions. The developed areas had approximately ten times the sediment yield. Much of this sediment yield was attributed to specific point sources: road cuts, unpaved roads, culvert outfalls, and rerouted drainage systems.

Undeveloped areas that experienced flash floods had continued elevated sediment yields, probably as a result of bank erosion and channel instabilities. A flash flood in 1967 on Second Creek transported 75,000 tons of sediment in one afternoon. Glancy describes area/altitude relationships for Third and Incline Creeks, two of the larger tributaries. Third Creek has substantial high altitude regions. Its hydrology is much more subject to flash floods than is Incline Creek, which transported most of its sediment during the less frequent large flow events. Glancy attributed this to high altitude snowmelt occurring quickly at the end of the snowmelt season. Glancy hypothesized that sediment pickup was occurring along the main channel, as there is no longer melting snow at lower elevations to transport sediment to the channel. He suggests measures to reduce sediment yield, including dispersing rather than concentrating runoff, minimizing land surface disturbance, concentrating land surface disturbance to resistant areas and during low runoff times, and restabilizing disturbed areas.

Sediment Inputs From LTIMP Streams

A preliminary analysis of the annual sediment loads and hydraulic discharge and average annual concentrations for the nine LTIMP tributaries from WY 1989 to 1996 is presented below. Rowe (1998) also provided a discussion of sediment load from WY 1989 to 1996. The east shore tributaries (Glenbrook and Logan House) had an order of magnitude lower sediment loading than the west shore tributaries (Ward, Blackwood, and General), the northeast shore tributaries (Third and Incline), or the Upper Truckee River. This is primarily due to a rain shadow effect. By the time weather fronts reach the east shore they have already lost most of their moisture. With less precipitation there is less flow for erosion and transport of sediment. The Upper Truckee River is the largest

contributor of sediment, followed by Incline Creek and Blackwood and Ward Creeks. In terms of concentration, Third Creek was exceedingly high, at a level of 616 mg/L. Incline and Blackwood Creeks were the next highest, at 97 and 71 mg/L, respectively. Glenbrook, Trout, and Ward Creeks and the Upper Truckee River were intermediate (29 to 43 mg/L), with Logan House Creek at 19 mg/L and General Creek the lowest, with an average suspended sediment concentration of 15 mg/L. These data reinforce the contention that General Creek is functioning as an undisturbed tributary despite its location on the wetter west side. Furthermore, the extremely high concentrations of total suspended sediment emanating from Third Creek suggests that a more careful survey of this watershed be conducted. Concentrations for particulate-P were also much higher in Third Creek over this same period, confirming the need for further investigation.

Stream	Total Suspended Sediment (mg/L) (annual average)	Flow (10^8L) (total annual)	Load (MT) (total annual)
Trout	29	275	797.5
Upper Truckee	42	787	3305.4
General	15	134	201.0
Blackwood	71	295	2094.5
Ward	43	209	898.7
Third	616	64	3942.4
Incline	29	11	31.9
Glenbrook	29	11	31.9
Logan House	19	3	5.7

The bulk of sediment is delivered during the spring snowmelt, but rainstorms can cause high runoff at any time. Therefore, sediment transport is variable, depending on the streamflow velocity and volume. Leonard et al. (1979) studied sediment nutrient flux into Lake Tahoe from Ward and Blackwood Creeks. Blackwood Creek is the third largest watershed in the basin and is similar in geology but substantially less vegetated than Ward Creek (50 percent sparse or no cover for Blackwood versus 31 percent for Ward). In Ward Creek suspended sediment was generally below detection (1 mg/L) during the low winter and summer flows of 1973. However, with the November rains of 1973 came peak sediment concentrations of 2,000 mg/L as a result of channel scouring. Following the scouring episode, sediment decreased to 200 mg/L (1974), 800 mg/L below previously recorded spikes of 1,000 mg/L before scouring. Of the bottom two reaches of Ward Creek, one is in a state of rapid adjustment and the other is in a state of accelerated channel erosion, due to channelization and adjustment to loss of floodplain access because of road encroachment. The first 790-meter reach was classified as a Rosgen F3 (1996), having little or no accessible floodplain within twice maximum bankfull depth. The next reach was classified as an unstable B3, even though B3 channels are frequently stable. In several places along this 6,780-meter reach the stream is responding by cutting into valley wall material. Protecting the floodplain and terrace edge from further development are important priorities (Butt et al. 1998).

In 1975, sediment concentrations in Blackwood Creek were twice as high as those in Ward Creek, probably due to the lack of vegetation and steep slopes. Diel patterns were exhibited in both creeks for streamflow and suspended sediment. Peak sediment levels in both creeks tended to precede the peak streamflow, then dropped rapidly afterward. In the water years of 1973 and 1975, over 95 percent of the sediment transported was associated with the spring snowmelt. However, in 1974 heavy rains in November, January, and July carried 50 percent of the total sediment load with 40 percent of the annual runoff. Sediment size distributions were as expected—silts at low flow and mostly sands when the suspended sediment levels were over 20 mg/L. Based on 83 samples, the ratio of silt to sand was approximately equal. In samples with large sediment concentrations, clays were detected up to levels of 25 percent, but most had very small amounts of clay. Despite the potential importance of fine-grained sediment particles to Lake Tahoe water clarity (Jassby et al. 1999), few data are available on the size distribution of sediment in runoff. It is important that these measurements be incorporated into future monitoring.

A percentage of the sediment reaching the lake enters directly via flow from zones intervening tributaries rather than first entering a tributary. The sediment contribution from these intervening areas

may be large because they are at low elevation, are highly developed, and cause runoff to be channelized. At low elevations a larger proportion of precipitation falls as rainfall rather than as snow; importantly rain has more erosive energy than snow. As recommended for nutrients, a much better understanding of sediment load from urbanized intervening zones will be critical for purposes of management. As discussed below, development can increase sediment loading substantially. LTIMP monitoring has identified watersheds that are major sediment sources.

Sources of Sediment Within a Watershed

The most significant sources of erosion in the Tahoe basin are eroding channel banks, rill and splash sources on unvegetated steep lands, and roads and urbanizing areas. Hill and Nolan (1987) constructed a sediment budget for four watersheds at Lake Tahoe: General Creek and Blackwood Creek on the west side and Glenbrook Creek and Edgewood Creek on the east side. A sediment budget is an accounting of sediment inputs from all source areas within a watershed. Using a variety of techniques—river crosssections, erosion pins, erosion boxes—Hill and Nolan quantified the different erosional processes operating in the watersheds. They inferred that 70 percent of stream total suspended sediment was coming from streambank and streambed erosion on low order channels.

Leonard et al. (1979) performed an extensive nutrient and sediment analysis of Ward Creek. Detachment and transport was evaluated from bank erosion in the lower stream elevations, splash and rill erosion at high elevation on unvegetated steep soils, and forested land contributions. Forested soils were not found to be major sources of sediment. Bank erosion was the greatest source of sediment in Ward Creek in water years 1973 to 1975. A downstream monitoring station measured two to four times greater suspended sediment and 1.5 times the streamflow of the upstream monitoring stations. Enhanced stream flow presumably was derived from ground water or overland sources through low gradient, low sediment-producing areas. The increase in sediment was out of proportion with the streamflow and indicates that the stream channel itself is a primary contributor of sediment to the lake.

Glancy (1988), working on five principal creeks in Incline Village, Nevada, suggested flash flooding and roadways as the largest sediment sources. A flash flood on Second Creek delivered 75,000 tons of sediment in a single afternoon. Glancy found that sediment yields from developed areas averaged ten times those from undeveloped areas in Incline Village. Flash flooding can produce sediment loads to the lake 10 to 100 times greater than average annual sediment loading. Such events are not common, but the effects can be devastating and can cause channel instability that contributes to future erosion problems. There is evidence of major flooding in the basin during the 1870s, which would account for floods following recorded logging and fire episodes. Such an environment would be at severe risk, and the floods probably resulted in major sediment discharges into the lake.

Another source of information on sediment sources within watersheds is the LTIMP multistation data as analyzed from WY 1991 to 1996 (Stubblefield and Reuter, unpublished). For Ward, Trout, and Incline Creeks and the Upper Truckee River there are yearly sediment yields for three locations: an upper headlands station, mid-watershed, and the mouth of the creek. Stations are the same as those used by Hatch (1997) (see section above on stream phosphorus). The data indicate large differences in the spatial pattern of sediment loading between watersheds (figures 4-16 to 4-19). For example, comparison of Ward Creek and the Upper Truckee River, shows that at least 50 percent of the sediment load in high and low flow years is coming from the headwaters of Ward Creek, an area of steep unvegetated soils. The Upper Truckee River has much smaller relative contributions from its headwaters, a heavily forested region. Incline Creek also shows most of the sediment contribution from developed areas lower in the watershed. On Trout Creek the pattern has been complicated either by Lake Christopher, an in-river lake, or by the wetland that was constructed in place of this waterbody. Sediment concentrations are lower downstream, suggesting a sediment trapping effect. Discussion of

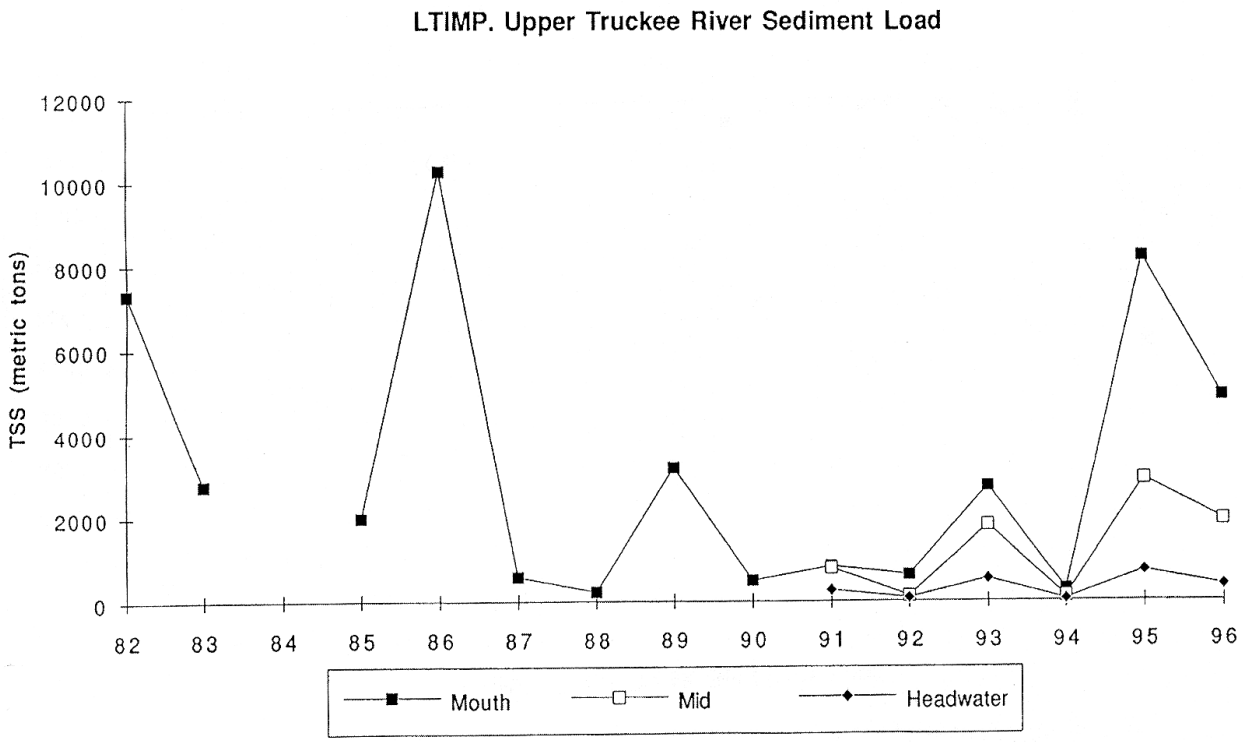


Figure 4-16—Annual load of total suspended solids in the Upper Truckee River. In recent years, sampling at multiple stations distinguishes TSS loads in certain subwatersheds.

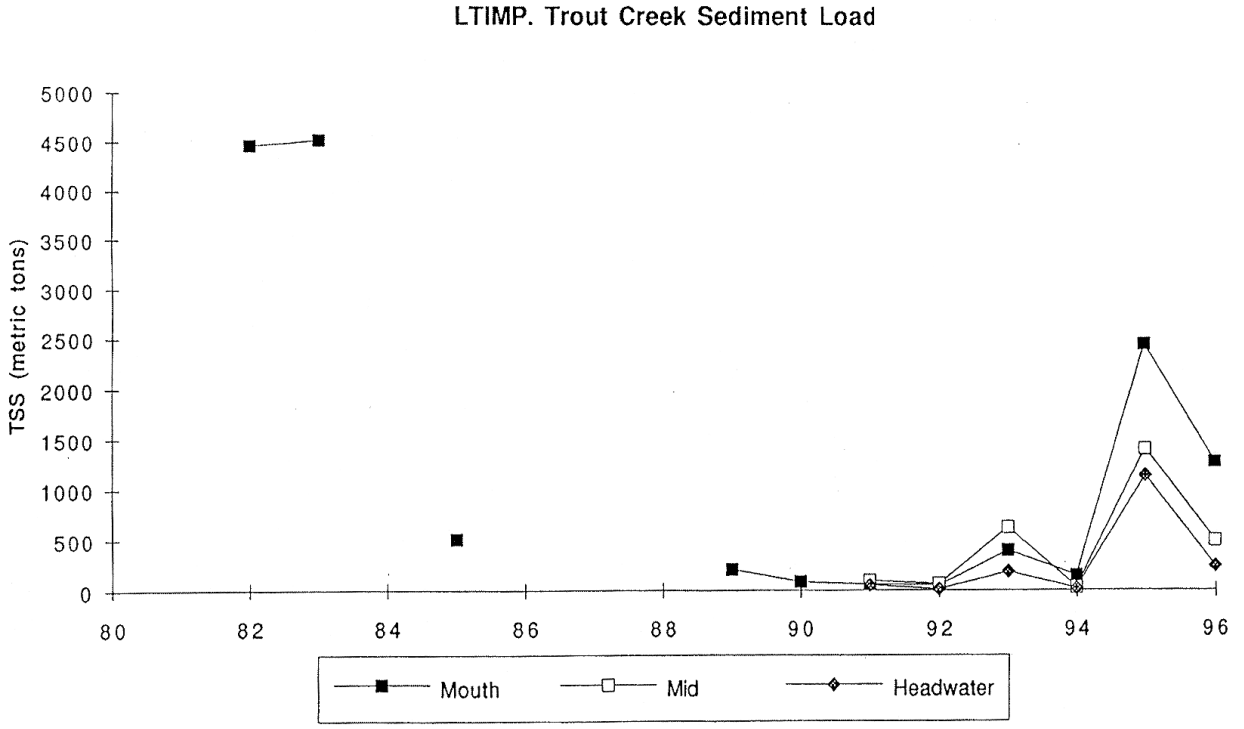


Figure 4-17—Annual load of total suspended solids in the Trout Creek.

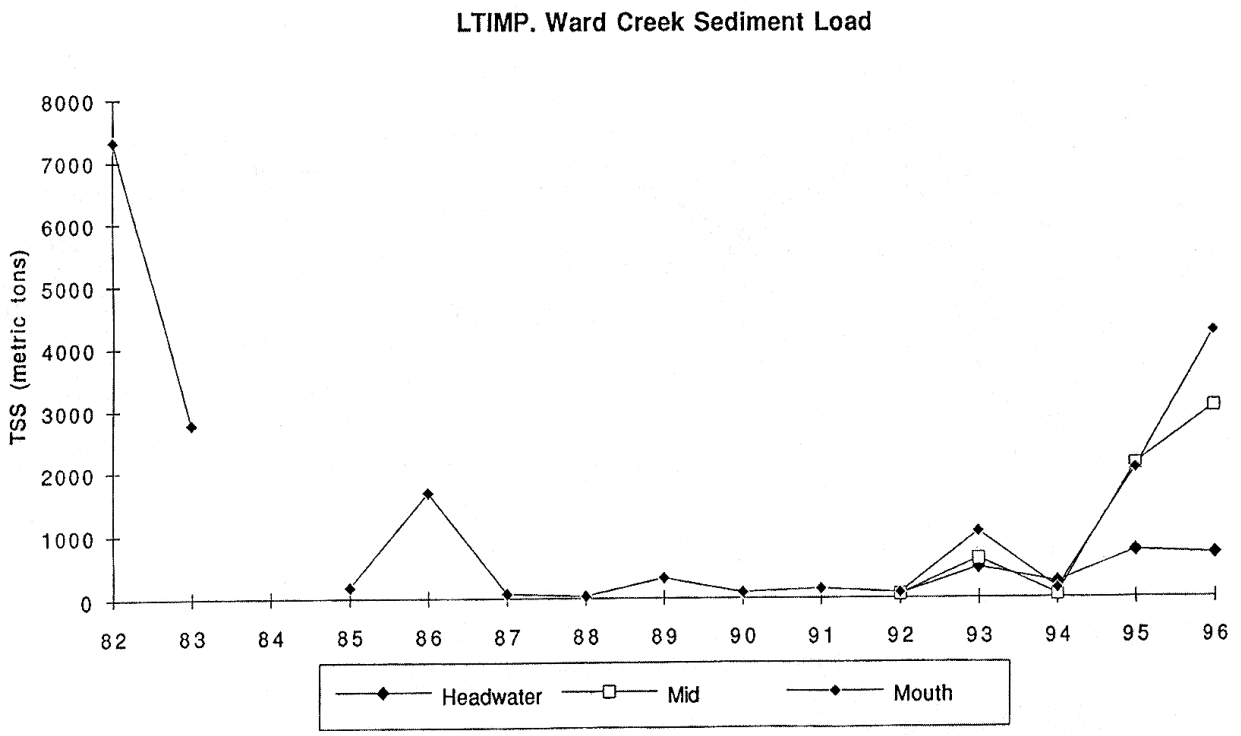


Figure 4-18—Annual load of total suspended solids in the Ward Creek.

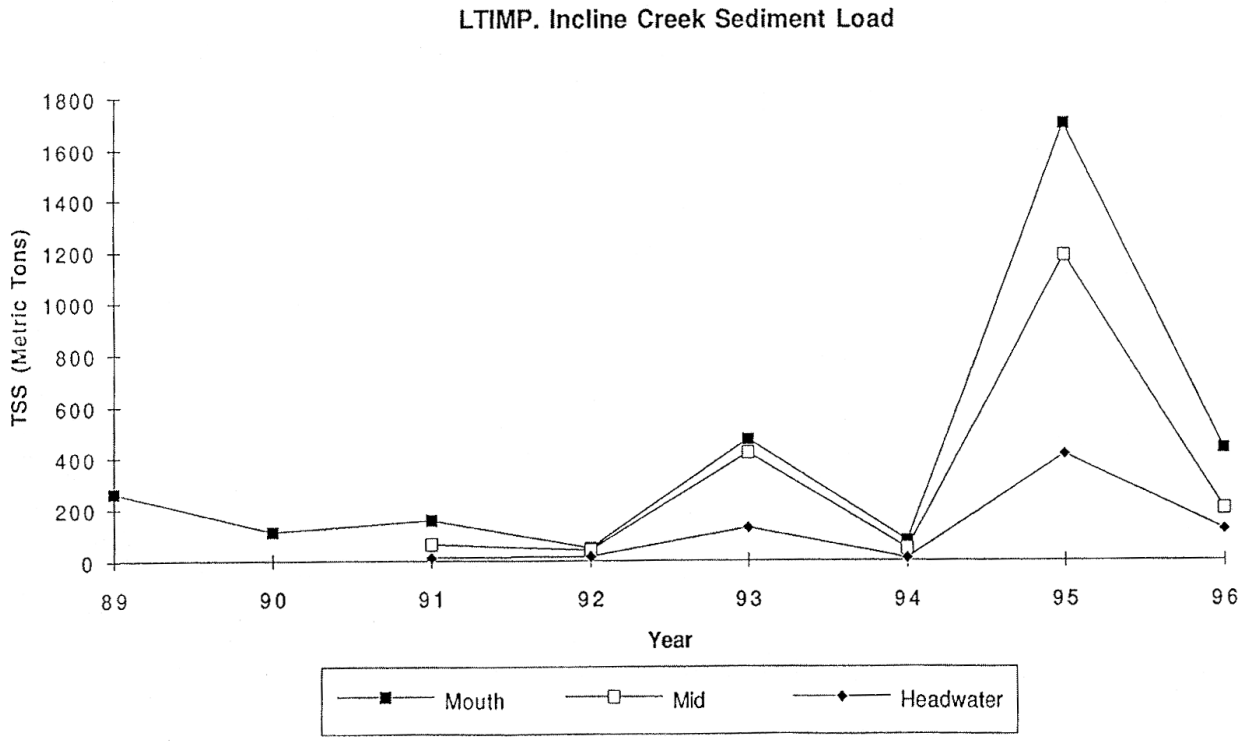


Figure 4-19—Annual load of total suspended solids in the Incline Creek.

sediment sources leads to discussion of the next question: evidence for the links between land use and watershed geomorphology and sediment loading. As observed for phosphorus, the greatest differences between stations within a single watershed occurred during high water years, such as WY 1995. Both WY 1993 and WY 1995 indicate that sediment load within the Ward Creek watershed is minimal between the middle and lake mouth stations. Again, for the Upper Truckee River, the pattern was the opposite; i.e., large amounts of sediment enters the river between the upper and middle stations, as well as between the middle and lake mouth station. For Trout Creek, a sizable portion of sediment load was observed between the middle and lake mouth stations.

Evidence Linking Watershed Characteristics to Sediment Load

Some degree of erosion is natural, especially on steep slopes. Erosion potential also is affected by soil type, litter layer, overland flow, slope, vegetation, and presence or absence of land disturbance (Guerrant et al. 1991; Naslas et al. 1994). Land development and lack of revegetation also can be major factors in sediment loading. Blackwood Creek had double the Ward Creek sediment loads in 1975. Compared to Ward, Blackwood has less vegetation and greater soil disturbance. High elevation, steep soils are subject to splash and rill erosion and mass wasting. This is well illustrated in the upper reaches of Ward Creek (Leonard et al. 1979). The developed watersheds (Blackwood and Ward) have sediment discharge levels that are an order of magnitude greater than less developed Meeks Creek and General Creek watersheds. This large amount of sediment is undoubtedly also the result of such natural factors as steep slopes and not solely from development.

Approximately 70 percent of the basin runoff is derived from granitic soils (Court et al. 1972). Indeed, erosion is very common on nonvegetated granitic slopes. Vegetation can minimize the kinetic effects of rainfall, reduce particulate detachment, remove sediments from runoff, and enhance infiltration (Gray et al. 1980). Blackwood Creek is characterized by a unique combination of high rainfall and steep, sparsely vegetated watershed slopes that make it a high sediment-producing tributary. Because of the high sediment loads, the lower channel is being aggraded. Furthermore, channel straightening has destroyed the flood pattern, which allows sediment deposition over a broad area. Now this sediment ultimately washes into Lake Tahoe (USDA Forest Service 1989b).

Blackwood Creek is destabilized by a combination of floodplain development, channelization, and channel incision. Furthermore, future channel incision is likely in some places and would exacerbate channel stability and bank erosion/water quality problems. Upland disturbances and in-channel construction projects have had a variety of mostly detrimental effects. However, headwater reaches appear to be quite stable. "The abundance of beaver activity on this stream appear(s) to be insufficient to stabilize it against the forces of high sediment supply and fluctuating runoff" (Butt et al. 1998).

Using the LTIMP database, Byron and Goldman (1986) found a significant correlation between percent disturbed of high/low hazard land in a watershed that is either covered or disturbed and sediment loading. They also found a correlation between road density/drainage density and the relative sediment loading to a watershed.

As mentioned above, Glancy (1988) found developed areas of the Incline Village watershed to be contributing 10 times more sediment than undeveloped areas. Within developed areas most sources of sediment input to Incline Creek could be traced to specific point sources. Roadways were the most obvious and widespread source of fluvial sediment. Within undeveloped areas the largest sediment source appeared to be flash floods and the elevated sediment yields resulting from flood-disrupted channel stability.

From 1972 to 1974, Kroll investigated sediment discharge from highway cut-slope in the Tahoe basin (Kroll 1976). At the same time, using continuous discharge measurements and frequent sampling of suspended sediment, Kroll estimated the suspended sediment contribution to Lake Tahoe from seven creeks (the Upper Truckee River, Trout Creek, Grass Lake Creek, Eagle Creek, Meeks Creek, Quail Lake Creek, and Dollar Creek). These study

basins represented 45 percent of the total water inflow to the lake. This 1972 to 1974 period was compared to a more extended database for six of these tributaries, which extended from 1961 to 1974.

The estimated sediment loading between 1961 to 1974 from the seven tributaries was 6,400 MT, of which 2,100 MT was fine sediment (>63 microns). For the period 1972 to 1974, loading from these tributaries was 4,900 MT, with 1,800 MT as fine sediment. For both periods, the fine sediment accounted for 30 to 40 percent of the total. Kroll estimated that the average discharge rate of fine sediment into Lake Tahoe from all streams was 4,000 MT/yr. He determined that 90 percent of the sediment load to Lake Tahoe in stream channels was suspended load rather than bedload.

To measure sediment from highway cut-slopes, Kroll installed 16 gutterflow stations and measured discharge and sediment load once or twice a week. During the spring snowmelt, he made measurements twice daily and occasionally hourly. The measured sediment discharge reflected not only erosion from highway cut-slopes but also sand applied for traction control on curves and hills. He found a mean annual sediment discharge of 272 MT, of which 27 MT was fine sediment; 180 MT of this was discharged at a single location, which had received large amounts of applied sand and gravel. The estimate of annual fine sediment discharge from cut-slopes along California state highways in the Tahoe basin was less than 91 MT, or approximately only two percent of the fines discharged by all tributary streams. Kroll stresses that not all the highway sediment will necessarily be transported to and deposited in the lake. Also, Kroll did not attempt to look at erosion and sediment transport in such places as roadside earthen-channels. Nevertheless, this 1976 report provides an excellent base from which to conduct a more detailed study.

Results from other watersheds may be informative in establishing the link between land use and sediment yield. Hollis (1975) found that urbanization increased the magnitude and frequency of floods in a watershed. This would increase bank erosion and sediment yield. Trimble (1997) found that two thirds of the sediment yield from urbanizing basins in Los Angeles was from bank erosion. Booth and Jackson (1997) monitored 80 urbanizing watersheds in the greater Seattle area and found that when the effective impervious area of a watershed exceeded 10 percent of the total watershed area, the creeks became highly unstable, having long reaches of eroding banks. The frequency and magnitude of floods increased as well. The results of these studies suggest that the following processes may be in operation at Lake Tahoe: urbanization is increasing the impervious cover in watersheds; increased impervious cover reduces infiltration rates so runoff reaches streams much more quickly; this reduced residence time results in larger and more frequent high flows; frequent high flows repeatedly damage stream banks before they have a chance to revegetate, resulting in high sediment yields.

Localized Sources of Sediment and Watershed Improvement Plans

A series of watershed improvement plans have been written for Lake Tahoe watersheds to assess current conditions, including localized sources of erosion. Between 1989 and 1994, each watershed was examined for obvious signs of erosion along system roads, trails, paved roads, and channels. Watershed slope, soil/rock types, and vegetation quantity and quality were noted, and each stream channel was evaluated for stability. This inspection of a watershed is tremendously important in determining actual conditions because models do not always correctly predict locations of severe erosion. (The watershed improvement plans are available through the USDA Forest Service, 1989a-c, 1990a-f, 1991a-g, 1992a-h, 1994a-c.) However, the riparian vegetation and channel form study described by Butt et al. (1998) provides more detailed information about the riparian focus areas of many of these watersheds, including Big Meadow, Blackwood, Burke, Burton, Cold, Marlette, Meeks, Slaughterhouse, Taylor, Third, Trout, Ward, Watson, and Zephyr Creeks and the Upper Truckee River.

What is the water budget for Lake Tahoe and how might future regional warming scenarios affect precipitation and runoff in the Tahoe basin?

Dominated by the 156 km^3 volume of water in Lake Tahoe proper, the hydrology of the Lake Tahoe basin naturally plays the primary role in affecting the ecological state of the lake itself and the surrounding terrestrial environment. Lake eutrophication is the consequence of nutrient inputs from the atmosphere and watershed. Because most nutrients are carried to the lake or discharged from it by the movement of water, it is vital to quantify, as accurately as possible, the lake's water budget. The major components of a preliminary water budget are summarized below and were taken from Marjanovic (1989). A summary of four other Lake Tahoe water budgets is presented in Thodal (1997) and include McGauhey et al. (1963), Crippen and Pavelka (1970), Dugan and McGauhey (1974), and Myrup et al. (1979), who report very similar values. However, Marjanovic calculated direct runoff into Lake Tahoe from the 52 intervening zones, and this component is important with regard to nutrient and sediment discharge from these often urbanized areas.

	Flux ($10^6/m^3/y$)	Percent Contribution
Sources		
Stream runoff	468.0	56.6%
Precipitation	299.0	36.2%
Direct runoff	54.7	6.6%
Ground water	4.81	0.6%
Total	**826.51**	**100.0%**
Sinks		
Evaporation	508.0	61.1%
Truckee River outflow	315.0	37.9%
Diversions outside the basin	9.01	1.0%
Total	**832.01**	**100.0%**

This budget leaves only 5.5 x $10^6/m^3/y1$, or <1 percent unaccounted for. The data records used to prepare the table are characteristic of the period between the 1960s and approximately 1991 and are not representative of periods characterized by prolonged periods of extremely wet or dry conditions; however, the water budgets cited above include the period from 1901 to 1970. Diversions outside the basin consist of the water exported by sewage and diversion of 2.34 x $10^6/m^3/y$ from Echo Lake to the American River basin.

Thodal (1997) reported that a ground water contribution of 40,000 acre feet, or 32.4 x $10^6/m^3/y$, may be a good first approximation. However, uncertainty due to measurement and extrapolation are large enough to raise this estimate to >81 $10^6/m^3/y$ (Thodal 1997). While ground water represents a negligible portion of the overall water budget, the potentially high nutrient content of ground water inflows can have a significant impact on the productivity of the littoral zone of Lake Tahoe. Thodal further estimated that ground water discharge represents about 11 percent of the mean annual precipitation falling on drainage areas tributary to the lake and that about 34 percent of the mean annual precipitation could be returned to the atmosphere by sublimation from snowpacks, evaporation of precipitation prior to recharge, and ground water discharge by phreatophytes (plants that obtain water from the water table).

Most of the precipitation in the Lake Tahoe basin falls as snow between October and May and runs off as snowmelt in May and June (Marjanovic 1991; Shelton 1992). Because the lake area itself is a large percentage of the basin's area, a correspondingly large portion of the water (36.2 percent) enters the lake in direct precipitation as snow or rain.

Nearly all the streams in the Tahoe basin lie on bedrock, with the exception of the south shore area, and some small aquifers associated with the lower reaches of some streams. While Loeb (1987) found that the aquifers for the Ward Creek, Trout Creek, and Upper Truckee River watersheds were sloped toward the lake (implying a net flow into the lake), some recent studies in the Pope Marsh area of the south shore indicate that under the influence of water pumping and seasonal effects, the net flow in some areas may be from the lake into the near-shore water table (Greene 1998; Fogg 1999).

Long-term Climate Change

Lake Tahoe exhibits evidence of dramatic responses to climate change in the past (Lindström 1990) and will continue to do so in the future. One

likely mode of change involves the Tahoe basin's response to global warming and its effects on the regional water budget and sediment and nutrient dynamics. Shelton (1992) points out that in regions where snowmelt is a significant component of runoff, such as Lake Tahoe, shifts in the relative amounts of rain and snow and in the timing of snowmelt due to warmer temperatures may change runoff patterns.

Frontal weather systems from the Pacific Ocean deliver over 75 percent of the watershed's precipitation between November and March, much of it as snow (Shelton 1992). Topography plays an important role in the spatial distribution of precipitation and in determining whether the winter precipitation occurs as rain or snow. Lower elevations receive about 500 millimeters (mm) of annual precipitation, but the upper elevations on the west side of the watershed receive about 1,500 mm.

Though the global circulation models (GCMs) on which Shelton's predictions rest have improved since his original work (Shelton 1992), the fundamental conclusions remain the same—that global warming (or more generally, climate change) could profoundly change the magnitude, timing, and form of precipitation and hydraulic discharge in the Tahoe basin.

Shelton chose to deal with the uncertainties of the available GCM models by investigating cases of the temperature (T) increasing by 1, 2, or 3 °C in combinations with precipitation (P) changes of 0, +/-10, and +/-20 percent. From among these he found that the case of T + 1 °C, P + 20 percent increased annual runoff over the historic amount by 25 percent, while the case of T + 3 °C, P-20 percent decreased annual runoff by 33 percent, with the other cases falling in between.

However, keep in mind that predicted annual averages do not reflect the much larger seasonal changes predicted in this study; seasonal variations were generally much larger than changes in annual averages. For example, the historical runoff pattern for the Upper Truckee River peaks in May, followed by June and April, accounting for 59 percent of annual runoff. In the case of T + 3 °C, P-20 percent, the maximal runoff period was shifted to the January to March winter period and accounts for 62 percent of the annual runoff. Spring runoff is reduced by 76 percent compared to the historic record. Summer (June to September) declines to a meager 10 percent of the historical amount, and fall (October to December) is changed little.

The monthly estimates of runoff for the Upper Truckee River reveal the influence of the seasonal pattern of precipitation; a decrease in the proportion of winter precipitation that falls as snow, and an earlier and faster spring snowmelt. Changes in the volume of the snowpack and in the timing of snowmelt tend to accentuate the wet-dry climatic regime of the region. A serious consequence of these changes is a seasonal redistribution of runoff away from the spring months and toward the winter months. For instance, in the T + 3 °C, P-20 percent scenario, the change in peak flow is a three-month shift from May to March.

Climate change can have a significant effect on runoff in the Tahoe watershed because small changes in temperature and precipitation have an amplified effect on runoff. The overall impact of a warm, moist future climate would be to increase annual runoff by as much as 25 percent. The runoff regime would be modified modestly, with the major change being an increase in winter runoff. A warm, dry future climate in the region would reduce runoff by 33 percent. Peak runoff would occur three months earlier in the year, and four months each year, would experience increased runoff compared to current amounts. This change in regime results from an increase in the elevation of the snowline and a decrease in the winter snowpack.

The hydroclimatology of the Tahoe basin plays a significant role in maintaining the distinctive clarity and blue color of Lake Tahoe. Streamflow delivers sediments and nutrients that act as fertilizers for phytoplankton and attached algae in the lake (Goldman 1989). Sediment and phytoplankton in turn increase light scattering and absorption, reducing clarity and changing the color of the lake. Strong seasonal streamflow enhances the erosional ability of runoff and concentrates into a few months the stream's capacity to deliver sediments and nutrients to the lake.

Issue 2: Reduction of Sediment and Nutrient Loading to Lake Tahoe using Best Management Practices, Restoration, and Other Management Techniques

With contributions from Kyle Comanor, Charles R. Goldman, Steve Goldman, Scott H. Hackley, Alan C. Heyvaert, Shari Silverberg, Sherm Swanson, and John Warwick

What management/restoration approaches are currently being used in the Tahoe basin?

Most management and restoration activities focus on mitigating erosion potential and reducing sediment and nutrient discharge to Lake Tahoe. Soil and slope stabilization, water conveyance structures, infiltration systems, constructed wetlands, and sediment retention structures all are believed to function in this capacity (Fenske 1990). The objective in this issue is not to address each individual land use practice or BMP used in the Tahoe basin; as stated below, this is needed but beyond the scope of this assessment. Rather, in this section an initial framework from which future activities might proceed is established.

Examples of General Management/Restoration Approaches

Incised rivers provide a great challenge to implementing various restoration/improvement/ stabilization solutions. The following information is key to restoring natural stability and function to incised rivers (Rosgen 1997):

- Understand the cause of the incision (entrenchment);
- Analyze watershed conditions that may not only indicate cause but may provide the solution;
- Select the stable stream type associated with the landform/valley type;
- Understand the restoration objectives and make sure they are compatible with the natural stable morphology;
- Obtain data from reference reaches of the stable stream type to be emulated;
- Understand the evolutionary tendencies of rivers and recognize where the particular river is in relation to its potential end-point of equilibrium;
- Select restoration priorities that allow the stream to speed up the process of natural stability along the evolutionary sequence;
- Avoid working against the natural probable state of the river, or "patching in place;" and
- Integrate geomorphology, engineering, biology, and botany into the restoration solution.

Soil compaction during road construction and timber harvest reduces infiltration and enhances surface runoff. Increased surface runoff results in greater particle detachment and soil surface erosion. One way to alleviate soil compaction is to avoid operating heavy equipment when soils are wet; however, this alone is insufficient. Other practices include mitigating unnecessary or temporary roads and trails by tillage and constructing small-scale water retention levies to enhance infiltration, thereby reduce runoff and erosion. For timber thinning, such alternative techniques as helicopter or over-snow harvesting are often used.

Slopes from road cuts are often unstable and subject to mass failure. Wood or rock retaining walls, coupled with improved drainage, are used to facilitate slope stabilization. Channel bank erosion is relatively common in the basin. Management for stream restoration includes creating meanders to reduce flow velocities, reshaping the banks, removing debris, and revegetating newly exposed banks. Waterbars, culverts, and diversion ditches are used to slow water flow and to direct it into sediment retention basins or constructed wetlands.

Increased infiltration significantly decreases direct nutrient and sediment transport to streams. Trenches, dry wells, and infiltration basins are used to collect surface runoff and to divert it into the subsoil layers. This practice is quite effective in reducing surface runoff and sediment transport; however, the effectiveness in terms of reducing ground water nutrient transport is much less certain. Homeowners in the basin are required to construct retaining structures, such as timber walls, revegetation projects, and rock-lined infiltration trenches, along drip lines below eaves and other impervious surfaces. Homeowners are expected to

mitigate the potential for erosion, sediment transport, and deposition from their lots (Tahoe Regional Planning Agency 1999).

Santini-Burton Act

Another strategy to mitigate impacts from development has been that of public land acquisition. The Santini-Burton Act allows environmentally sensitive lands to be purchased or exchanged and then managed in the public interest. Land exchanges and purchases via the Santini-Burton Act have increased national forest land in the Tahoe basin to 158,000 acres. The United States Forest Service now owns and manages approximately 77 percent of the basin. Significant portions of the Tahoe basin also are owned by the states of California and Nevada. Special effort is made to acquire those lands in stream zones and wetlands or that are otherwise environmentally sensitive. Public ownership allows for the preservation of sensitive land areas for recreational use and for controlled management and restoration. Development is kept at a minimum, and lands are continuously monitored for potential impacts (enhancement or degradation) on discharge water quality. It is not surprising that the Forest Service conducts most of the basin-wide management and restoration activities, including watershed restoration and fire management. Fire hazard reduction is a rapidly growing concern and includes removing dead trees and developing defensible space at the urban/wildland interface (Sierra Nevada Ecosystem Project 1996).

Integrated Management Approach

Many state, federal, and local government agencies play vital roles in managing watersheds and in implementing restoration and other improvement projects. In addition to the Tahoe Regional Planning Agency, both Nevada and California have very active programs for land acquisition, planning, site improvement, and large-scale management. The California Tahoe Conservancy (CTC) exemplifies a well-integrated program whose goals include preserving environmentally sensitive lands through acquisition, repairing disturbed land through erosion control grants, restoring degraded wetlands and watershed areas, facilitating the transfer of development rights from more environmentally sensitive areas to ones that are less sensitive, managing acquired lands toward the purpose for which they were obtained, protecting, preserving, and enhancing wildlife and the habitats that sustain them, and enhancing public access and recreational opportunities (CTC 1997).

While it is beyond the scope of this assessment to provide a detailed accounting of all the environmental restoration and related projects that have been done in the Tahoe basin, a summary of CTC activities provides an illustrative example. According to CTC statistics, since its inception in 1984, it has authorized the expenditure, either directly or through grants, of more than $150 million in site improvements and acquisitions. These include acquiring various interests in over 5,450 parcels, totaling greater than 6,450 acres, and implementing over 325 improvement projects. CTC (1997) provided the following summary of activities in terms of dollars spent since 1984 (values are expressed in millions of dollars):

Program	Improve-ments	Acquisi-tions	Total
Acquisition of environmentally sensitive lands		$69.4	$69.4
Land coverage		$4.9	$4.9
Management program and planning		$7.0	$7.0
Erosion control grants	$27.1	$7.9	$35.0
Stream environment zone and watershed restoration	$4.7	$1.4	$6.1
Wildlife enhancement	$3.1	$1.7	$4.9
Public access and recreation	$6.6	$16.2	$22.9
Total	**$48.7**	**$101.9**	**$150.6 Million**

According to the CTC, these efforts have resulted in 71 soil erosion control projects, revegetation of 115 acres, restoration of 85 acres of disturbed wetlands and meadows, construction of 78 miles of roadside drainage facilities, mitigation credit for over 2,200 public and private projects and transfer of coverage and other credits for 220

residential and commercial projects, increased public access to over 1.5 miles of lake frontage, and restoration of 1.340 acres of wildlife habitat and 15.5 miles of inland stream habitat.

What types of runoff treatment and erosion control techniques have been used in the Tahoe basin?

Best Management Practices (BMPs) are techniques for protecting or improving water quality. These can include BMP installation on new projects or BMP retrofits. This latter group forms an important component of the restoration strategy. Certain BMPs are required by regulatory agencies as conditions for constructing new structures or for remodeling existing structures. Examples include infiltration requirements for runoff from impervious surfaces and requirements to vegetate bare areas with approved plants. Other BMPs are used on projects constructed by public agencies to mitigate impacts of past development. Examples include lining earthen ditches and gutters with concrete, rock, or vegetation, installing sediment traps and basins to remove sediment from runoff, and spreading runoff across natural or constructed wetlands to remove nutrients.

Most BMPs were developed based on physical principles and experience from other areas. There is a limited amount of monitoring data at Lake Tahoe that has been used to evaluate the effectiveness of BMPs. Agency staff and project designers make decisions daily concerning what projects to fund and how to design the improvements. These decision-makers need to know which measures are working or not working and why. If a measure is not working effectively, they need to know how to make it work better. The monitoring data that exists is not readily available to the decision-makers.

A large number of erosion control and other water quality improvement projects have been constructed in the Tahoe basin over the past 15 years. Much has been learned from the experience of designing and constructing these projects and from observing project performance in the field. This information has been used to improve the designs of subsequent projects. However, most of the information has been qualitative and based largely on occasional site inspections and observations. Quantitative research on BMP effectiveness, focused on the questions below, should yield valuable data both for enhancing the performance of existing projects and for improving the designs of future projects.

At the request of the California Department of Transportation (Caltrans), scientists conducted a literature that which identifies stormwater quality BMPs that could be implemented for highways in the Tahoe basin (Currier et al. 1998). Summaries included four BMP characteristics: engineering feasibility, pollutant removal efficiency, cost, and secondary environmental impacts. The document also notes characteristics of BMPs that are not well researched and prioritizes further areas of study. The literature for this review was obtained from a number of sources throughout California, including the Lahontan Regional Water Quality Control Board (LRWQCB), CTC, TRG, and TRPA. It was found that the LRWQCB maintained the largest collection of relevant material. BMP categories are organized on the basis of snow and ice control, source control, vegetated systems, infiltration and filtration, detention/sedimentation, and channel linings. Each is summarized below and focuses on those aspects directly related to sediment and nutrient loading to the lake via surface and ground water runoff. In the sections below, information from the University of California, Davis report is combined with written material from Steve Goldman of the CTC, which was presented to the Tahoe Water Quality Working Group for distribution at the Second Science Symposium held at Lake Tahoe on February 10 and 11, 1999.

Utilized BMP Techniques

Snow and Ice Control Management Practices—Four general categories were identified: substance application, mechanical removal, traffic control, and construction. The use of salt can have significant effects on roadside vegetation, which could affect erosion.

Sanding is an abrasive application and has been used for many years. The efficiency of sand is size dependent, with the best particle size between one and two millimeters. When traffic grinds this sand into smaller particles it can become suspended in urban runoff. The nutrient budget presented in

this assessment reported on the large amount of phosphorus entering Lake Tahoe via direct runoff. Highway and road runoff, which includes road sand, may be an important contributor. Furthermore, if sand is ground sufficiently fine its delivery to Lake Tahoe could directly affect water clarity. In the Tahoe basin, Caltrans used 35,706, 22,649, 24,137, 21,044, 19,420, 14,840, 22,678 and 16,759 tons of sand per year from 1988/1989 to 1995/1996.

Source Control Management Practices—Source control management practices are intended to minimize contamination in runoff before it is discharged to receiving waters. According to Currier et al. (1998), erosion prevention techniques are most widely used and appear to be the most cost-effective for highway maintenance. Once established, erosion prevention techniques typically require less maintenance than other BMPs. (Detailed information on feasibility was not found for most erosion controls.) Source control management practices were divided into those that work and those that have significant limitations for use in the Tahoe basin. Based on the review, the authors do not recommend the following systems for highway stormwater management: catch basins (sand traps), soil/water separators, porous pavement, and swirl concentrators. The first two have maintenance problems that result in high costs, but the nutrient removal characteristics of catch basins will be of interest because of the number already in place at Lake Tahoe. Catch basins have limited removal efficiency; approximately 40 to 75 percent removal of TSS, 15 to 30 percent of nitrogen, and only two to six percent removal of phosphorus (Lager et al. 1977). Removal efficiency will diminish with inadequate maintenance or increasing flows. The most likely area for further research is erosion control methodologies. While the cost of erosion controls are well known, the actual efficiencies and impacts on water in the Tahoe basin are not known (Currier et al. 1998).

Variability of climate, hydrology, soil type, topography, and maintenance in the Tahoe basin make outside research only marginally applicable. Research and monitoring should focus on the following: contaminant and runoff loading before and after BMP implementation, preventative capacity of the BMP, removal efficiency for loading, and project longevity. The BMPs considered to show demonstrated promise in the Tahoe basin include catch basins (limited application), maintenance practices, road reclamation, curbs, gutters and roadside channel stabilization, retaining walls, slope stabilization, stormwater diversions, and vegetative erosion control.

Vegetated Systems and Constructed Wetlands Practices—Vegetated systems, including wetlands and riparian zones, are recognized for their contribution to soil development, aeration and stabilization, shoreline protection, water treatment, erosion protection, ground water recharge, and many other aspects that contribute to a health ecosystem. In the Tahoe basin, stream environment zones (SEZs), described as wetlands or riparian zones, are recognized to provide an effective mechanism for nutrient and sediment removal from stormwater, for reduced flood peaks, and for increased retention time of surface flow (Currier et al. 1998). As a result, basin agencies not only encourage but require control measures for preserving and restoring SEZs. About 75 percent of the wetlands in urban areas at Lake Tahoe have been destroyed or altered, and TRPA has a goal of restoring 1,100 acres of these wetlands. Because of the natural treatment ability of wetlands and TRPA's goal, a major strategy of erosion control and water quality projects is to use wetlands for water quality treatment. The report concludes that "vegetated systems are effective in nutrient and suspended sediment removal; however, it is difficult to estimate the effectiveness level because the hydrology of the systems is not well understood. This limitation makes it difficult to predict the removal processes, efficiencies, and the relative roles of surface flow and subsurface flow." Because spring snowmelt dominates the seasonal hydrology in the Tahoe basin, water residence times for many vegetative (and mechanical) treatments is relatively short; this reduces treatment efficiency. Nutrient removal is further retarded by cold water and soil temperatures during the spring. Reuter and Goldman (1989a, b) provide examples of how hydrology and water residence time were factored

into estimates of a combined detention basin/wetland treatment system. Hydraulic loads were used in the calculation of N, P, and TSS removal from these two components as part of the Ski Run Water Quality Treatment Facility and the Tahoe City Urban Improvement Project. In both, urban flow first was routed through a detention basin then was discharged to a linear wetland. Total calculated nutrient removal from the Tahoe City project was projected at 37 percent for total-N and 30 percent for total-P.

Commonly applied vegetated systems as BMPs in the Tahoe basin include wetlands, wet ponds, and buffer zones/SEZ. Sufficient information is available to show a demonstrable promise for wetlands and buffer zones/SEZs. Including wet ponds, filter strips, and grass swales to this list rounds out the list of BMPs with potential promise for Caltrans facilities in the Tahoe basin (Currier et al. 1998). Wetland treatment systems involve spreading runoff across well-vegetated areas, such as meadows. Studies have shown that wetlands are highly effective at removing sediment and nutrients from runoff. Most of the studies have been conducted outside of the Lake Tahoe basin. The literature suggests that a five-day residence time in a wetland is needed for maximum nutrient removal. Little or no conclusive data exists on nutrient removal in high elevation conditions or by season (such as when plants are dormant). As mentioned continuously throughout this section, research and monitoring on effectiveness of these systems is largely lacking.

Infiltration Management Practices—Infiltration practices remove sediment and nutrients as stormwater percolates into underlying subsoil. Infiltration structures often are termed retention basins. There are four general categories of infiltration practices: infiltration trenches, infiltration basins, exfiltration trenches (infiltration trenches with perforated pipe underdrains), and drainage/dry wells (Currier et al. 1998). The drainage area for infiltration trenches should not exceed five acres, and the site slope should not exceed five percent. The depth from trench bottom to the water table is three to 10 feet. A typical infiltration trench has a length to width ratio of at least 5:1, with a retention time of 48 to 72 hours to optimize removal efficiencies. Infiltration basins impound incoming stormwater until it percolates through the basin floor. Depending on the percolation rates, these basins are applicable for catchment areas between one to 12 acres.

The LRWQCB and TRPA require that runoff from impervious surfaces be infiltrated on-site. The standard is 100 percent retention of the 20-year, one-hour storm (one inch of rain in one hour at Lake Tahoe). This requirement is based on the fact that a forested watershed has little surface runoff (less than one percent of precipitation). In an undisturbed forest, nearly all rain and snowmelt travels to streams, lakes, or the ground water through the soil (i.e., very slowly and not on the surface). When land is paved, compacted, or covered with buildings, more than 90 percent of the precipitation runs off. Because this runoff occurs rapidly, in high volumes, and on the surface, erosion potential downslope in the watershed is greatly increased. Of greatest concern, high runoff rates change streamflow patterns, which may destabilize channel banks or cause channel bed incision in the lower watershed. Once started, this channel adjustment process can continue for many years. The infiltration requirements are intended to maintain or restore the natural hydrologic pattern.

Infiltration systems are required for new developments or remodels (residential and commercial) and for public improvements. At present, only a small percentage of Tahoe basin development, public and private, has been retrofitted to this standard. Eventually, all development in the basin may be required to be retrofitted. Infiltration systems on both private and public lands need to be monitored to determine how effectively they are performing and whether the performance declines over time. Data on effectiveness of infiltration in the Tahoe basin are limited; indeed, additional research is needed to determine the performance of these BMPs in cold-climates nationwide. If used in the Tahoe basin in conjunction with highway runoff, pretreatment measures to remove road sand would be needed.

Additional research and monitoring is critically needed. On erosion control projects at present, the agencies require only the portion of the road right-of-way within the project area to infiltrate. Sediment basins typically are sized to retain the runoff from the right-of-way area only, although basins often receive runoff from private lands and from national forests or other public lands. Private portions of the watershed are assumed to be retrofitted with infiltration systems at a later date. The effects of these additional runoff sources on basin performance is not known; however, basin trap efficiency is closely related to basin inflow rates. If a basin receives more runoff than it can store, overflows will occur. The overflows may contain high concentrations of fine sediment because the trap efficiencies for small particles are likely to be low (see discussion under sediment basins). In addition, high flows cause turbulence and resuspension of particles that were trapped during smaller storms. Currier et al. (1998) concluded that of all the potential infiltration techniques, only the infiltration trenches and basins are commonly used at Tahoe with demonstrated promise, and this technique could be used for highway facilities.

Detention/Sedimentation Management Practices—Detention is the short-term storage of stormwater to reduce flooding and to improve water quality. Sedimentation is the process whereby particles settle out of the water and onto the bottom. Aquatic vegetation and bacteria in these ponds also act to remove soluble nutrients via biological uptake. Detention basins also are referred to as wet ponds. The two general categories of detention basins are wet detention ponds and dry detention ponds (Currier et al. 1998). Wet ponds have a permanent pool and a storage volume that receives runoff, detains it, then releases it at a known rate. Extended detention allows for maximum pollutant removal. Dry detention ponds are dry between storms and are designed to hold peak design flows.

The trapping efficiency of a sediment basin is a function of each of the following key factors:

- Particle size of sediment;
- Basin surface area relative to inflow rate;
- Inlet-to-outlet relationship;
- Length-to-width relationship;
- Length-to-depth relationship; and
- Vegetative cover in basin.

Most basins seem to be effective at trapping large particles (sands and gravels). Small basins generally are ineffective at trapping fine particles (silts and clays). Most basins that are constructed are small relative to the volume of inflows; i.e., they are too small to trap fine sediment. Nutrients are believed to be associated with smaller particles. In any case, small particles, particularly clay-sized particles, stay in suspension for long periods, making them available for discharge to the lake. Basins that trap only coarse particles therefore, may be ineffective at trapping much of the nutrient load in runoff. Small basins may trap a high percentage of the sediment load in small storms, only to lose it during large storms when sediment becomes resuspended by high flows. Vegetation may reduce the degree of resuspension. Sediment basins are sometimes intended to serve the dual purposes of runoff infiltration and sediment trapping (see discussion under Infiltration Systems). While basins can perform both functions, they may be ineffective at one or both of them unless properly designed. For example, sizing a basin based on storing the runoff volume for a 20-year, one-hour storm may not provide enough surface area for trapping fine sediment, since basin surface area rather than volume is critical for sediment trapping. Secondly, sediment that settles in a basin bottom may reduce infiltration rates.

Fenske (1990) provided a number of examples of wet pond application in the Tahoe basin that included a review of many erosion control practices at Lake Tahoe. The High Sierra Pond and Harvey's Pond on the southeastern Nevada side of the basin were constructed in 1982 and 1983, respectively. Both are two to three acres in size and both have had problems related to high ground water levels resulting from project drainage. Bank erosion problems result from a lack of established vegetation around the High Sierra Pond; abundant vegetation around Harvey's Pond enhances nutrient uptake. Other examples of applications in the Tahoe basin include the Douglas County Dump

Restoration Project (1986), the Lower Kingsbury basin (1985), Tahoma Sediment basin (1988), and Granlibakken Sediment basin. For the Tahoe area, Fenske (1990) reported removal efficiencies of 70 percent for TSS, 35 percent for TP, and 30 percent for TN.

Most sedimentation/detention projects in the Tahoe basin have not been continuously monitored since their inception. This type of limited long-term BMP monitoring precludes understanding of how these BMPs operate at Lake Tahoe. Both monitoring and maintenance are necessary to analyze performance within the framework of adaptive management. Wet detention ponds, extended dry detention ponds, multiple pond systems, sedimentation traps and sedimentation basins all show promise in the Tahoe basin. However, as commonly observed, more information is needed regarding optimal design for the Tahoe basin, effectiveness, and maintenance requirements.

Channel Linings

There are about 435 miles of city and county roads on the California side of the Tahoe basin. In Nevada, there are county roads, state highways, national forest roads, and private roads. Most of these roads have unprotected drainage ditches along or below them. In the past 15 years, more than 100 miles of roadside drainage and channel improvements have been constructed or funded. Most of these improvements consist of asphalt or concrete curbs and gutters, culverts, and rock-lined or vegetated ditches. Curbs and gutters prevent erosion along road shoulders but do not provide water quality treatment. Because water flowing in paved gutters and culverts speeds up and cannot percolate into the ground, increased erosion potential often exists downstream of these hard structures. Rock and vegetative linings are intended to slow water velocities, prevent erosion, and allow some infiltration. Lined channels can be scoured if not properly designed or installed. Rock-lined ditches sometimes have been designed to also serve as infiltration systems. On some projects, a deep section of rock has been specified for this purpose. It is generally believed that infiltration is minimal on steeper slopes and during high flows. There is little data on the performance of channel improvements.

Review of Selected Case Studies from the Tahoe Basin

This section does not attempt to review all the restoration, BMP, or management projects that have been conducted in the Tahoe basin. Many projects do not have associated monitoring/evaluation reports, and those that do are too numerous to include here; consequently, selected examples are presented.

The Lake Tahoe Basin Management Unit of the USDA Forest Service has produced an extensive series of water quality monitoring reports that evaluate specific restoration projects, BMPs, and other management implementation. The goal here is not to review all these documents but to highlight the findings of a selected few with emphasis on common observations, sampling/monitoring design, and conclusions.

South Zephyr Creek Water Quality Report

Between 1987 and 1989, the Zephyr Cove Resort underwent extensive BMP retrofit work under the Federal Facilities Compliance Program (Lowry et al. 1994). This work included redesigning and paving parking lot parcels, installing curb and gutter, restoring a one-acre parking lot to a meadow, and installing 1,200 feet of infiltration trench. In total, the project was intended to prevent highly erosive overland flow on exposed soil with subsequent transport to the stream. The impact of a horse stable operation near the stream also was evaluated during the monitoring. Each of four stations was sampled 10 to 15 times each year. During base-flow periods, sampling was monthly but increased to weekly during spring runoff. Only mean annual discharge and suspended sediment concentration showed a significant decreasing trend using the data available for 1985, 1988, 1989, 1990, and 1991. However, Lowry et al. (1994) point out that because parameters such as suspended sediment and total-P are associated with flow, making comparisons among the various water years is difficult; that is, drought conditions may have been the cause for the reduction in suspended sediment. The authors discussed the possibility that the

magnitude of improvement in water quality easily could have been masked by the even larger effect of the natural variation of precipitation and runoff on suspended sediment and other water quality constituents.

Water quality monitoring was also done in association with storms, when possible, and six such events were sampled between 1985 and 1990. In general, nutrient values did not increase dramatically over background levels during these events; however, an exception was a storm on August 18, 1985, when total-P was found to be 0.433 mg/L, or 24 times greater than the annual mean.

Griff Creek Erosion Control Project

Griff Creek was monitored in each of the nine years between 1985 and 1993. According to Lowry and Norman (1995), this monitoring was done to determine the effects of an erosion control project completed in 1984 designed to reduce erosion and sediment/nutrient loading to Griff Creek. This work was done as part of an effort to restore the original lower Griff Creek channel. Specifically, the objectives of the monitoring study were to determine if an in-stream sediment reduction basin could be effective in reducing concentrations of suspended sediment and nutrients in the creek and to determine the success of the streamside revegetation. These authors reported that the Griff Creek sediment retention basin was of limited use in long-term retention of sediment." The water quality monitoring data indicated that only during the first two years of operation did the retention basin reduce stream sediment. The maximum difference in flow-weighted annual mean concentration was 7 mg/L in 1986. After that time, there was no significant difference in suspended sediment above and below the basin, with only about a 2 mg/L difference. It was concluded that sediment retained in the basin during certain times of the year most likely was transported downstream as bedload during relatively high flows. As a result, downstream concentrations could exceed inflow concentrations as this material was flushed from the basin. Lowry and Norman noted that sediment trapped in the basin provides for less slowing of streamflow and therefore less trapping efficiency. Also, this BMP did not significantly reduce sediment during storms. A slight decline (not statistically significant) in nutrients was observed below the basin, which Lowry and Norman attributed to uptake by algae and other vegetation within and alongside the basin.

Vegetation colonization and growth along the stream and in the basin were very successful. The amount of vegetation in 1993 was reported to appear adequate to insure streambank stability during various flow conditions. The riparian species of willow and alder were particularly abundant.

Watson Creek Salvage Timber Sale

The Watson Creek, Carnelian Bay Creek, and Carnelian Canyon Creek watersheds were extensively logged between 1860 and the late 1960s. The most recent harvest activity, the Watson Creek Salvage Timber Sale, was implemented in 1990. The sale included 1,505 acres within these three watersheds. Approximately a third of the stand in the harvest or treated area was removed in a sanitation salvage operation. According to the LTBMU report, this operation included harvesting trees considered to be dead or dying and thinning overstocked stands. The operation was conducted by standard tractor logging techniques. Water quality monitoring was primarily limited to the Watson Creek watershed despite the fact that only five percent, or 80 acres, in the entire watershed was treated. This was largely because the intermittent nature of the flow in the drainage of the other two watersheds, which were more heavily treated (41 to 56 percent), prohibited an adequate upstream versus downstream sampling design. Samples were taken in 1990 (considered a preharvest year) and in the four subsequent years, 1991 to 1994.

Norman (1996c) concluded that "the results of this analysis indicates that timber sale activity appears to have had negligible effects on water quality." The application of this finding to other timber sale parcels was not discussed. Increases in nitrogen were observed in Watson Creek below the sale site, but this was observed in the 1990 pretreatment data set. The variability of the data was such that it was difficult to statistically detect upstream versus downstream differences; however, based on the available database there did not appear to be a large or consistent effect in sediment or

nutrient levels. The report concludes by stating that further monitoring is needed to better understand the effect of timber harvest activities on sediment and nutrient loading to tributaries.

Wasiu I and Wasiu II Timber Sale

This report evaluated the impacts of the Wasiu I and II timber sales on the water quality of Meeks Creek (Norman 1997b). These sales were implemented between 1989 and 1995. The purpose of this harvesting was to remove stands of mistletoe-infected lodgepole and decadent Jeffrey pine and white fir from the Meeks Creek meadow. Thirty to 100 percent of the stand within the harvest area was removed in a manner similar to that described above for the Watson Creek project. A hundred and sixty-four acres were harvested, which represents 13.7 percent of the nearly 1,200 acres in the subwatershed between the two monitoring stations.

The USDA Forest Service began monitoring the water of Meeks Creek in 1980. This provides an extensive preharvest database, something that is lacking in many of the BMP-type restoration projects in most watersheds nationwide. For the purpose of their analysis, LTBMU scientists considered the 1980 to 1986 database to represent pretreatment conditions and the 1990 to 1994 database to characterize conditions during harvest. Post-harvest was interrupted by a 100-acre burn in the project area in the fall of 1995.

Nonparametric statistics were used to determine if statistically significant changes in water quality were observed between the before and after timber sale data. These tests examine the differences in the median rather than the mean data points and are used when data is not normally distributed or when it cannot be appropriately transformed. The following conclusions appeared in this report:

- Suspended sediment did not increase during the sale years except in 1992. The raw data showed that during three weekly samplings in the spring, suspended sediment concentrations were much higher at the downstream site.
- The difference between the below versus the above harvest sites for turbidity increased from 0.0 Nephelometric Turbidity Units (NTU) before the sale to 0.085 NTU after the sale. This was significant at the 95 percent confidence level.
- Concentrations of nitrate were consistently higher at the upper site before and during the timber sale; however, the decrease between above and below was significantly reduced during the sale. Because harvesting was to the edge of Meeks Creek and most of the removed trees in this area were live, this decease in nitrate reduction could have been due to less biological uptake by riparian vegetation (Norman 1997b).
- Neither dissolved or total phosphorus increased during the timber sale.

The report clearly states that this analysis should not be the final word on the impacts of timber harvesting on water quality; however, the results are encouraging in that they do not show a major change. These conclusions are significant in that they are based on a robust, long-term data set. Norman recommends continued monitoring at future timber sales, whenever the following criteria can be met: above and below sites can be established on perennial streams, and a significant portion (25 percent) of the subwatershed between these two sites will be harvested, and at least three years of preproject data can be obtained. These criteria require careful planning of not only the monitoring programs but of the restoration and implementation activities.

An update of this study, which presents the results of monitoring through 1998, is being peer reviewed but will be available through the USDA Forest Service (Widegren 1999).

Pope Marsh Burn

Water and soil quality in Pope Marsh was monitored from 1995 to 1997 to evaluate the impacts of an 11-acre low-intensity controlled burn in September of 1995. The water quality monitoring was to determine concentrations and duration of nitrogen and phosphorus release to surface waters resulting from this burn.

Soil was monitored for nitrogen content

prior to snowfall in 1995, 1996, and 1997 (the 1995 sample was after the controlled burn) (Norman and Widegren 1998). Water quality samples were collected during the spring runoff period at three sites: upstream, below Highway 89, at the Tallac Lagoon inlet, and at the outlet of Pope Marsh below the burn site. According to Norman and Widegren (1998), soil chemistry indicated that ammonium-N concentrations increased by almost 15 times over background in the first year after the burn. Nitrate-N doubled two years after the burn. Both these soluble forms of nitrogen returned to background concentrations the following year.

Comparisons of spring runoff data from 1995 and 1996 did not exhibit a noticeable change in water quality associated with the burn; however, the authors did caution that this is a limited database and that more sampling is required. The report stated that "spring runoff data does indicate that sediment and turbidity levels decrease from the Highway 89 inlet to the outlet of Pope Marsh, whereas nutrient concentrations are consistently higher at the outlet, regardless of the effects of the burn." In general the results led Norman and Widegren (1998) to speculate that this portion of Pope Marsh may have exceeded its ability to filter nutrients. They noted that if this is true it could be due to the flow regime and urban influences on incoming nutrient levels; however, more specific analysis is desirable.

One-day intensive sampling at multiple sites indicated that in 1996 and 1997 nitrogen concentrations, as nitrate and TKN, were nearly double below the burn, compared to above the burn. In 1996 the USFS reported that concentrations fell to above burn levels at the marsh outlet, while in 1997 concentrations at the outlet were similar to those below the burn. It was unclear why nitrogen at the marsh outlet increased between 1996 and 1997; Norman and Widegren (1998) suggest it was due in some manner to the fact that the marsh outlet was blocked for almost all of 1997. Regardless, this work indicates that in Pope Marsh this burn many have contributed to nitrogen mobilization and transport. The authors acknowledge that this data set is too limited to yield unambiguous conclusions.

Douglas County Department of Public Works

In 1982, a number of erosion control structures were placed along Nevada State Highway 207 (Kingsbury Grade) to reduce sediment and nutrient transport to Edgewood Creek. Structures consisted of rock gabions, wooden retaining walls, rock lining on roadside ditches, curb and gutters and vegetative slope stabilization. Sediment retention basins were also built. The effect of this work on sediment and nutrient transport was monitored (Garcia 1988). Before construction and after construction monitoring lasted for approximately 12 months each.

Three sites in the Edgewood Creek watershed were used to examine the efficiency of erosion control structures (Garcia 1988). The first site was located in a relatively undisturbed area. Although there was one urban area, runoff first passed through a meadow before reaching the stream. The second site received urban runoff, and had several erosion control structures consisting of rock gabions (cages), retaining walls, rock linings of roadside ditches, curbs, gutters, and slope vegetation located throughout to control runoff from State Highway 207. Site 3 was downstream and received the total streamflow from sites 1 and 2. The stream water was studied between 1981 and 1983 and was tested for velocity, total sediment, total N, total P, and total iron. The erosion control structures were built in 1982, so it was possible to compare the streamflow characteristics before and after implementation. Site 1, the control, contained more sediment, which may have been the result of increased precipitation that year. At site 2, sediment concentrations were reduced significantly, from 24,000 to 410 mg/L. This is particularly significant because stream discharge increased due to greater precipitation. The sediment load at Site 3 also was reduced by a factor of about 10. Nitrogen concentrations did not change much at any site as a result of erosion control. Total P was unchanged at Site 1 but was significantly reduced at Site 2, presumably because of the reduction in sediment discharge. Despite the decrease in sediment

discharge, the total P concentration actually increased at Site 3. The reason is unclear, but it is possible that finer sediments that are more likely to contain mineral complexed-P were not retained.

California Tahoe Conservancy

The following examples are case studies of projects that have been constructed in the Tahoe basin, as written by Steve Goldman of the CTC. They also illustrate some typical problems and conditions and explain what kinds of monitoring are needed and why. The focus of these examples is wetland treatment, because this approach is a key element of the water quality improvement strategy for the basin.

Ski Run, Tahoe City, and Stateline Water Quality Improvement Projects

Key features of these projects include a centralized treatment approach with a two-stage system of constructed wetlands. A major water quality control strategy in the Tahoe basin is to collect and treat runoff from large urban areas in a centralized treatment facility, which uses constructed wetlands. This approach is generally used in association with community redevelopment projects. However, these larger centralized projects cannot necessarily be done to the exclusion of individual treatment BMPs on private parcels when they are needed. Three multimillion dollar projects recently have been constructed, which employ a two-stage treatment system for urban runoff (a 175-acre developed area between Highway 50 and Pioneer Trail near Wildwood Avenue in South Lake Tahoe, the Stateline area just west of Park Avenue and below Highway 50 in South Lake Tahoe, and the Tahoe City urban area above Highway 28 west of Grove Street). The first stage is a large basin designed to hold the runoff of a 20-year, one-hour storm from the surrounding area. The second stage is a constructed wetland designed to receive a controlled flow from the basin, thereby to remove sediment and nutrients. The concept is to collect and store the runoff so that it can be treated slowly over time because it is believed that high rates of nutrient removal will be achieved with trickling flows through wetlands.

The above projects were designed with controllable inlets and outlets and bypass systems, so that flows through wetlands can be adjusted. It is important to implement effective, long-term monitoring programs for these projects to determine how effective they are and to determine how they could be made more effective, particularly because this approach has a high construction cost and is being proposed to be implemented again on other sites. Monitoring program descriptions have been developed for each of these projects but have not yet been put in place. At the Tahoe City site, the basin and wetland have been constructed, but the drainage collection system to convey runoff from the urban area to the basin is expected to be completed within the next two to three years.

Pioneer Trail I Project

Key features of this project include enhanced meadow treatment as a moderate cost, one-stage treatment system. On many sites, existing wetlands or meadows provide opportunities to treat runoff. On the Pioneer Trail project, runoff from subdivisions along Pioneer Trail discharges into a disturbed meadow near the intersection of Highway 50 and Pioneer Trail in Meyers. The meadow was altered by human activities and had relatively poor vegetative cover at that time. The runoff had carved a ditch along the far side of the meadow. This project, which was constructed in 1989 and 1990, rerouted the runoff into the center of the meadow. Willow brush fences, willow wattling, and rock check dams were constructed to cause the water to spread laterally across the meadow.

This project was monitored from 1989 to 1991 (Reuter et al. 1990; Reuter and Goldman 1992). Data from this site during the first winter after construction showed up to a 50 percent drop in runoff volumes from the upper to the lower end of the meadow. While the mean sediment concentration and load dropped by 30 to 40 percent between the inflow and outflow, nutrient concentrations did not change significantly. This lack of change may have been due in part to the low density of vegetation in the meadow at the time of construction. During the initial part of the monitoring period, a rise in suspended sediment concentrations between inflow and outflow was observed. When the site was inspected, runoff was found to be escaping from near the middle of the meadow back toward the ditch on the periphery. As

water fell down the embankment into the ditch, scour was occurring, which explained the spike in sediment concentrations. After this short-circuiting was corrected, sediment concentrations in the meadow outflow returned to previous levels. This example illustrates the importance of evaluating BMP monitoring data, analyzing anomalies, and inspecting the site.

Monitoring at the Pioneer site ended after the first year due to a lack of funding. When the project was constructed and monitored, plant density on the treatment area was relatively sparse, with plants about three feet apart. In the nine years since construction, plant density throughout the meadow has increased substantially. Monitoring this site again would help to determine if the relationship between sediment and nutrient concentrations between the meadow inflow and outflow points has changed since the initial monitoring period. Because this is one of the oldest meadow treatment sites in the basin and was well monitored during the first year after construction, this monitoring would provide important information to validate the effectiveness of wetland treatment systems.

West Sierra Project

Features of this project include a small-scale wetland constructed in an excavated basin on a wet well-vegetated site, with a small surface area relative to inflow. The West Sierra basin is located along Sierra Boulevard at Chris Avenue in South Lake Tahoe. This basin receives runoff from Highway 50 and a portion of the Sierra Tract. It was constructed in 1989 and now contains a dense stand of sedges, rushes, and grasses in the basin bottom. Though this basin occupies three vacant lots, its surface area is small, relative to the inflow rate (i.e., residence times are not ideal for large storms). Because the basin is so well vegetated, it would be an excellent site to evaluate the ability of vegetation to enhance detention basin performance (e.g., by trapping fine sediment by mechanical filtering and preventing resuspension). If such basins are shown to be effective, they may offer an alternative to increasingly difficult land acquisitions needed to achieve design capacities.

Angora Project

The Angora project uses an existing meadow to treat runoff. Street runoff is routed into the meadow, and berms are used to spread flows. This project is being monitored by El Dorado County with a grant from the CTC. The USFS is assisting El Dorado County in monitoring the Angora project that began in 1998; the USFS began monitoring for an eventual upstream-downstream comparison in 1994.

What is the effect of large hydrologic events on BMP and restoration effectiveness?

Large hydrologic events, such as floods, present an obstacle to effective planning. Unfortunately, there is even less information available on the effects of extreme hydrologic events on BMPs than there is on general BMP effectiveness. There is no question that much more event-based data are needed to assist planners and decision-makers in setting their project priorities. Clearly, extreme events are beyond the design capacities of most BMP and restoration projects within the basin. They are important however, because such events disturb natural systems for long periods; hence, planners need to know and understand the hydrologic history of a subbasin before restoration goals can be adequately established. Evaluation teams are needed to assess damage to existing BMPs after large hydrologic events.

The Second Creek flood of 1967 produced approximately 75,000 tons of sediment in a single afternoon, which is more than the estimated combined annual average for First, Second, Wood, Third, and Incline Creeks (Glancy 1969). Often, current and historic land use and the effects of previous extreme events overlap. Glancy (1988) reported that the amount of available sediment in Second Creek increased after the flood but before stabilizing vegetation was reestablished. Landslides into the channel (but not out of the drainage) created a pool of available sediment with no vegetation to retard mobilization of the sediment after the

mudflow. Sediment yield (tons/mi^2) was larger for Second Creek than all the others (Glancy 1988) for the entire study (1970 to 1973). However, four years is probably too short a period for adequate recovery from the flood and mudflow event.

Other more indirect sources of information can be derived from BMP monitoring over periods that have included storms of above-average intensity. For example one large event in Incline Creek was found to produce more sediment and nutrient discharge than all other summer events combined in 1996 (Sullivan et al. 1998). Another documented example is the Apache Erosion Control Project (Robinson 1996). With five years of monitoring (WY 1991 to WY 1995), there were enough hydrologic events to separate normal rainfall from violent thunderstorms. The latter were found to result in tributary nutrient and sediment discharge concentrations that exceeded rainstorms by factors of 2 to 30. This significant departure from a typical average annual scenario indicates the potential for extreme thunderstorms such as that of the Second Creek flood to negate BMP and restoration project effectiveness.

Can the expected reduction in sediment and nutrient loading to Lake Tahoe assuming varying restoration and implementation scenarios be quantified?

Restoration activities monitoring has not been sufficient to quantify load reduction on a large-scale basis. The effectiveness of management strategies often depends on yearly precipitation and large storms. Time scale also is a factor. Erosion control structures in particular are expected to lose their effectiveness with time. For example, a well-monitored sediment retention basin on Griff Creek was found not to reduce sediment discharge after only two years of operation, nor was it effective during large storms (Lowry and Norman 1995). Unfortunately, sediment and nutrient loading is most severe during large storms when BMPs are generally not effective.

Adequate site-specific quantification of nutrient and sediment loading is problematic. Annual, seasonal, and even daily changes in tributary discharge make adequate measurement difficult to attain. Rates of vegetative growth and nutrient uptake, rain-on-snow events, soil conditions, and localized atmospheric deposition all are factors that enhance or reduce nutrient loading, and all are difficult if not impossible to predict. A loading reduction following channel stabilization in one particular watershed cannot be interpreted as being able to provide the same level of effectiveness in a different watershed.

Note that each watershed contains site-specific conditions that cause it to respond differently to given restoration activities. With proper monitoring and subsequent interpretation of data, however, it is possible to identify trends in the characteristic effectiveness of specific restoration projects. Sufficient monitoring over time on enough different sites throughout the basin, where the same or similar restoration activities have been implemented, can provide useful information on the potential for success or failure in a given situation. New and innovative techniques in particular need careful multiyear monitoring to allow for trend assessment. For instance, sediment loading may be reduced by 35 to 50 percent in the first year, but it then decreases about 10 to 15 percent in effectiveness each following year. Such reductions must take into account changes in streamflow and annual events. The effective lifetime of a sediment detention structure is a function of streamflow and precipitation. Trend analysis is then useful for predicting which restoration activities could be expected to exhibit a positive effect on nutrient and sediment load reduction and for how long.

Long-term BMP effectiveness monitoring is rare because it is very expensive. However, in the long run it would be much more cost-effective to determine how well BMPs work over time, before millions of dollars are invested in projects that may or may not meet their objectives (Sierra Nevada Ecosystem Project 1996).

How will prescribed burning affect sediment and nutrient reservoirs in the watershed and the system hydrology and ultimately the loading of these materials to Lake Tahoe?

The frequency and intensity of wildfires in the US has increased over the last two decades. Fire suppression efforts since European settlement may have delayed wildfires, but they cannot over the long term prevent them. Prior to 1900, low intensity burns characterized both ponderosa and Jeffrey pine

sites, which had average fire return intervals of 2.5 to 15 and 14 to 18 years, respectively (Dietrich 1980). After the early 1900s, the introduction of domestic livestock and fire suppression led to the establishment of numerous new trees in these ecosystems. Dense stands of young trees, lacking recurrent fires, readily built up high levels of fuels such that present-day fires are often catastrophic, killing virtually all trees in the fire zone (Mueggler 1976; Peet 1987).

Statistics on wildfire extent indicate a bimodal distribution reflecting first fire suppression between 1916 and the 1950s, when wildfire extent decreased from 0.4 to 1.5 million ha/yr to <0.3 million ha/yr, followed by an increase to approximately pre-1930s levels in the 1980s and early 1990s (Arno 1996). The latter increases are attributed to a combination of woody understory fuel buildup due to past fire suppression and to drought and insect attacks. If projections for drier and warmer climates in the southwestern US hold true, the extent and frequency of wildfires can be expected to increase in the future.

From a public safety perspective, the threat of catastrophic wildfire in semiarid ecosystems has increased dramatically over the last few decades, due to past fire suppression and consequent fuel buildups, a danger that may be exacerbated by climatic change. Revegetation of areas burned by wildfire presents significant problems for land managers. Furthermore, biogeochemical cycling in semiarid forest ecosystems will require shifting from solution fluxes, which dominate inputs and outputs in humid forests, to the more episodic flux of gaseous exports and N_2 fixation inputs, which tend to dominate fire-structured ecosystems. Prescribed fire almost certainly will be required to reduce the threat of wildfires.

As urban populations grow, they expand into forests and rangelands, and concern grows about the fire danger near the urban/wildland interface. Hence, forest managers are becoming increasingly concerned about higher fuel loads and fire hazard adjacent to areas of development. The use of prescribed fire as a management tool for reducing fuel and improving forest health is appealing. Public perception and understanding of prescribed burning, however, can limit its applicability. Overall assessment of prescribed fire as an effective BMP in the Tahoe basin cannot be adequately evaluated without a more complete understanding of the processes in their social and ecological context. Knowledge of the probable long-term results of prescribed fire for plant communities and the kinds of burning and revegetation techniques that will best achieve desired forest, rangeland, and environmental conditions is also needed. Understanding of vegetation dynamics, requires additional knowledge of how fire or a burning program affects nutrient storage and movement through the ecosystem; that is, the functional processes that underlie forest and rangeland conditions. Burning affects infiltration rates, nutrient content, and nutrient cycling.

Approximately 25 to 49 percent of standing trees in the Tahoe basin are dead or dying (Sierra Nevada Ecosystem Project 1996). Dead or dying trees are easy targets for disease and insect infestation and catastrophic wildfires. There are two forest fire scenarios. On the one hand, a high intensity wildfire would destroy all vegetation, filling the basin with smoke and potentially creating conditions conducive to excessive sediment and nutrient loading. On the other hand, a low intensity fire generally occurs over a smaller surface area with less heat. The duff layer remains intact, and soil water repellency following a low intensity burn reportedly has been minimal (Norman 1997a). The potential for site erosion following a fire depends on the initial erodibility of the soil, slope, precipitation characteristics, severity of fire, development of soil water repellency, and plant cover remaining following the burn (Pritchett and Fisher 1987). If a fire does not consume the entire surface organic horizon, the effects on infiltration and pore space are generally minimal. Hence, runoff, erosion, and sediment and nutrient transport presumably would be lessened. Through prescribed burning, the forest would seemingly reap the benefits of fire without having to endure the adverse ecological impacts of a catastrophic high intensity wildfire. An average of 500 acres per year have been burned by prescription in the past 10 years. Prescribed burns have taken place in Incline Village and on the southwest side of the lake (Rowntree 1998).

Effects on Nutrient Cycling and Transport

Post-fire revegetation is a severe problem in many cases. *Ceanothus velutinus* is a pioneer species that invades after site such disturbances as fire in the eastern Sierran forests. *Ceanothus* is especially adapted to fire; heat treatment followed by cold stratification is required for seed germination (Zavitkovski and Newton 1968; Youngberg and Wollum 1976). Seeds lying dormant in forest litter for many years are activated by fire and winter weather, resulting in prolific germination in areas of wildfire, clearcut, or slash burn. *Ceanothus* is shade-intolerant and therefore disappears with overstory canopy closure; however, *Ceanothus* presents serious competition for forest regeneration after fire, when it is not controlled by other means. For example, *Ceanothus* completely dominates areas of the former Donner Ridge fire (1960) near Truckee, California. Forest regeneration is virtually absent. On the other hand, in Little Valley, Nevada, patches of *Ceanothus* are common in a mosaic of 110-year-old Jeffrey pine forests. Furthermore, the benefits of *Ceanothus* on site fertility are clear; it replaces the N lost in fire and usually results in greater soil carbon and N contents than were there originally (Youngberg and Wollum 1976; Binkley et al. 1982; Johnson 1995). A prescribed low intensity burn in Pope Marsh resulted in increased nitrogen loading in spring runoff prior to the reestablishment of vegetation on the site (Norman 1997a). Monitoring was not continued following revegetation, but available nitrogen would be expected to decrease with enhanced plant uptake. The long-term effects of low intensity prescribed burning is under investigation (Miller and Johnson, unpublished).

The long-term deterioration of water quality in Lake Tahoe has been clearly documented, with a possible shift from N limitation to one of N and P co-limitation or P limitation over the last few decades as N inputs to the Lake have increased (Goldman et al. 1993). This deterioration is thought to be due to increasing nutrient loading from development, atmospheric deposition, and possibly N-fixation by riparian mountain alder (Coats et al. 1976; Leonard et al. 1979; Byron and Goldman 1989). Thus, the effects of fire (wild or prescribed) on N and P transport to the lake are of considerable concern. One study thus far has reported that P concentration in runoff was the same from an unburned forest as from an area where prescribed burning had taken place (Rowntree 1998). Rowntree (1998) also found that nutrient availability was affected by other factors after a burn, such as calcium, which formed a Ca-P complex that would be biologically unavailable for algal uptake.

Fire also can have a longer-range and more indirect effect on Lake Tahoe because of dry deposition of particulates from smoke (Goldman et al. 1990). Although smoke has been observed to increase algal blooms (Goldman et al. 1990), why this occurs is unclear. Studies that address the specific composition of forest fire smoke are needed. It may be that different varieties of trees produce different constituents in the smoke, or that burning at different times of the year would have dissimilar effects. This may be especially true for nitrogen, which is held in the vegetation and soil in greater amounts at different times of the year (Rowntree 1998). Nitrogen is volatilized at temperatures exceeding 200 °C (White et al. 1973), and 85 percent of the soil organic matter is lost at temperatures between 200 °C and 300 °C. Prescribed fires, however, usually remove less than half of the surface organic layers (Pritchett and Fisher 1987). These immediate losses in N can be regained as the site is re-vegetated. Nitrogen-fixing vegetation such as *Ceanothus* thrives on burn sites but can serve as a source of excess leachable N (Johnson 1995).

Are the available data from demonstration projects and other monitoring activities in the basin adequate for management decisions at the watershed scale? What are the concerns associated with managing restoration at both the project and watershed scales?

For environmental sustainability and restoration practices to be most effective, the efficacy of available BMPs should be known before they are implemented. Unfortunately, complete monitoring data for BMP application in the Tahoe

basin are largely lacking. Previous site-specific activities provide a starting point for generating a BMP effectiveness database, but efforts to incorporate BMP analysis at the watershed level are just beginning.

Sources for currently available data are varied. The USFS has produced a number of project reports that include project monitoring information, as previously described. The private sector often produces similar reports, although these are not as readily available to planners/managers who were not associated with the original project effort. The LTIMP program routinely collects and distributes surface and subsurface water quantity and quality data for Lake Tahoe. While these data are generated basin-wide, they are intended to measure nutrient and sediment loading in some of the basin's major tributaries and not to evaluate BMP effectiveness. The TRPA also collects and reports water quality data relative to established environmental threshold values (Hill 1994); but again, these data are not necessarily related to BMP evaluation.

The types of BMP demonstration projects studied to date are varied and include erosion control (Hoffman 1991; Robinson 1996), ground water (Duell 1987), timber sales (Norman 1996b), an analysis of land use and tributary water quality (Byron and Goldman 1989), and stream restoration (HydroScience 1997; Inter-Fluve and Services 1996). These individual studies can provide some useful information to planners and managers about effective sampling design and site-specific concerns but do not allow for techniques to be implemented basin-wide with high certainty of success. Even monitoring efforts with similar goals (e.g., erosion control effectiveness) can be incomparable if different techniques or measurements are employed. Basin-wide integration, or even effective integration over a single sub-basin, has yet to be proven successful.

To facilitate comparison among the various demonstration and monitoring projects, only those reports prepared by the same agency were evaluated. Thus, issues of different field and data analysis techniques can be largely avoided.

The USFS has conducted several monitoring projects related to BMP effectiveness (Hoffman 1990, 1991, 1986; Norman 1996a, 1996b. 1996c, 1997a, 1997b). While it appears that many erosion control projects have been somewhat effective in reducing sediment loads, some have been unsuccessful. For example, several projects on Blackwood Creek failed to reduce either sediment or nutrient loading. Undiminished levels of sediment and nutrients were attributed, in part, to historical activities (Lowry et al. 1994). However, there is also evidence that the reduction of sediment load is short-lived. A sediment retention basin in the Griff Creek basin was found to reduce sediment load over a two-year period, after which the sediment leaving the structure was equal to that entering (Lowry and Norman 1995). Furthermore, erosion control projects have provided little evidence supporting a consistent trend with regard to nutrient loading. Indeed, Robinson (1996) provides data illustrating considerable variability in nutrient loads downstream from erosion control projects.

Data from another management practice, controlled burning, have demonstrated increased nitrogen discharge from burn sites immediately following burning (Norman 1997a). The increase in loading continued until vegetation had reestablished. Although this was a short-term and controllable process (BMP), the effect must be explicitly considered when evaluating total nutrient loading to adjacent tributaries and the Lake itself.

Establishing SEZs is another BMP currently applied within the Tahoe basin. While there are other well-established benefits, SEZs can exhibit a major effect on nutrient transport processes. Restored floodplains allow suspended sediment to settle out of suspension before entering the lake and can reduce total sediment and nutrient load. Several specific projects (HydroScience 1997; Inter-Fluve and Services 1996) also have been successful in creating long-term habitat stability. However, the effectiveness in terms of nutrient loading is unknown. The geomorphic properties of natural SEZs are developed over time and are influenced by watershed level, if not basin-wide ecosystem interaction. Attempts at channel restoration, without a clear understanding of how the total ecosystem interacts, ultimately may result in project failure and be expensive to both the environment and the

economy. Because there is no existing presettlement database from which to work, projects that seek to restore channel morphology to presettlement status are certainly problematic. SEZ projects, more than others, must be considered at the watershed level of cause/effect interaction.

The most significant finding from a review of the literature is that none of the projects effectively reduced existing loads to below TRPA threshold level specifications. When stream water quality was above the specified threshold prior to project implementation, it remained so even when the project was effective in reducing total sediment and/or nutrient loading. In addition to site-specific evaluation, BMP effectiveness also should be evaluated at the watershed scale. This is clearly the case for fluvial processes. It is possible that sediment loading to the lake may be reduced by projects implemented outside the actual areas of proposed disturbance. When TRPA thresholds are exceeded upstream of developed areas, control projects have to mitigate local disturbance and the natural or background upstream water quality. Only combined scale assessment (including land use history) will ultimately determine what levels of BMP effectiveness are truly possible.

The 63 watersheds within the Tahoe basin are subject to different stages of land development and contain different geomorphology, soils, precipitation, and vegetation. Such diverse areas may behave quite differently when disturbed or restored. To be most successful, restoration needs to be tailored to specific watershed conditions.

Because there are so many variables affecting watershed sensitivity, different watersheds may need to be managed separately. As part of the Forest Service's Watershed Improvement Plan Series, each watershed under examination was examined to provide information on soils, vegetation, land use, channel stability, erosion hazards, and water quality. Suggestions for channel restoration, erosion abatement, and land use management were included. Updates of this program are essential to identify what kinds of problems are most easily addressed. Once a workable solution is found for a given type of problem, it may or may not be feasible to use it basin-wide. The more that is known about a specific watershed, the more feasible it will be to restore it into its previous or desired condition. Comprehensive monitoring of the effects of restoration in any given watershed is a critical step before restoration is attempted elsewhere in the basin.

The aforementioned issues of watershed variability not withstanding, there might be real value in establishing one or more demonstration watersheds. These demonstration watersheds could serve as models for how to, or how not to, design, implement, and monitor BMPs to achieve positive results at the watershed scale. While specific results might still vary among watersheds, the process of designing, implementing, and monitoring would be more robust.

What are the primary characteristics of a potential project that should be used to rank its priority (e.g., distance from the lake, proximity to roadway, land slope, soil erodibility, and hydrologic connectedness to other disturbed areas)?

The highest priority projects should be those that will have the most significant beneficial impact on discharge water quality and, consequently, lake clarity. The role of the Lake Clarity Model, in development, is significant in this regard. Relatively easy cheap projects include revegetation, trail maintenance, and channel stabilization. If done properly, these projects have a good chance of immediately reducing sediment and nutrient transport and deposition. Erosion control projects are generally high priority for reducing sediment transport and discharging particulate P sources. Sources of accelerated erosion within a watershed are usually apparent. System roads often have gullies or spurs from excessive erosion. The LTBMU's Watershed Improvement Plans provide a list of erosivity problems for each watershed. The most serious problems identified occurred on system roads, recreational trails, streambanks, and drainages and were due to off highway vehicle use. Projects near streams are important because stream zones are more likely to increase nutrient and sediment loading with disturbance. Restoration of wetlands is equally

important because of the potential for both enhanced nutrient and sediment removal.

TRPA rates building suitability of residential parcels by the Individual Parcel Evaluation System (IPES). Sites with high scores are considered to have low impacts on watershed processes and therefore are suitable for development. In order of most to least critical, the classification evaluates erosion potential, runoff potential, ease of access, SEZ proximity, condition of watershed, revegetation ability, need for water quality improvements, and distance from lake. Disturbed parcels with very low scores should be a priority for remediation (Tahoe Regional Planning Agency 1999).

It is important to differentiate between feasible projects and those that are infeasible because of cost or inherent nature. For instance, Blackwood Creek has steep slopes with rock outcrops. These slopes would not be good candidates for revegetation, but the watershed might well benefit from measures to reduce the runoff velocity (USDA Forest Service 1989b). Erosion control projects at Blackwood Creek reportedly have been unsuccessful due to naturally high levels of sediment discharge from the adjacent slopes (Lowry et al. 1994). The target level for restoration should be based on what is reasonably expected and on the monitoring and evaluation of similar projects elsewhere. Restoration in the Tahoe basin should be focused on cost-effective simple solutions and should be based on the possibility that a severe hydrologic event could destroy constructed improvements.

Because the lake responds to nutrient or sediment loading regardless of the watershed of origination, those projects that have the shortest delivery time (time of transport) to Lake Tahoe should be the focus. As presented in the discussion of the nutrient budget, direct runoff from the urbanized areas around Lake Tahoe appear to be significant contributors of phosphorus. Projects located more upland in the watershed may generate pollutants that are trapped or otherwise removed as flow proceeds downslope. These would not be identified as priority projects. Projects that directly discharge to the lake or its tributaries should be attended to first.

In any new attempt to prioritize restoration projects in the basin, previous restoration efforts should not be ignored. For example, in 1986 the CTC entered into an agreement with the Tahoe Resource Conservation District (RCD) and the USDA Soil Conservation Service (now NRCS) to produce an evaluation report of 95 proposed projects (Sletten 1992). A similar approach was used to rank 22 projects in Nevada in 1988. Similarly, a priority list of erosion control projects was developed as part of the original 1978 TRPA 208 Plan and the 1980 State Water Resources Control Board Lake Tahoe Basin Water Quality Plan.

The evaluation scoring system proposed by Sletten and others ("Tahoe Basin Capital Improvement Program—Evaluation of Proposed Erosion Control Projects") considered six aspects: sediment reduction in terms of pounds per dollar, watershed condition (referenced from TRPA Code, IPES Program), public or private benefit, distance from SEZ, distance from project to Lake Tahoe, and average flow of major stream within project watershed. Sediment reduction was determined as the difference between calculated "before" and "after" erosion rates from each parcel. Before rates were obtained from the SCS Universal Soil Loss Equation, or the empirical estimate for concentration flow erosion (Sletten 1992). BMP effectiveness values were used to estimate the reduction in sediment loss.

As discussed elsewhere in this section, restoration activities should be considered on a number of levels, including effectiveness at the project scale (i.e., removal capacity) and the watershed scale (i.e., overall contribution of a project to reduce nutrient and sediment loading). It was beyond the scope of this document to assess whether individual projects in multiple watersheds is preferable to focusing a major restoration effort in a single watershed; to the extent that unpercolated flow from an upstream project increases erosion downstream, the latter may be more effective. This is an issue that must be addressed further in any consideration of project priority.

What are the implications for future monitoring?

Specific BMP effectiveness in the Tahoe basin is largely unknown due to the overall lack of

comprehensive monitoring data and the absence of a thorough and well-integrated review and evaluation of all existing data. The aggregate effect of previously implemented BMPs is also unknown. It may be that the BMPs installed to date have not been as effective as hoped or more likely, that the number of implemented BMPs has not been sufficient to stem the magnitude of sediment and nutrient loading, in which case a much larger effort would be required. Given the estimates that nutrient retention times in Lake Tahoe are on the order of decades (Jassby et al. 1995), lake clarity responds not only to annual loading but to historical loading as well. This condition underscores the need for predictive modeling of lake response based on management scenarios.

BMP effectiveness can be studied over a much shorter time frame if there is a clear understanding of the various nutrient pools, how they cycle biologically, and the pathways by which nutrients are transported into tributaries and to the lake. Unfortunately, critical information along this continuum also is lacking in the basin. The nutrient pools and transport mechanisms can be reasonably expected to vary by subbasin, yet this is precisely the type of site-specific information necessary for planners to direct and prioritize BMPs.

The lack of comprehensive and unambiguous data on historic BMP implementation presents another barrier to a clear understanding of their effectiveness. For example, a historic record for type of BMP applied, specific location, dates of operation, and success/failure evaluation does not exist except for a few more recent projects. Without such information, stream measurements of nutrient and sediment discharge (for example) provide little insight as to the effects of a given BMP.

The series of monitoring reports issued by the LTBMU for the many and diverse projects they oversee represent a very valuable resource for the scientific community. Not only do they provide a good database for runoff water quality, they represent excellent "point-in-time" sampling, which can be used in comparisons as the projects mature. Quite often, an individual project does not come of age for a number of years. In these cases, early and routine monitoring is quite useful.

These and the other reviewed reports also bring out a number of important issues regarding the design and implementation of BMP monitoring and adaptive management.

First, unambiguous conclusions regarding the effectiveness of these projects were not always possible. The lack of long-term monitoring data typically prohibits conclusive findings. Not only do many BMPs take years to reach peak effectiveness, the imposition of hydraulic variability during a short monitoring period adds significant complications to the evaluation efforts.

Second, many BMP evaluation studies at Lake Tahoe lack reference or control sites. For example, the need for multiyear data on preproject conditions is rarely in hand before a project is started. An example where this was clearly not an issue was the Wasiu Timber Sale Project, which capitalized on a 10- to 15-year database from routine LTBMU monitoring in Meeks Creek. All things being equal, confidence in the results when this type of supporting database is available will be much higher. Because of the complex landscape in the Tahoe basin and the location of urbanized pockets of land, it is also difficult to find adequate upstream control sites.

Third, limited budgets and staff time constrain the sampling design to a point where only the most general of speculations are possible. This is not uncommon in the Tahoe basin nor in many other watersheds throughout the country. For all BMP efforts, the existing data show that well-designed and fully funded projects are needed to obtain usable conclusions. Unless the effect is dramatic, evaluating projects with limited data will yield limited conclusions.

We strongly recommended that monitoring of BMPs *not* be viewed as the sole responsibility of the implementing agency; rather, the conclusions that result are of significance to successfully restoring Lake Tahoe and must be approached from a multi-agency and interdisciplinary perspective.

Existing BMP evaluation studies show that complete water chemistry monitoring is not always feasible nor desirable, depending on the questions

being asked. Photographic evidence and visual surveys may be sufficient. This is especially so for revegetation and certain erosion control projects and forms the basis for additional monitoring being considered by the USFS (Hazelhurst 1999).

Finally, most of the reviewed projects clearly show that source control should be considered the preferred option for reducing sediment and nutrient loading.

The process of identifying management issues and research needs for the Lake Tahoe basin related to BMPs and restoration has been an ongoing process. Basin agencies, university scientists, and other interested parties began to formalize this during the initial Lake Tahoe Science Symposium held in October 1998. The Research and Monitoring Subcommittee of the Lake Tahoe Basin Water Quality Group reviewed the proceedings from this symposium and assisted in developing a list of water quality-related research needs and analysis questions.

Reducing sediment and nutrient loading to Lake Tahoe is expected to be an iterative effort developed through future symposia and by basin groups collaborating with stakeholders. Some of the issues are addressed in this assessment, but many others remain to be answered. This represents a major step toward the integration of not only science and management but also toward all interested parties planning cooperatively. The success of restoration and adaptive management in the Tahoe basin depends on this type of cooperative effort.

Issue 3: Ecology, Biology and Biogeochemistry of Lake Tahoe, with Emphasis on Water Clarity

With contributions from Charles R. Goldman, Alan D. Jassby, Alan C. Heyvaert, Scott H. Hackley, Brant C. Allen, Debbie A. Hunter, Robert C. Richards, and Ted J. Swift

What has been the long-term trend for algal growth in Lake Tahoe? What are the major factors regulating the phytoplankton primary productivity?

Primary productivity is a measure of growth rate by plants. In Lake Tahoe, primary productivity is dominated by phytoplankton, the free-floating microscopic algae that inhabit the water column. The growth of attached algae (periphyton) and submersed higher aquatic plants (macrophytes) is also of concern and is discussed below. The trophic status or productivity of lakes has long been of interest, not only to water quality scientists but to water suppliers and the public at large. When uncontrolled, cultural eutrophication marks the growth of excessive quantities of algae and other aquatic plant material, loss of dissolved oxygen, loss of clarity, dominance of unwanted biota, and other characteristics that significantly interfere with a lake's beneficial uses. In many waterbodies, the unchecked addition of nutrients has resulted in an increase in fertility. Typically, it is the loading of nitrogen and phosphorus that leads to cultural eutrophication. Lake Tahoe is characterized by phytoplankton populations that are very sensitive to any increase in nutrient loading (Goldman 1990).

According to Goldman, "primary production provides the best single integration of the biological, physical, and chemical factors at work in a lake." Viewed in this manner, changes in a lake's primary productivity are almost always linked to changes in the surrounding watershed. Again, Goldman (1990) observed that since development in the Tahoe basin began to escalate in the late 1950s, phytoplankton productivity and the human population density have risen with striking similarity. Human activities that have led to the increased loading of nutrients and sediment from either the watershed or airshed are linked to the decline of water quality at Lake Tahoe.

Nationally, and specifically at Lake Tahoe, considerable sums of money have been spent to reduce nutrient inputs by controlling wastewater discharge, agricultural drainage, and, most recently, nonpoint source runoff. Once classified as severely lacking in plant nutrients (ultra-oligotrophic), Lake Tahoe has been moving away from its unique pristine nature for many decades. The pioneering work of Dr. Charles R. Goldman and his colleagues at the University of California, Davis, has been instrumental in identifying the onset of cultural eutrophication in Lake Tahoe in the late-1960s and early-1970s, in documenting the long-term trend, in relating nutrient loading to increases in algal growth

rate, and in identifying sources of nutrients to the lake. Phytoplankton primary productivity, along with its relationship to lake clarity, has been fundamental to most water quality management policies in the Tahoe basin, including the exportation of sewage and the need for watershed restoration. The water quality thresholds established by TRPA include a standard for annual mean phytoplankton primary productivity of 52 g $C/m^2/yr$. This reflects levels measured from 1967 to 1971. Neither this initial value or the interim target of 145 g $C/m^2/yr$ for Water Year 1995 are being met.

The first measurements of phytoplankton growth in Lake Tahoe were carried out in 1959. At that time, the annual rate was slightly less than 40 g $C/m^2/yr$ and typical of an ultra-oligotrophic status. For years prior to 1959, average annual primary productivity was reconstructed from an analysis of deep lake sediment cores. Heyvaert (1998) concluded that the baseline predisturbance (prior to 1850) primary productivity was 28 g $C/m^2/yr$. Interestingly, his calculations for the period from 1900 to 1970, a time between the effects of the Comstock logging era and the onset of urbanization, was identical to the baseline at 29 g $C/m^2/yr$. Both these values were only 25 to 30 percent less than the earliest measurements in 1959. As discussed below, the virtual recovery to baseline conditions following the extensive timbering activities during the Comstock Era provides evidence that Lake Tahoe can recover from watershed disturbance.

The annual primary productivity of Lake Tahoe has more than quadrupled since 1959 with recent measurements exceeding 160 g $C/m^2/yr$ (Figure 4-20). Annual estimates are based on measurements taken at 13 individual depths (0 to 105 m) on approximately 35 dates throughout the entire year. Goldman (1988, 1992) reported that although there is some year-to-year variation, a second order polynomial fit to the productivity data shows a highly significant trend ($p<0.001$). This trend continues to increase at a rate of approximately five to six percent per year. While the primary productivity values for successive years might decline, only twice has this decline occurred for two consecutive years, 1975 to 1977 and 1980 to 1982. The largest single-year increases were found in 1983 (28 g $C/m^2/yr$ or 32 percent), 1989 (30 g $C/m^2/yr$ or 25 percent), and 1993 (33 g $C/m^2/yr$ or 22 percent). Curiously, the magnitude of these three large annual increases was very similar to baseline conditions during the early part of the 20th century. This highlights the impact that nutrient loading has had on Lake Tahoe. As noted by Goldman (1988) for the 1983 increase, the 1989 and 1993 increases also occurred when total lake mixing was accompanied by heavy precipitation and runoff. As discussed below, the fundamental reason for the long-term trend in phytoplankton growth is accumulation of nitrogen and phosphorus from both watershed runoff and atmospheric deposition.

Causes of Eutrophication in Lake Tahoe

The causes of long-term increase in primary productivity in Lake Tahoe are attributable to increased nutrient loading acting in concert with the lake's long retention time and efficient recycling of nutrients (Goldman 1988). Bioassays of Lake Tahoe water have linked nutrient additions to stimulated algal growth. Many factors contribute to nutrient loading at Lake Tahoe, such as land disturbance, urbanization, increase in impervious surfaces, erosion, atmospheric deposition, fertilizer application, ground water, and loss of such natural filters as wetlands and riparian corridors.

An early study by Paerl (1973) provided the first evidence that much of the bioavailable particulate organic matter in Lake Tahoe is decomposed before settling to the bottom. Using scanning electron microscopy, he observed that at shallower depths (20 m) there was a close association between bacterial and fungal cells and detrital or decomposing organic material, much of which is presumed to be phytoplankton. At deeper depths (75 m) microbial growth on these particles was much reduced. Between 150 and 400 m there was little change to the structure of the microbial association with detritus. At these depths there was little microbial attachment. Paerl concluded that detritus settling on the bottom of Lake Tahoe appeared to be unreactive because it was attacked by only a small amount of bacteria.

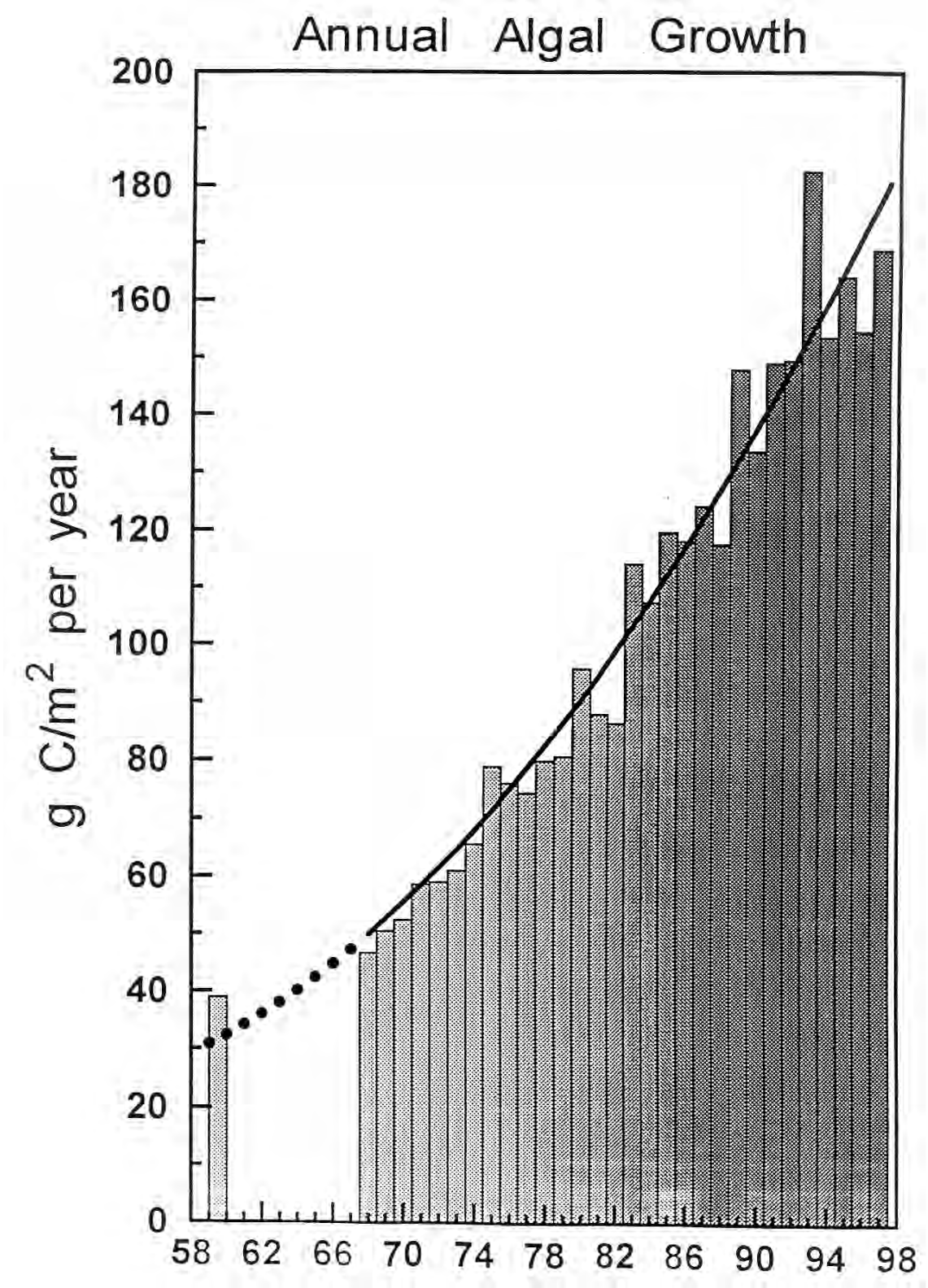


Figure 4-20—Long-term trend of increasing algal growth rate in Lake Tahoe.

Given the continual and increased loading of nutrients to the lake, plus the effective recycling of a large portion of the bioavailable fraction contained in phytoplankton and other organic matter, the accumulation of nutrients in Lake Tahoe is likely. This steady accumulation is believed to have led to the observed long-term increase in primary productivity. The increases in primary productivity initially were fueled by atmospheric deposition of nitrogen (Jassby et al. 1994); however, with the increased sensitivity of algal response to phosphorus, the most appropriate courses of action are careful management of development and land use, restoration of existing erosion problems, purchases of sensitive lands, and treatment of urban surface flow .

Interannual Fluctuations in Primary Productivity: Meteorological Forcing

Goldman et al. (1989) provided an explanation for the year-to-year variability seen around the long-term trend. These authors reported a close relationship between maximal spring mixing depth and the interannual variability seen around the long-term trend. Vertical mixing is known to be critical in maintaining a lake's productivity level. Goldman et al. found that "our data indicate that the intensity of vertical mixing not only maintains a characteristic trophic state, or level of production, but also, through year-to-year variability in maximum mixing depth, is tightly linked to interannual fluctuations about this level." Since 1973, deep-mixed years (turnover >400 m) include 1973 to 1975, 1983, 1985, 1989, 1993, possibly 1997, and 1998. During other years, the lake mixes from between 100 m to 300 m, with a median value of approximately 200 m.

Goldman et al. (1989) developed a model of depth of mixing versus primary productivity after first statistically "pre-whitening" the data to remove the upward trend. This de-trending removes autocorrelations in the data (Goldman 1990). The results were significant ($p<0.05$). Depth of mixing, when used as the single predictor, accounts for 53 percent of the interannual variability (Figure 4-21).

Annual primary productivity in Lake Tahoe did not exhibit anomalous behavior during El Niño years. That is, phytoplankton growth rate during these years was typically within ± 1 standard error of the regression describing the long-term trend. Furthermore, the depth of mixing appeared best correlated with March precipitation ($p<0.05$). According to Goldman et al., the significance of these findings is that when the water column at Lake Tahoe is near a condition where the temperature is uniform from top to bottom (around March), a single intense storm can cause a complete mix. With regard to lake mixing during a rather narrow window of time (about a month), the impact of El Niño years (whether wet or dry) are typically felt over a period of many months.

The stimulation of primary productivity by spring mixing is related to the return of regenerated nutrients from deep waters to the euphotic zone. For example, prior to mixing, deep-water nitrate can reach a concentration of from 20 up to >35 μg N/L . This is in contrast to summer euphotic concentrations of 1 to 2 μg N/L, reduced as a direct result of algal uptake. To appreciate the magnitude of internal loading of nutrients from the aphotic (receiving insufficient light for plant growth) and deeper waters in Lake Tahoe to the euphotic zone during mixing, internal loading can range from between one and two orders of magnitude (10 to 100 times) higher than the combined external loading from watershed runoff and atmospheric deposition (Byron and Goldman 1986). Clearly, in light of the long resident times for nitrogen and phosphorus in Lake Tahoe, the progressive accumulation of nutrients in the lake can remain available to fuel algal growth for many years.

Finally, other studies have shown that algal cells in the deep waters of Lake Tahoe are viable and capable of photosynthesis once reintroduced into the euphotic (receiving sufficient light to support percent growth) zone. This raises the possibility that spring mixing events also inoculate the surface water with phytoplankton (Tilzer et al. 1977; Vincent 1978; Goldman and Jassby 1990).

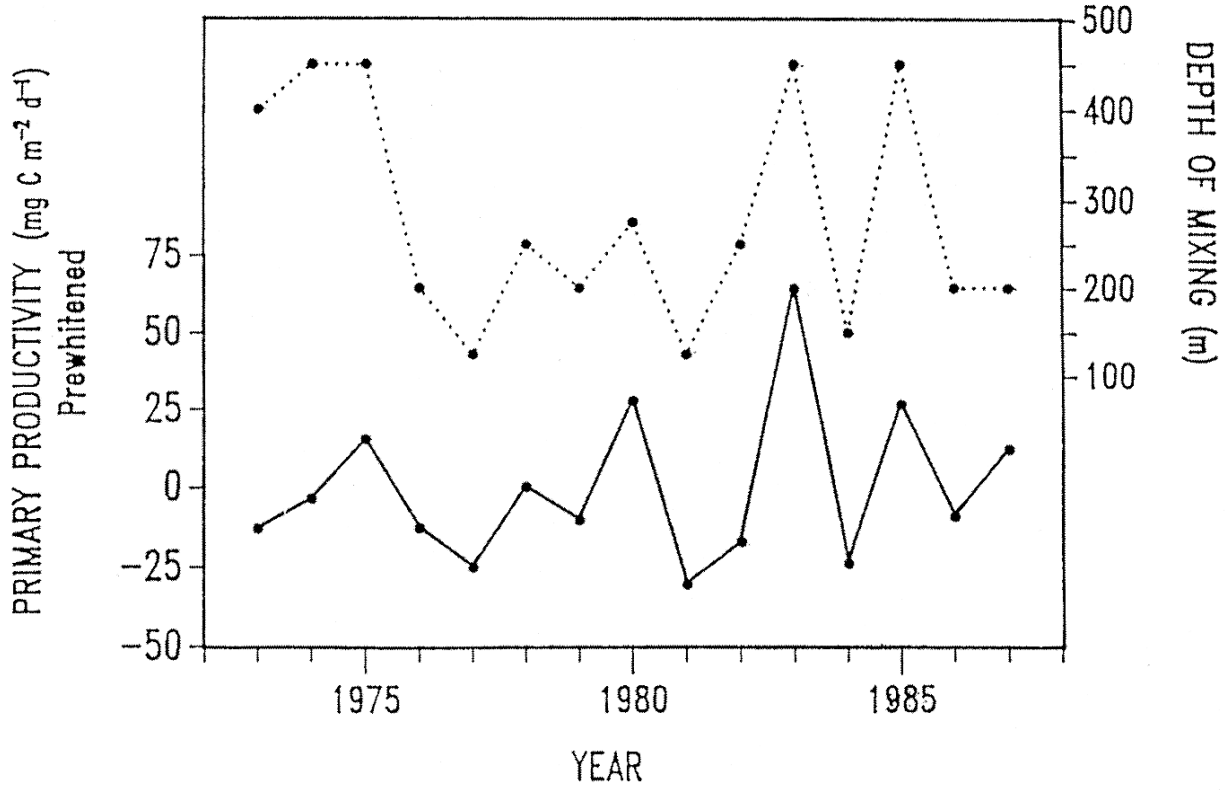


Figure 4-21—Depth of mixing in the winter-spring exerts a significant influence on the year-to-year variability in primary productivity (from Goldman et al. 1989).

Seasonality, Cycles, and Irregular Fluctuations in Primary Productivity

Jassby et al. (1992) have described a number of mechanisms underlying variability in the productivity record. The material presented in this section is taken from that publication.

Seasonality—The basic time-series of monthly primary productivity exhibits strong seasonality in addition to the significant upward trend. The standard deviation of the monthly values is proportional to the annual mean, thus the difference between the seasonal maximum and minimum also has increased. Jassby et al. (1992) extracted a typical seasonal cycle from the mean monthly primary productivity series, which was statistically adjusted to account for the dominating upward trend (Figure 4-22). Seasonality at Lake Tahoe also has been discussed in several other publications (e.g., Goldman and de Amezaga 1975; Goldman 1981). The seasonal pattern is marked by a monthly median peak in July and a minimum in January. Median primary productivity increases between January and May, remaining relatively uniform between May and August. This seasonal pattern follows the annual solar cycle with a lag of one month. Seasonality on the whole was subdued, with less than a factor of two difference between the highest and lowest median monthly values. The mechanisms driving seasonality are primarily physical and apparently are not related to trophic cascade or food web dynamics (Jassby et al. 1992). Little feedback occurs from the sparse mesozooplankton populations (Elser et al. 1990), and the seasonal nature of primary productivity is regulated primarily by the interaction of the solar cycle with lake stratification. The role of bacterial and microbial grazers is unstudied in Lake Tahoe, and Jassby et al. note that a different view of the role of grazing may emerge as information on the microbial loop becomes available.

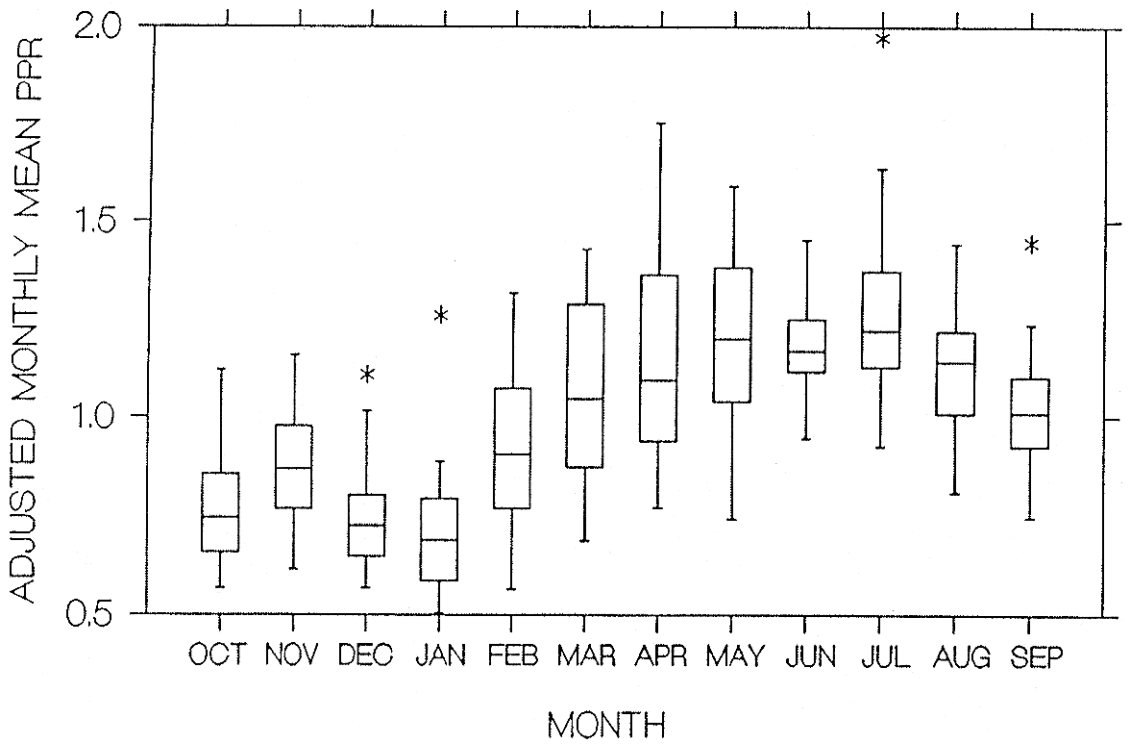


Figure 4-22—Seasonal pattern for month mean primary productivity in Lake Tahoe using historical database (from Jassby et al. 1992).

Cycles—Jassby et al. (1992) also uncovered the existence of a three-year cycle in primary productivity using more sophisticated tools of data analysis such as Principle Components Analysis (PCA) and spectral analysis (Figure 4-23). The reason for this cycle was not established; however, the authors considered several mechanisms. No cycles of similar period were apparent in meteorological conditions at Lake Tahoe. Solar radiation and water temperature did not show patterns greater than one year in length.

Regular oscillations can arise from the interactions of phytoplankton species and their limiting nutrients. Data on individual phytoplankton species are not sufficiently detailed at this time to look for multiyear cycles in the numbers or biomass of individual taxa.

Cyclical patterns in primary production can be generated by oscillations at higher trophic levels, for example, grazers with a three-year generation time. While the reported lack of significant grazing control by zooplankton on phytoplankton at Lake Tahoe discourages this as an explanation, the opossum shrimp (*Mysis relicta*) has been hypothesized to play a significant role in the downward transport of nutrients during their daily vertical migrations between the surface and bottom waters (Rybock 1978; Marjanovic 1989). According to estimates given in Jassby et al. (1992), *Mysis* can ingest nitrogen on the order of all of the available N in the euphotic zone. Because a significant portion of ingested material is excreted at depth, *Mysis* could clearly influence nutrient availability and primary productivity. With a generation time of two to three years (Levitan 1999) *Mysis* might be a likely explanation of the three-year cycle in primary productivity. However, no statistically significant cycle could be discerned from the *Mysis* density series obtained from vertically towing the water column. Jassby et al. suggest that these complete vertical tows do not distinguish between migrating and nonmigrating animals, resolution of this awaits further study.

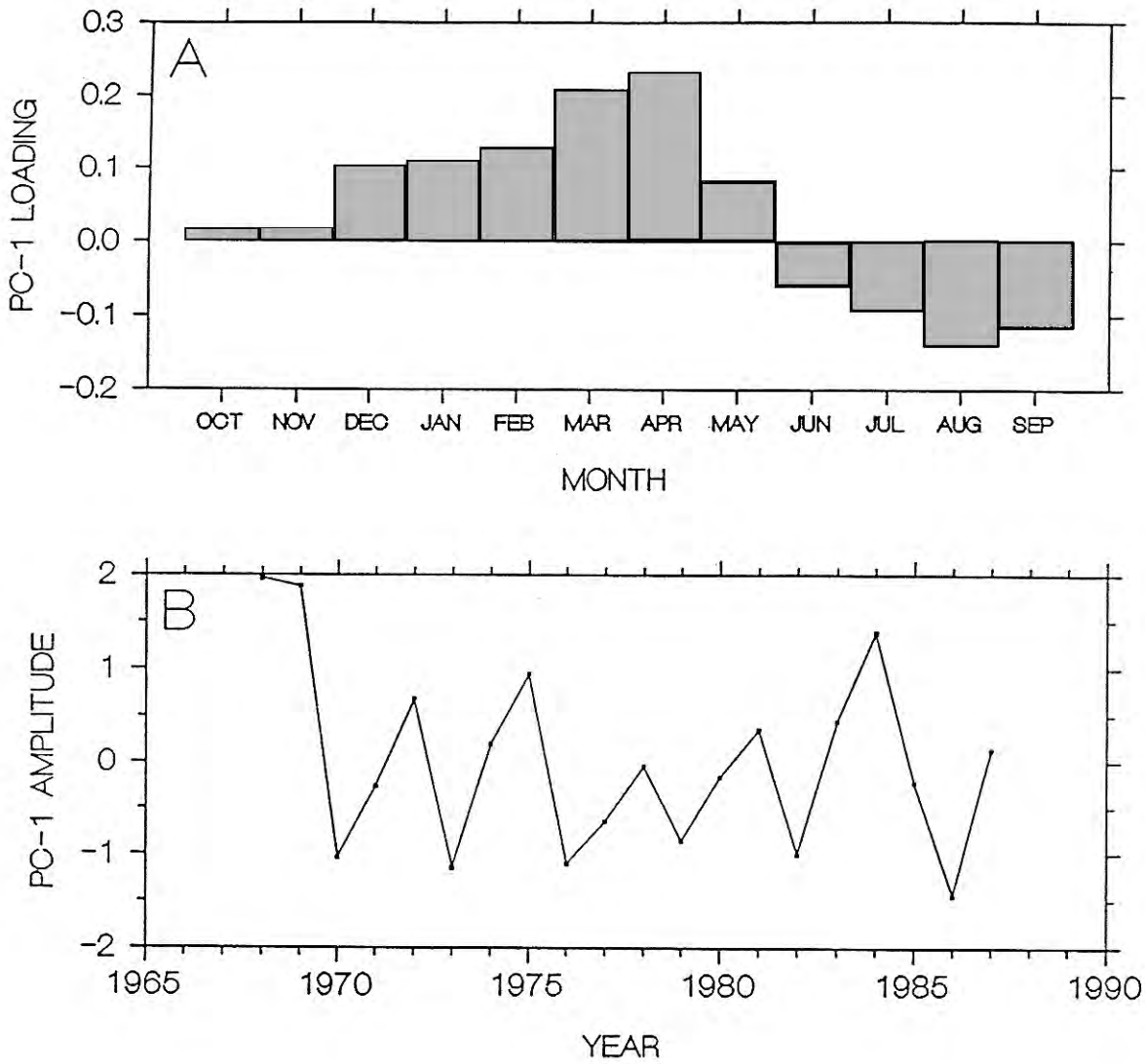


Figure 4-23—Principle components analysis of long-term primary productivity data indicating a consistent three-year cycle (from Jassby et al. 1992).

Irregular Fluctuations—This includes variability that does not belong to the categories discussed above. For example, the 1985 Wheeler fire in the Los Padres National Forest in southern California had a marked stimulatory effect on Lake Tahoe primary productivity in July of that year (see below). While the contribution of these isolated events is not necessarily important to the variability of the long-term record, they can have significant impacts on the timing and magnitude of primary productivity during that year. As discussed below, if forest fires become a more frequent feature in the Tahoe basin, they cease to be isolated events and need to be factored into considerations of the long-term trend in phytoplankton growth.

A second category of irregular fluctuations includes annual phenomena with irregular magnitudes. As discussed above (Goldman 1988; Goldman et al. 1989; Goldman and Jassby 1990), the depth of spring mixing falls into this category.

Forest Fires, Atmospheric Deposition, and Primary Productivity

The effect of forest fires on lakes in the western United States is not well known. Even those few studies that have been done elsewhere suggest

that the response of lakes to increased runoff can be mixed. Fires also can modify the light climate through smoke production and can contribute products of combustion to the atmospheric deposition on lake surfaces. Goldman et al. (1990) directly documented this phenomenon at Lake Tahoe, providing further documentation for the link between atmospheric pollution and its effect on Lake Tahoe water quality and primary productivity. The discussion below is based on that study.

On July 1, 1985, the largest fire in the US occurred in the Los Padres National Forest in southern California, burning nearly 50,000 hectares of brush. Smoke from this fire clouded the southern part of the state and traveled in a dense plume northward to the Tahoe basin. Air quality at Lake Tahoe was visibly affected by this smoke, suggesting a possible impact on Tahoe's unproductive waters. Visibility decreased by July 3, and the entire basin was covered in smoke by July 11. At that time, surface irradiance declined by a factor of two, and photosynthetically active radiation penetrating into the lake was reduced even further due to the settling of ash particles into the water.

The effect of this event was a large increase in primary productivity. Algal growth increased by more than a factor of three with a rise in the depth of the mixed layer peak from 10 to 15 m to 5 m (Figure 4-24). A second and deeper peak in productivity, which is typically found below the thermocline at a depth of 50 to 70 m disappeared at this time. Since Secchi disk clarity is measured only within the upper 20 to 30 meters, any change in the distribution of primary productivity could affect clarity. While a release from photoinhibition in the surface waters could explain the change in the vertical distribution of primary productivity, Goldman et al. reported that it does not account for the dramatic increase in photosynthesis. Similarly, because phytoplankton biomass did not change appreciably during this period, Goldman et al. (1990) concluded that "productivity increases during the fire thus are due to a true stimulation of photosynthetic activity and (do) not reflect only changes in biomass or a reduction in light inhibition."

Experimental evidence suggests that nutrients contributed by dry fallout during the fire were the likely cause of the observed increase in primary productivity. Using algal bioassay procedures, the authors found a stimulation in primary productivity when atmospheric filtrate from the July fire was added to Lake Tahoe water. This stimulation was similar to that resulting from the addition of phosphorus and nitrogen; that is, photosynthesis was approximately 140 percent of the control (Figure 4-25). Previous bioassays using fallout from atmospheric deposition showed no stimulation in the absence of forest and brush fires. Observations of Lake Tahoe water using microscopic techniques revealed the presence of numerous small particles on the order of 10 μm in size, presumably deposited during the fire. Leaching of nutrients from these particles was suggested but direct tests were not made.

The impact of the fire also was evaluated in the context of the long-term primary productivity record for Lake Tahoe. This analysis clearly showed that the high values in 1985 were anomalous for the month of July. While not as pronounced, there was some indication of an effect on annual productivity. As mentioned above, the effect of fires on the long-term trend of increasing productivity has been trivial; however, increased fire frequency is likely to have an effect.

Recent but limited data suggest that coniferous forest fires in the vicinity of Lake Tahoe may be much less fertilizing than the 1985 brush fire (Goldman 1999). Even though atmospheric deposition did stimulate phytoplankton response, there was no significant difference between deposition collected during smoke and smoke-free periods.

What is the long-term trend for water clarity in Lake Tahoe and how is clarity affected by phytoplankton and suspended mineral sediment?

Optical clarity is important in making judgments about water quality. Indeed, it was the combination of increasing primary productivity and decreasing clarity that documented the onset of cultural eutrophication in Lake Tahoe (Goldman and de Amezaga 1975; Goldman 1981, 1988, 1999). Much of the public concern regarding priority issues

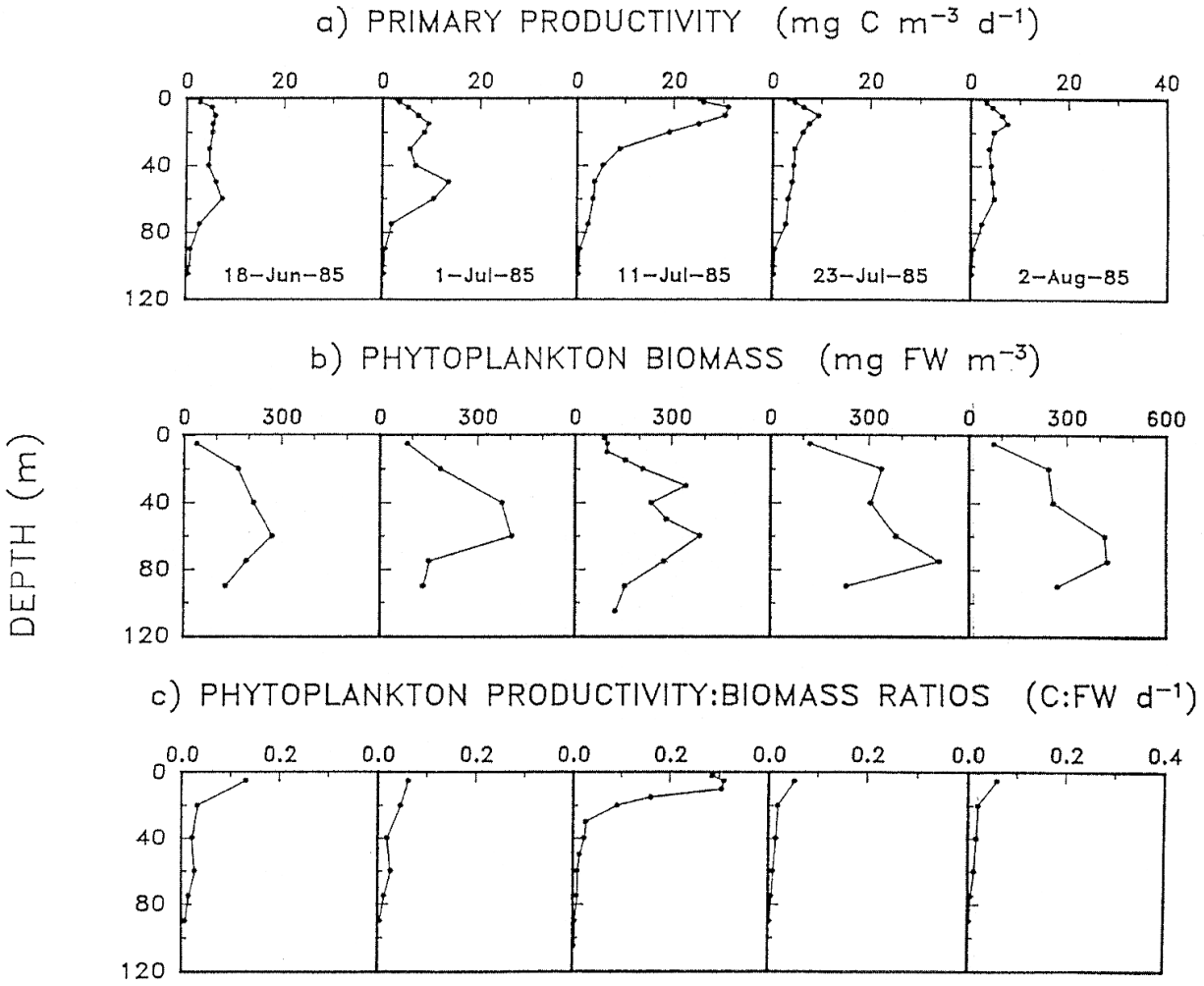


Figure 4-24—Effect of fire in Los Padres National Forest in southern California on primary productivity in Lake Tahoe. Notice change in the bimodal profile on July 11, when the effect was greatest (from Goldman et al. 1990).

at Lake Tahoe focuses on lake clarity. In a survey taken by Senator Barbara Boxer in September 1997, lake clarity was identified as the number one concern by over a third of the respondents and was 68 percent higher than the runner-up. The public is very aware of the long-term decline in clarity and this topic is frequently discussed in public forums and in the local and regional newspapers. TRPA also has established a water quality threshold for clarity. The adopted standard is that average Secchi depth, December to March, shall not be less than 33.4 m. Currently this standard is not being attained.

Water clarity is an excellent indicator of lake response in Lake Tahoe and has been measured using a Secchi disk since 1968. Not only have the historic Secchi data provided water quality scientists with an important understanding of lake function and response, they embody the issue of changing water quality at Lake Tahoe in an easily understood fashion. The importance of this database and that for primary productivity is recognized by resource policy-makers, environmental scientists, the judiciary (Garcia 1984), and the public.

Le Conte (1883) was the first to measure the clarity of Lake Tahoe with a Secchi disk. In

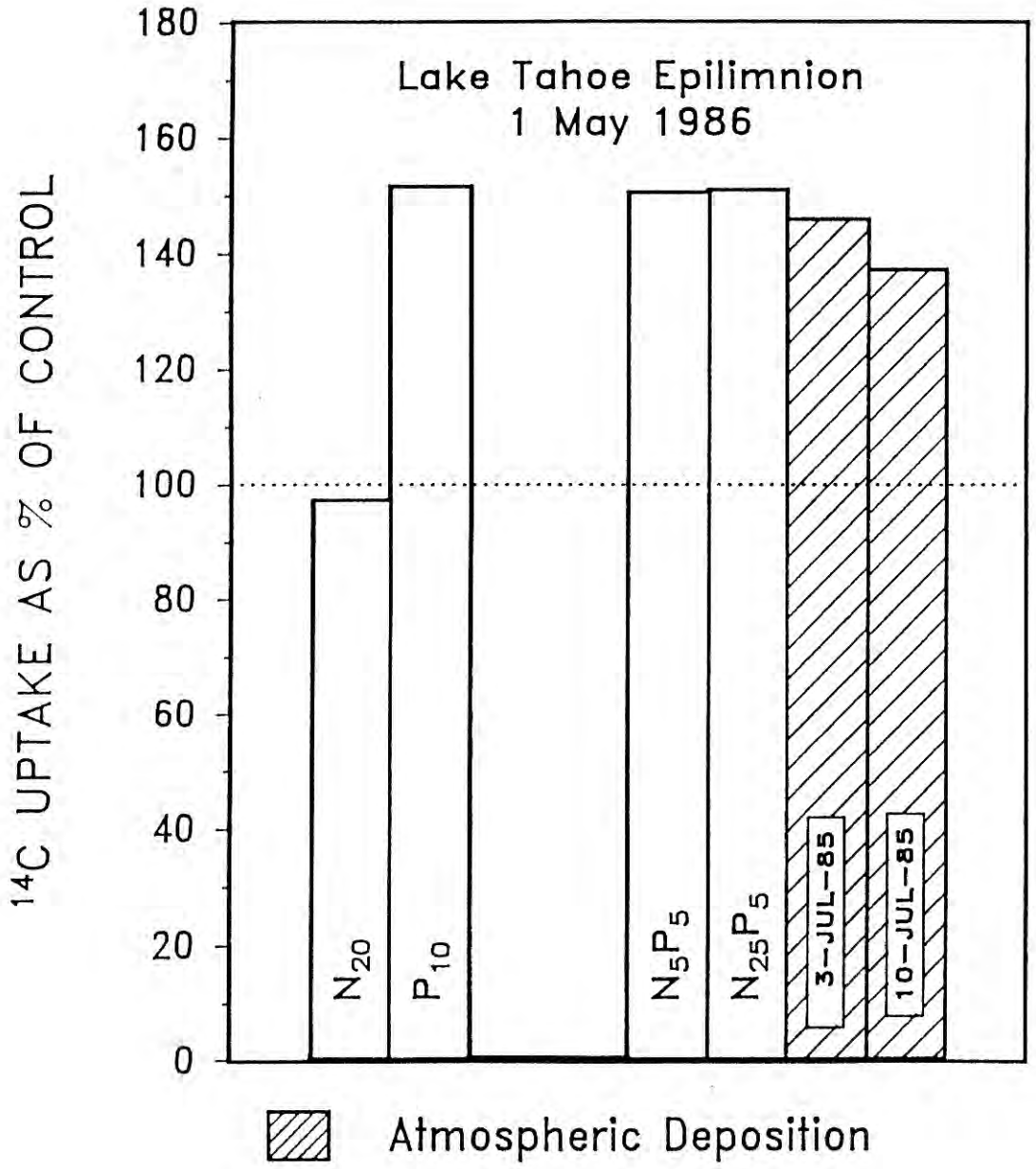


Figure 4-25—Leached nutrients from dry fallout during the Los Padres fire stimulate primary productivity in algal bioassay experiments (from Goldman et al. 1990).

September 1873 he recorded a value of 33 m using a 24-cm plate; today, a 20-cm disk is used. Secchi depth measurements ranged from 24 to 32 m in 1959 and 33 to 36 m in 1960. During these initial years, measures were too infrequent to calculate an annual average. Goldman (1988) summarized the Secchi depth data through 1986 in his key paper on early eutrophication in Lake Tahoe. The 30-year database for annual average Secchi depth is shown in Figure 4-26. As observed for primary productivity, a highly significant ($p<0.001$) long-term trend in lake clarity can be seen despite interannual variability. Individual single measurements of Secchi depth in Lake Tahoe over the period of record have ranged from as great as 43 m during an upwelling event on February 8, 1968, to as low as only 8.5 m on June 1, 1983, during a wet El Niño year. The lowest recorded measurements are associated with years of

deep lake mixing and high surface runoff. The lake water appeared green when the 8-m value was measured. This provides strong evidence that the lake has the capacity to reach these unwanted conditions and underscores the urgent need for restoration efforts. As part of the material prepared for the 1997 Presidential Forum, Goldman and Reuter (1997a, 1997b, 1997c) stressed that if the decline in lake clarity continues over the next 30 years at the same rate it has over the past 30 years (approximately 0.25 m per year) the resulting transparency will be on the order of 12 to 13 m. A change of this magnitude has already occurred in the polluted regions of Russia's Lake Baikal (Goldman et al. 1996).

An important lesson contained in the long-term Secchi depth data is that by using a short-term subset of even five to six years, it is easily possible to arrive at a totally incorrect interpretation of the data (Goldman 1993). Goldman has effectively emphasized on numerous occasions that had the measured water clarity data from Lake Tahoe during the period 1973 through 1977 or 1983 through 1988 been used to assess the status of Lake Tahoe, one would have erroneously concluded that lake clarity was actually improving (Figure 4-27). For 1983 to 1988, the increase in clarity was even statistically significant ($p<0.01$). In fact, the apparent improvement was only short-term due to the combination of reduced runoff and an absence of deep mixing during drought years. Well-planned and executed, consistent and long-term monitoring insured that these types of interpretation mistakes were not made at Lake Tahoe. This conclusion is not only important for lake clarity but must be considered during discussions of design and implementation for future monitoring at Lake Tahoe.

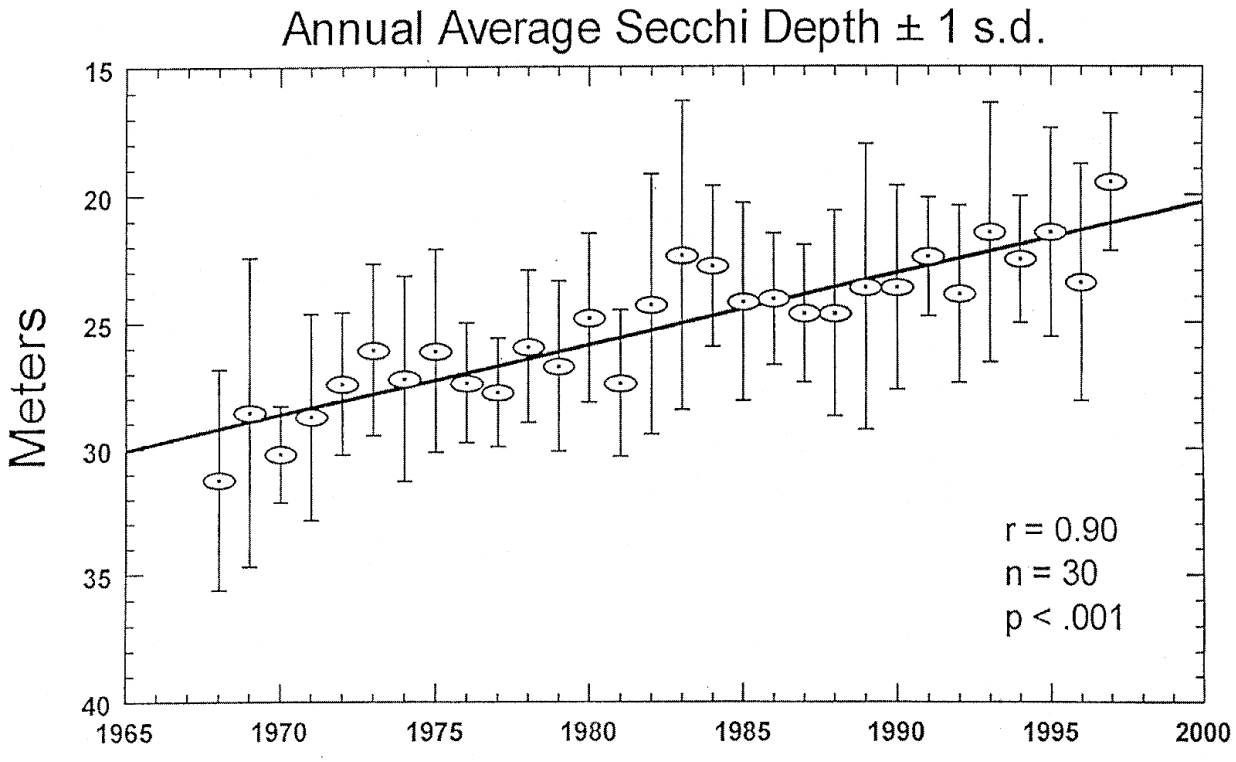


Figure 4-26—Average annual Secchi depth at the TRG index station through 1997. Each year represents the mean of observations taken every 10 to 15 days throughout the entire year.

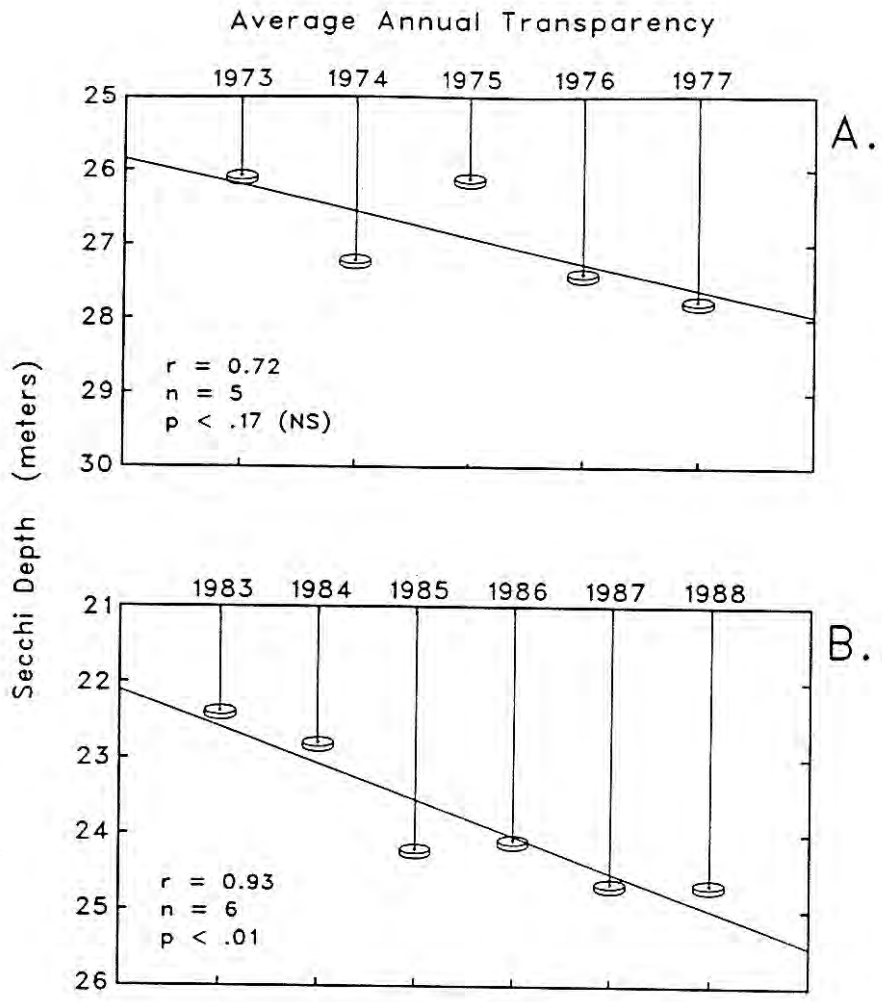


Figure 4-27—Analyzing isolated segments of the long-term clarity database can lead to false conclusions regarding trend in transparency (from Goldman 1993).

Explaining Long-term and Other Scales of Temporal Variability in the Transparency of Lake Tahoe: The Contribution of both Phytoplankton and Suspended Fine Sediment

The simultaneous increase in primary productivity and decrease in clarity strongly implicates the role that nutrient loading has had on the long-term decline in Secchi disk measurements, that is, on increased algal growth. However, even large lakes are subject to influence by fine sediment particles derived from the surrounding watershed. Until recently, the contribution of these terrestrially derived particles, such as silts and clays, has not received as much attention as the phytoplankton component. Many substances contribute to light absorption and scattering and, consequently, the reduction of clarity. Based on origin, these can be categorized as water molecules, phytoplankton plus detritus recently derived from phytoplankton, material produced in the lake but not containing photosynthetic pigments (including bacteria, viruses, dissolved and particulate organic matter, and biogenic minerals), and materials derived from out-of-lake sources, especially mineral suspensoids from erosional or aeolian fine sediment.

Jassby et al. (1999) have recently published an analysis of the origins and scale dependence of temporal variability in the transparency of Lake Tahoe from 1968 to 1996. The primary objective of this study was to establish the dominant modes and causes of seasonal, year-to-year, and decadal variability in lake clarity according to the measured Secchi depth time series of 29 years. This time series is of sufficient resolution and exhibits characteristics that enable some differentiation to be made among the various categories of light-attenuating factors cited above. Jassby et al. also employed a shorter time series for chlorophyll *a* (the major algal pigment and an estimate of biomass) and recent measurements of suspended particulate matter. Figure 4-28 shows the relationship between "contract attenuation" and Secchi depth. Increasing contrast attenuation corresponds to an increase in materials in the water that reduce light penetration. In a more dilute waterbody, such as Lake Tahoe, very small increases in these materials can result in large changes in Secchi depth.

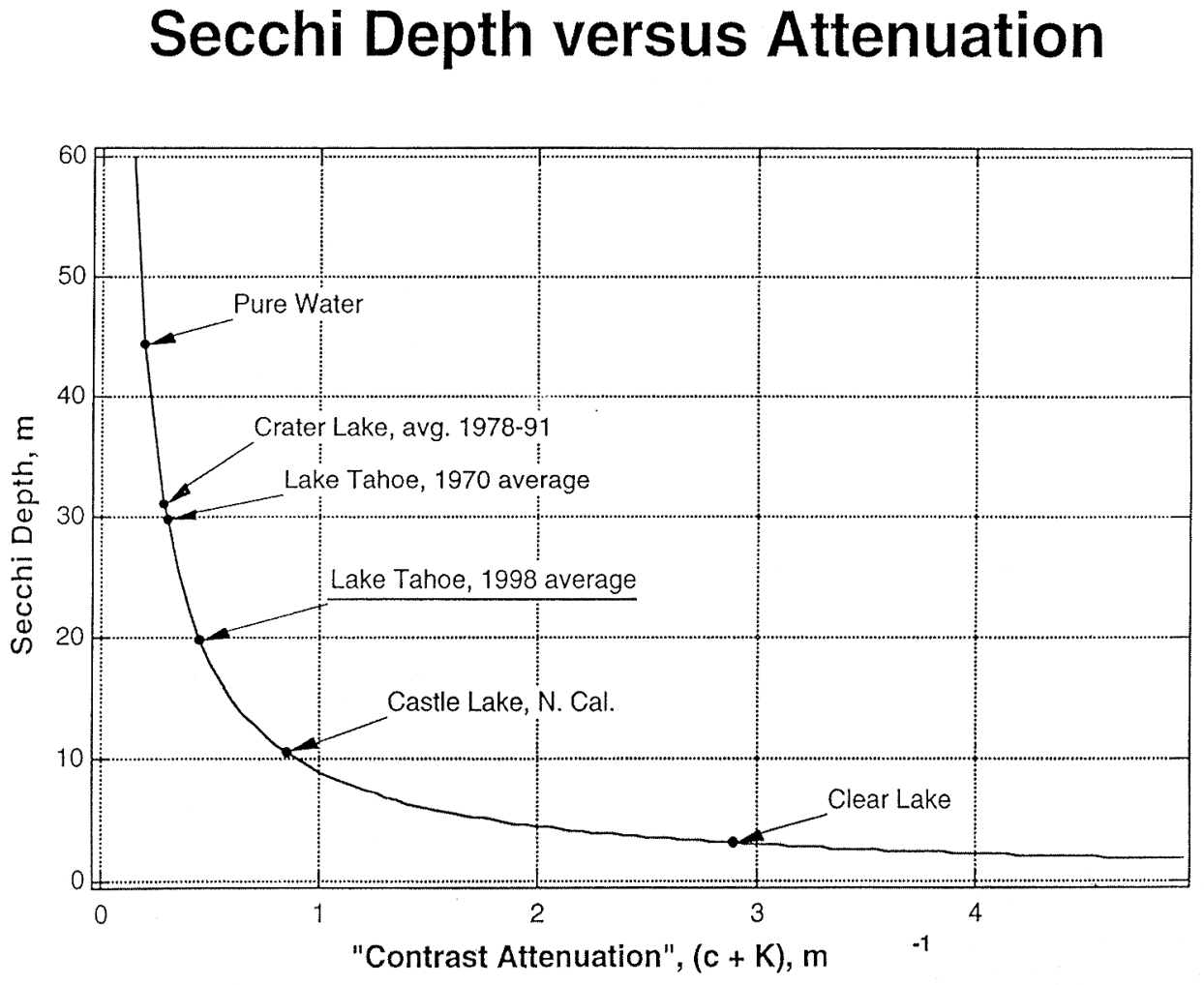


Figure 4-28—Relationship between Secchi depth and contrast attenuation. The contrast attenuation is a function of material in the lake, which reduces light penetration. In dilute waterbodies, such as Lake Tahoe, small changes in the amounts of these materials can have large effects on Secchi depth.

Long-term Trend

The monthly time series at the index station exhibits considerable variability at the seasonal scale. Filtering the data to remove this seasonal effect and to accentuate variability at longer time scales, Jassby et al. (1999) found lake clarity to be dominated by a long-term decreasing trend, similar to previous analysis using average annual values. This trend was highly significant ($p<0.0025$), with a slope of -0.25 m/yr. While this study reports that this decreasing trend was due mostly to changes before 1985, the analysis did not include 1997 and 1998, which corresponded to the two lowest annual average Secchi depths on record, 19.6 m and 20.1 m, respectively. Prior to these last two years, monthly Secchi values only infrequently dipped below 20 m. Additionally, the early portion of the post-1985 period was characterized by an extended state-wide drought. In the seven years between 1986 and 1992, the lake mixed completed only in 1989.

According to Jassby et al., "the long-term (decadal-scale) change in Secchi depth appears to be due to an accumulation of materials in the lake." This is a critical observation from the perspective of lake and watershed management. The importance of reducing particulate matter cannot be overemphasized. This particulate matter either enters Lake Tahoe by surface runoff/stream discharge from the watershed (primarily eroded soil sediment) or is produced in the lake as phytoplankton that use nutrients loaded either from watershed runoff or from atmospheric deposition.

Jassby et al. (1999) addressed the issue of the nature of the accumulating particles and in particular, chlorophyll-associated materials versusinorganic sediment. Using the regression model developed from the 1995 to 1997 field measurements of Secchi depth, chlorophyll, and total suspended solids, it was concluded that either phytoplankton-derived materials or mineral suspensoids could have explained the decline in clarity. The database needed to more accurately determine the relative contribution of these materials is simply too short to allow for an unambiguous answer. However, the authors did hypothesize a significant role for mineral suspensoids, emphasizing that fine inorganic sediment in the size range of 0.5 to 2 μm have the highest light scattering efficiency and that particles in this size range might not settle to the bottom before being resuspended by mixing or other forms of vertical exchange. Based on stream sediment loading data from the Lake Tahoe Interagency Monitoring Program's database, these authors concluded that "only a small fraction of cumulative suspended sediment from just one source [the Upper Truckee River] needs to be retained in the water column to account for loss of clarity."

Ultimately, the recovery of Lake Tahoe clarity depends on the rate at which the supply of suspended particulate matter can be reduced in relation to the effective rate of loss of material from the water column. Management can significantly influence the former; the latter (sedimentation rate) is beyond the control of this group, in Lake Tahoe. These results suggest that it is not enough to simply institute erosion control measures that target total suspended sediment if the smaller particles are allowed to get through unabated. If smaller mineral suspensoids are in fact important in the observed long-term decline in lake clarity, evaluating the success of erosion, dust, and other sediment control projects simply by the bulk amount of material retained may result in lake clarity improving far less than anticipated. Clearly, further studies are required to delineate the roles of these different light-attenuating materials. It would be particularly valuable if monitoring and research on sediment loading and BMP effectiveness included a component for particle size determination.

Seasonal Variability

Not only was the overall long-term trend in clarity negative but so were the long-term trends for each of the individual months (Figure 4-29). All were statistically significant, save that for July. The rate of clarity loss was less during the months of stratification from June to October (-0.1 to -0.2 m/yr) relative to the remaining months ($\geq$ -0.3 m/yr). The mean seasonal pattern over the period of record was bimodal, with a strong annual minimum Secchi depth in approximately June and a weaker local minimum in December. The overall maximum

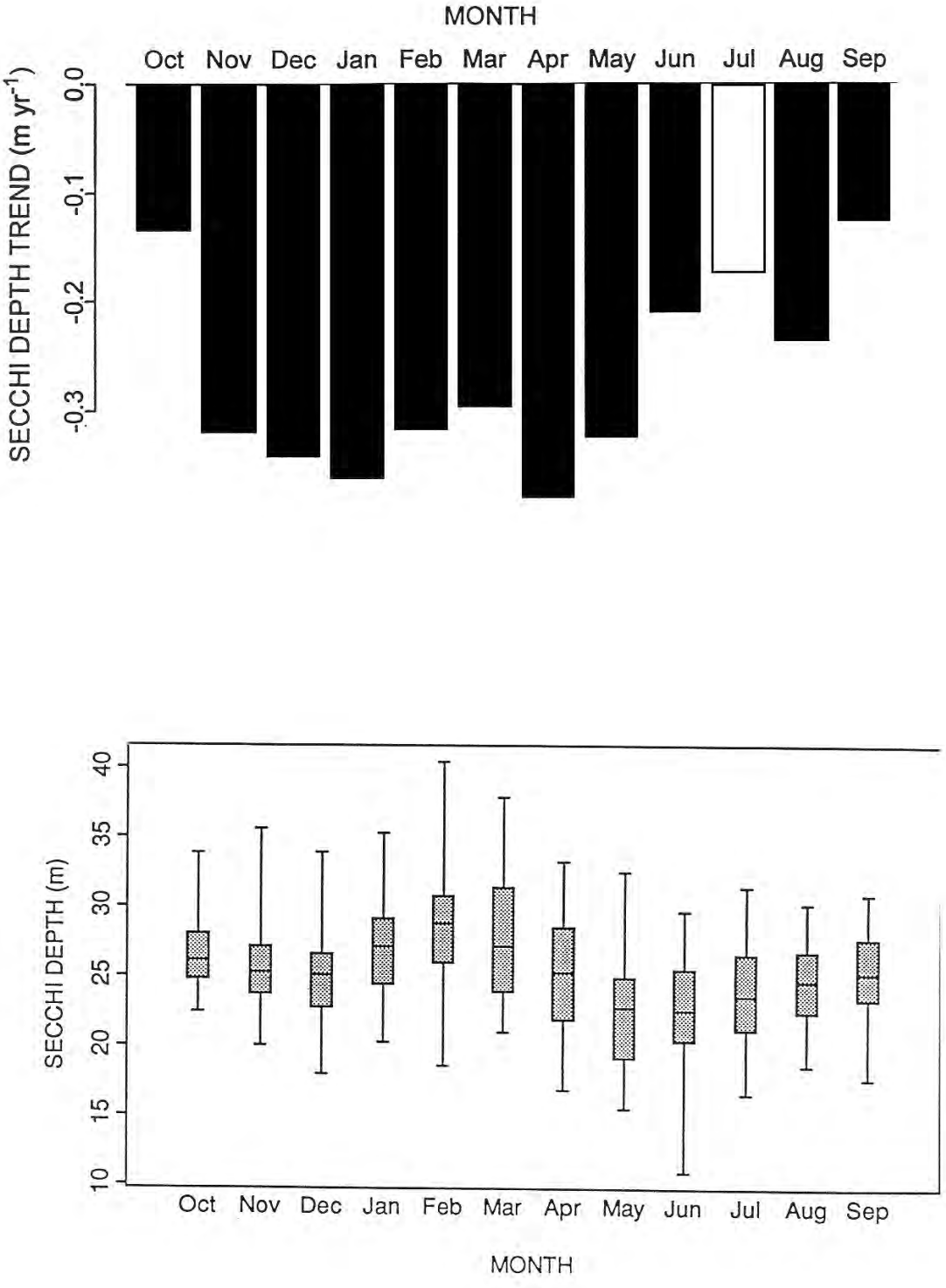


Figure 4-29—Upper panel shows trend in loss of clarity in Lake Tahoe for individual months. Lower panel combines the long-term Secchi depth record to show the seasonal pattern of clarity. Note reduced clarity in May-June and December (from Jassby et al. 1999).

was in February, with a secondary local maximum in October. Secchi measurements at the mid-lake station were less frequent (approximately a monthly schedule), but the time series for both stations were similar. Mean annual Secchi depth at mid-lake is commonly from 0 to 2 meters deeper than the index station, which is closer to shore.

Jassby et al. (1999) considered the June minimum in Secchi depth to be due to the cumulative discharge of suspended sediment following melting of the seasonal snowpack (Figure 4-30). This was found to be consistent with the measured seasonal pattern of suspended sediment discharge and with visual observations of sediment plumes entering the lake. For example, if the 8.85 tons per day average suspended sediment discharge from the Upper Truckee River from 1972 to 1988 were distributed evenly over the entire 0-30 m stratum of the lake, this rate is equal to 0.23 mg/L in a single year. A change of only 0.1 mg/L could account for a 5 to 10 m change in Secchi depth, which is the magnitude of the seasonal change. As the sediment load diminishes in June and thermal stratification intensifies, the balance between watershed inputs and outputs by sedimentation begins to shift, resulting in the gradual increase in clarity from June to October.

The December minimum was attributed to the deepening of the mixed layer as the thermocline erodes at that time of year and passes through layers of phytoplankton and other light-attenuating particles, which reach a maximum below the summer mixed layer, e.g., the deep chlorophyll maximum that is found below 50 to 60 m in Lake Tahoe (Abbott et al. 1984). Based on sediment trap data for Lake Tahoe (Heyvaert 1999), Jassby et al. hypothesized that it is the combination of phytoplankton and inorganic particulate matter that accumulate at intermediate depths which is mixed into the surface waters and results in the December minimum in clarity.

Seasonal and trend analysis of the transparency data using advanced statistical treatment revealed a strong change in the seasonal effects over the 29-year record. In the late 1960s and early 1970s, the seasonal pattern was essentially unimodal with a midwinter maximum, usually in February and a late spring-early summer minimum, usually in June. By the mid-1970s, a late fall-early winter secondary minimum, usually in December, gradually began to develop. This pattern has continued to the present strong bimodal pattern of December and June minima (Figure 4-31). Another feature of the time course is a long-term decline in the seasonal amplitude, i.e., less variation between seasonal high and low values in recent years.

Interannual Variability

PCA provides an understanding of the longer-term variability of Secchi depth. Two modes were found to be significant, each exhibiting a decadal-scale trend as well as a year-to-year variability around this trend. One was observed during the weakly stratified autumn-winter period and the other during the more stratified spring-summer period. Mode 1 represents the autumn-winter period of weak or no thermal stratification, during which the thermocline erodes and mixing occurs; as discussed above, the depth of mixing is variable and not always complete. Mixing depth has a significant influence on the year-to-year variability around the trend line but not in the same manner in which it controlled primary productivity. The coefficient for mixing depth is positive, implying that deeper mixing results in higher Secchi measurements. Once the depth of mixing exceeds an intermediate depth (approximate depth range for the deep chlorophyll maximum and other suspended particulate matter), deeper mixing brings up waters with less particulate matter. The effect of deep mixing is best understood as a dilution of light-attenuating particles, be they phytoplankton or inorganic sediment.

Mode 2 represents variability around the trend line during the spring-summer when the lake is more strongly stratified. As observed for the seasonal minimum at this time, the interannual variability in stream discharge causes the year-to-year difference in clarity at this time. Blackwood Creek spring streamflow as an index of sediment discharge gave a very good prediction of the interannual variability seen in Mode 2. Blackwood Creek was used because it has a continuous database extending back prior to 1970 and because of its proximity

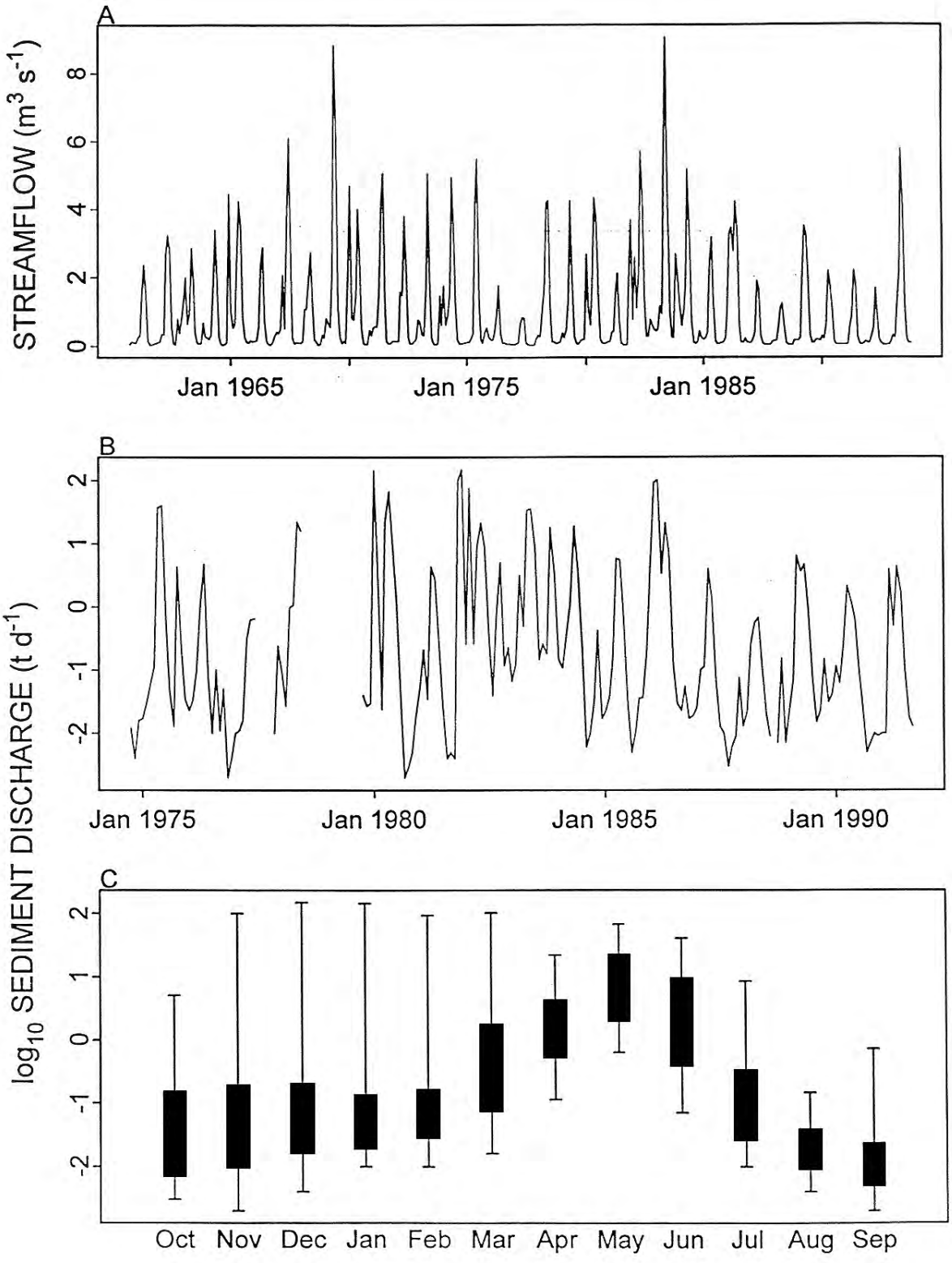


Figure 4-30—Seasonal decline in clarity during May and June related to sediment discharge from inflowing tributaries (from Jassby et al. 1999).

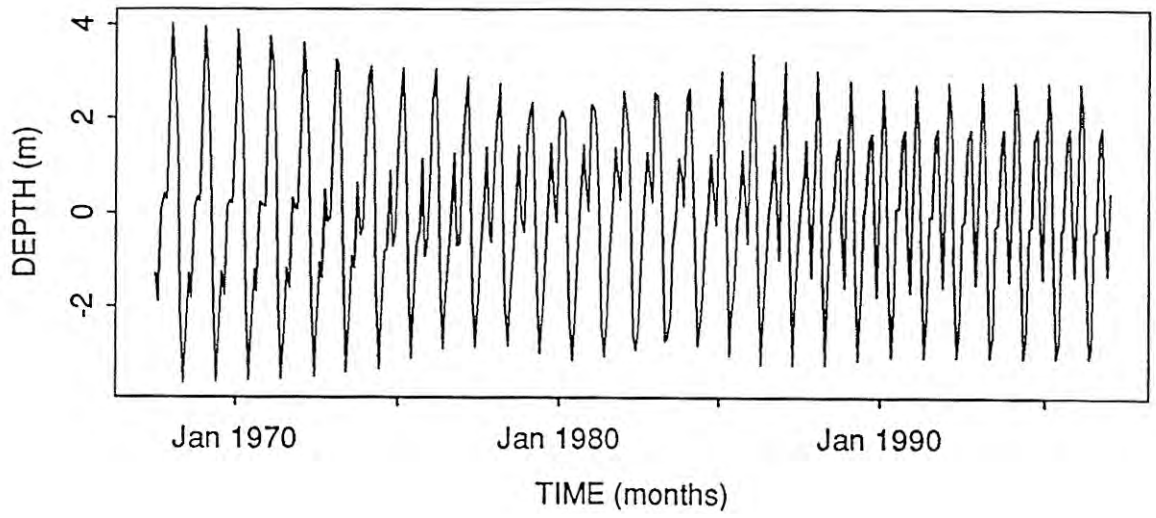


Figure 4-31—Development of bimodal pattern of clarity with the onset and intensification of a secondary minimum, usually in December (from Jassby et al. 1999).

to the index station where the long-term Secchi measurements are made.

Compression of Euphotic Zone

Goldman (1988) emphasized that from 1979 to 1986 there was a trend toward a reduction in the depth of the euphotic zone with the average depth of maximum photosynthesis moving closer to the surface. Long-term monitoring of lake in vivo fluorescence or chlorophyll shows a prominent peak in algal biomass at a depth of 50 to 90 meters. This peak is significantly below the typical Secchi depth of 20 to 25 meters and therefore has no direct influence on the documented decline in clarity, as measured by Secchi disk. This deep chlorophyll maximum can be anywhere from three to 10 times more concentrated than in the water between the surface and the Secchi depth. If decreasing clarity causes a rise in the deep chlorophyll maximum, this could result in a dramatic acceleration of the decrease in clarity in the surface waters, which would be significantly more dramatic than the steady decline that has been observed to date. Given the thickness of the deep chlorophyll layer (approximately 60 meters) and its elevated mean concentration, the amount of algae in this region is on the order of at least ten times higher than that in the waters down to the Secchi depth. Obviously, changes in the location of this layer have potentially dramatic consequences for lake water quality. A compression in the euphotic zone also would effect the distribution of submerged aquatic plants, which are important to the life history of the lake trout population in Lake Tahoe.

What has been the pattern of algal response to nutrient additions? Should management focus on reduction of a single nutrient?

The response of Lake Tahoe water to nitrogen and phosphorus enrichment has been tested using algal bioassays since the 1960s. Goldman et al. (1993) presented a 25-year record of bioassays conducted at Lake Tahoe showing that a decadal scale transition from N and P colimitation to primarily P limitation occurred around 1980. They also examined interannual and seasonal scales of macronutrient (N and P) limitation. Recent work done by Hatch et al. (in press) using algal bioassays has provided information on the fraction of TP in stream inflow, which is readily biologically available to lake phytoplankton.

Algal bioassays are experiments in which small amounts of nutrients or other chemicals are added to algae under controlled conditions, with the

change in growth directly measured. The bioassays most commonly done at Tahoe since the 1960s have been over three to seven days in duration and utilize the natural phytoplankton community. These assemblages, obtained directly from the lake, are used because they are adapted to the nutrient supply conditions in the lake and include the naturally diverse composition of algal species (which also may have differing nutritional needs). Enrichment bioassays provide an indication of nutrient limitation. A nutrient is said to be "limiting" when it is in shortest supply relative to phytoplankton needs, and therefore its abundance controls the growth of the organism. In extrapolating the bioassay results to the lake as a whole, the fact must be considered that these small-scale bioassays eliminate many important nutrient fluxes and alter the physical, chemical, and biological environment. However, because the euphotic zone of Lake Tahoe is not significantly influenced by nutrient processing in the bottom sediments, because the residence time for nutrients can be on the order of decades, and because top-down or biological processes do not appear to regulate algal biomass, the results of these bioassays are considered to be highly relevant. The long record of bioassays gathered from Lake Tahoe using a consistent method has proved extremely useful for evaluating long-term changes. When combined with lake chemistry data and information on atmospheric and watershed nutrient loading ratios, these simple enrichment bioassays have provided valuable complementary evidence on the temporal dynamics of nutrient limitation in the lake.

Long-term Shift in Bioassay Response

In a typical bioassay, lake water is collected from the upper photic zone (0 to 40 m), prefiltered through 80-μm mesh netting to remove the larger zooplankton, and returned to the lab. The water is distributed among experimental flasks to which small amounts of N (20 μg N/L) or P (10 μg P/L) or the combination of both are added. One set of flasks is left as a control, and all treatments are triplicated. The flasks then are placed in a laboratory incubator under fluorescent lighting at ambient lake temperature and daylength, and growth response of phytoplankton is measured over a period ranging from three to seven days. Relative growth is assessed by measuring carbon 14 (^{14}C) accumulated in phytoplankton during growth, or by measuring changes in algal biomass (i.e. fluorescence or chlorophyll *a*). Treatments are stimulatory if the mean growth response exceeds the control at the $p=0.05$ level of significance.

Goldman et al. (1993) examined the long-term set of 110 bioassays (1967-1992), that tested response to either N or P additions alone, for the presence of trends on the decadal scale. The most outstanding feature of this record is a long-term shift from colimitation by both N and P to predominant P limitation. In earlier tests (1967-1981), growth stimulation was observed in about 45 percent of the N bioassays and in about 25 percent of the P bioassays. In later tests (1982-1992), P stimulation was observed more frequently (nearly 90 percent of the P bioassays), while N stimulation was rare (occurring in six percent of the N bioassays) (Table 4-5). The exact timing of the shift is difficult to discern, but it was concluded to have occurred in the late 1970s or early 1980s.

Other data also suggest that the nature of nutrient limitation had changed in Lake Tahoe. Chang et al. (1992) combined field measurements of lake chemical and biological indicators with single-species bioassays during 1988 and 1989. Their results suggested that phosphate was limiting algal biomass during that period. Hunter et al. (1990) described an increasing abundance of the chrysophytes *Dinobryon*, *Kephyrion*, *Synura*, and *Uroglena* in Lake Tahoe phytoplankton during the 1980s and argued that the species changes indicated higher ratios of available N:P. Marjanovic (1989) collected sedimenting material in traps suspended at several depths in Lake Tahoe; in the shallowest traps (140m) from June 1 through August 31, 1988, (approximately the period of highest productivity) material had an N:P (molar) ratio of 70, indicating extreme P deficiency (Healey and Hendzel 1979). No particulate N:P data exist for the earlier period, but Holm-Hansen et al. (1976) reported a particulate C:N (molar) ratio of 19 in the mixed layer at the end of the bloom in August, symptomatic of extreme N deficiency (Healey and Hendzel 1979).

Table 4-5—Summary of long-term change in nutrient limitation in Lake Tahoe to a phosphorus stimulated system (from Goldman et al. 1993).

	Not Stimulatory	Stimulatory	Total
	NO_3 bioassays		
1967-81	16	12	28
1982-92	29	2	31
Total	45	14	69
	PO_4^3 bioassays		
1967-81	14	5	19
1982-92	4	28	32
Total	18	33	51

Jassby et al. (1994) hypothesized that the shift from N and P colimitation to predominant P limitation is due to a slow, decadal change in the relative sizes of lake N and P reservoirs fueled by atmospheric deposition.

Interannual and Seasonal Changes in Bioassay Response

Goldman et al. (1993) examined the bioassay record for year-to-year variability. To avoid the confounding effects of long-term shifting nutrient limitation, these authors focused on the period from 1982 to 1992, in which P enrichment was consistently stimulatory. The magnitude of P response (expressed as percent of control response) was compared for bioassays done in, or close to, July each year. The magnitude of P response fluctuated from year to year and ranged from 199 percent in 1985 to 108 percent in 1990 . To see whether the fluctuations in magnitude of P response were related to spring mixing depth, Goldman et al. (1993) compared July bioassays, which had similar duration (six days), with spring mixing depths for the corresponding year. A significant positive association was found between depth of spring mixing and magnitude of P response, i.e., deeper mixing resulted in a more positive P response. Adding N and P together typically resulted in the largest response, as well as the highest interannual variability in response. In general, the largest source of interannual variability identified for Lake Tahoe is the depth of spring mixing (Goldman et al. 1989). Deeper mixing results in an increased upwelling of regenerated nutrients from the lake depths and a higher annual primary productivity.

Goldman et al. (1993) also looked at seasonal variation in responses. Because the number of bioassays was limited each year, their comparison focused on the highly stratified period (July through September) and the remainder of the year, which was either weakly stratified or non-stratified. The significance of bioassay response was independent of the seasonal period for both N and P; that is, N or P stimulation was not associated with either the highly stratified period or the remainder of the year. This lack of seasonal effect on the significance of bioassay response is an important observation. It supports assessment of the long-term shift without taking into account a possible confounding effect of season.

The authors also examined the effect of season on the magnitude of bioassay response. To minimize confounding factors they focused on the period beginning in 1982 when P stimulation, and lack of N stimulation was a consistent feature of the bioassays. The highest magnitude of responses (greatest stimulation relative to the control treatment) tended to occur during stratification. Two potential causes for the increased summer response were forwarded. First, incubation under summer conditions of higher temperatures and longer daily light cycles may have resulted in a faster growth rate in the summer bioassays, and thereby may have affected the magnitude of response. Alternatively, changes in the ratio of available N:P between the

two periods could underlie the seasonal differences much as for the interannual differences.

Contribution of Nutrient Loading to Changes in Lake Response

Jassby et al. (1994) analyzed atmospheric and tributary N and P loading data to assess their roles in the shifting lake response to nutrients. They found that the N:P (atomic) ratio in atmospheric loading was well above the "Redfield ratio" of 16N:1P and much more likely to favor P than N limitation (Flett et al. 1980; Levine 1983). In tributary loading, the N:P ratio was less than 16 and more likely to favor N limitation. For 1989 to 1991, atmospheric and tributary loading combined had a dissolved inorganic-N to soluble reactive-P (DIN:SRP) ratio of 33 and a total-N to total-P (TN:TP) ratio of 26; the effect of atmospheric deposition on the ratio overwhelmed that of runoff, and total loading favored P limitation. These loading data are consistent with the persistent P limitation observed from 1982 to 1992 and indicate a potentially strong influence of atmospheric deposition on nutrient limitation.

Jassby et al. (1994) hypothesized that the shift from N and P colimitation to predominant P limitation is due to a slow decadal change in the relative sizes of lake N and P reservoirs fueled by atmospheric deposition. When Jassby et al. (1995) examined the consistency of this hypothesis with lake water chemistry data collected since the mid-1970s, they found the monthly time series for lake NO_3^- and THP data only weakly reflected long-term changes in phytoplankton activity. This was not unexpected, given the masking effect of large interannual variability caused by spring mixing and the nearness of expected changes to analytical limits of detection. However, when they assessed loading rates and pools of nutrients in the lake, they found that the time scale necessary for change in the size of nutrient pools was of sufficient magnitude to account for the shifts in nutrient limitation. Significant changes in the N:P ratio over a period of several decades are quite conceivable, and shifting nutrient limitation accordingly can be attributed to loading. Atmospheric deposition is essential to account for the observations. In the absence of atmospheric sources, the TN:TP ratio can be shown to slowly move toward N limitation, with a "halving" time of at least 150 years.

Although P limitation was more common than N limitation in nutrient enrichment bioassays conducted from 1980 to 1992, Jassby et al. (1995) indicated that the conditions in the lake at this time, probably favor P limitation only marginally. For example, the mean annual TN:TP ratio in the photic zone was 25 ± 0 for 1992 to 1993. In comparison, Downing and McCauley (1992) found that N limitation was significantly more frequent in lakes with ratios less than 31. Although values from such comparative cross-sectional studies must be applied with caution to individual lakes, their study does suggest that Lake Tahoe may still be close to the boundary separating predominantly N from predominantly P limitation. Some lakes are so closely in balance that adding N and P simultaneously is required to obtain any stimulation of primary productivity (Blomqvist et al. 1989). Presumably, small changes in the N and P balances due to, for example, a change in zooplankton composition (Peinert et al. 1989) or denitrification rate (Levine and Schindler 1992) or other causes could induce a reversal in nutrient limitation. Although recent bioassay data (1992-1998) and the long-term data set have not yet been completely analyzed, brief inspection indicates that N and P colimitation has been observed in several of the bioassays since 1992 (TRG, unpublished). This seems to support the idea that N and P are closely in balance. No evidence exists, however, that the 1980s shift at Lake Tahoe is in fact due to causes other than the cumulative effect of loading. The above analysis indicates that, in the absence of loading changes, the TN:TP ratio should continue to increase, with N limitation even less frequent. This is especially true given the overwhelming and continued importance of atmospheric deposition to the nitrogen budget.

Relative Importance of Stream-borne Phosphorus to Lake Tahoe Phytoplankton

Lake Tahoe basin streams contribute a significant portion of the P loading to the lake. This TP is contributed as dissolved and particulate forms of inorganic and organic phosphorus; however, not

all of this P is readily biologically available to lake phytoplankton, that is, it is not readily taken up for use in metabolism, primary production, or storage by the phytoplankton. While, dissolved inorganic P (PO_4^{-3}) is generally considered to be immediately bioavailable to phytoplankton, only a portion of the DOP is thought to be readily bioavailable, and the bioavailability of PP is quite variable among aquatic systems. To better assess the importance of stream TP for lake phytoplankton growth, the bioavailability of P needs to be assessed.

Hatch et al. (in press) performed a series of bioassays during the spring runoff period and summer of 1996 to characterize the short-term (six days or fewer) bioavailability of stream P from seven basin tributaries. The lake phytoplankton response to different percentage additions of stream water in lake water (ranging from one percent to 10 percent) was tested, as well as the response to 0.45 μ-filtered, 63 μ-filtered, and unfiltered tributary water. The latter bioassays were done to determine the proportion of the phytoplankton response attributable to soluble and particulate fractions in the tributary water.

These authors found dissolved inorganic P best represented Lake Tahoe short-term stream bioavailable P, while particulates (>0.45 μm) did not contribute much short-term bioavailable P. Because the lake was predominantly P-limited during the study, with algae showing only slightly higher growth response to N and P added in combination than to P alone, much of the bioassay growth responses could be attributed to biologically available P in the tributary water. Hatch et al. found all the tributary waters to stimulate algal growth, with increased response associated with higher percentage additions of stream water. Approximately 75 to 90 percent of bioassay response was found to be due to nutrients in the less than 0.45-μm (dissolved) fraction of the tributary water (Figure 4-32). PO_4^{-3}, and to a lesser extent DOP concentrations in the tributary water, was significantly correlated with bioassay responses, while particulate-associated P fractions were not significantly correlated with bioassay response.

The study indicated that PO_4^{-3} is the fraction of TP loading from streams, which is readily available to phytoplankton in the short term. Hatch (1997) estimated that PO_4^{-3} composed about six to 19 percent of the annual TP concentrations for Lake Tahoe tributaries from 1989 to 1996. Approximately 75 percent of the annual stream $PO4^{-3}$ loads occur during the spring runoff (Hatch 1997). Thus a significant "pulse" of available P as PO_4^{-3} enters with the spring runoff to help fuel spring and summer primary production. DOP also showed a weak correlation to bioassay response, indicating that it also may contribute some readily bioavailable P. However, only a portion of the DOP is likely to be readily bioavailable (Sonzogni et al. 1982). In addition, it seems likely that only a relatively small portion of the DOP is short-term bioavailable P in Tahoe, based on DOP and PO_4^{-3} concentrations in the stream treatments and bioassay responses in Hatch et al. (in press), however, additional work is needed to confirm this. Hatch estimated DOP to range from six to 42 percent of the annual TP concentrations for Lake Tahoe tributaries from 1989 to 1996. Note that Holm-Hansen et al. (1976) also provided evidence that a portion of the DOP is utilized in Lake Tahoe. He found that much of the DOP between 5 and 100 m in Lake Tahoe had been depleted, suggesting that hydrolysis of DOP compounds by algal phosphatases may provide a source of PO_4^{-3} to phytoplankton in the photic zone.

Hatch et al. (in press) indicate that much of the particulate P contributed by tributaries is not likely bioavailable in the short term. This is significant because particulate phosphorus is a significant fraction (45 to 88 percent) of annual TP concentrations in Tahoe tributaries (Hatch 1997). While much of this PP may not be available for uptake on the scale of six days, it may become available over longer time scales, for example, weeks to months. They found that 23 to 80 percent of the PP in stream samples tested was in the silt- and clay-sized fraction. These small size fractions with associated P may remain in suspension in the photic zone for extended periods of time, increasing their potential for bioavailability over longer time spans. Therefore, while dissolved P is most important to algal

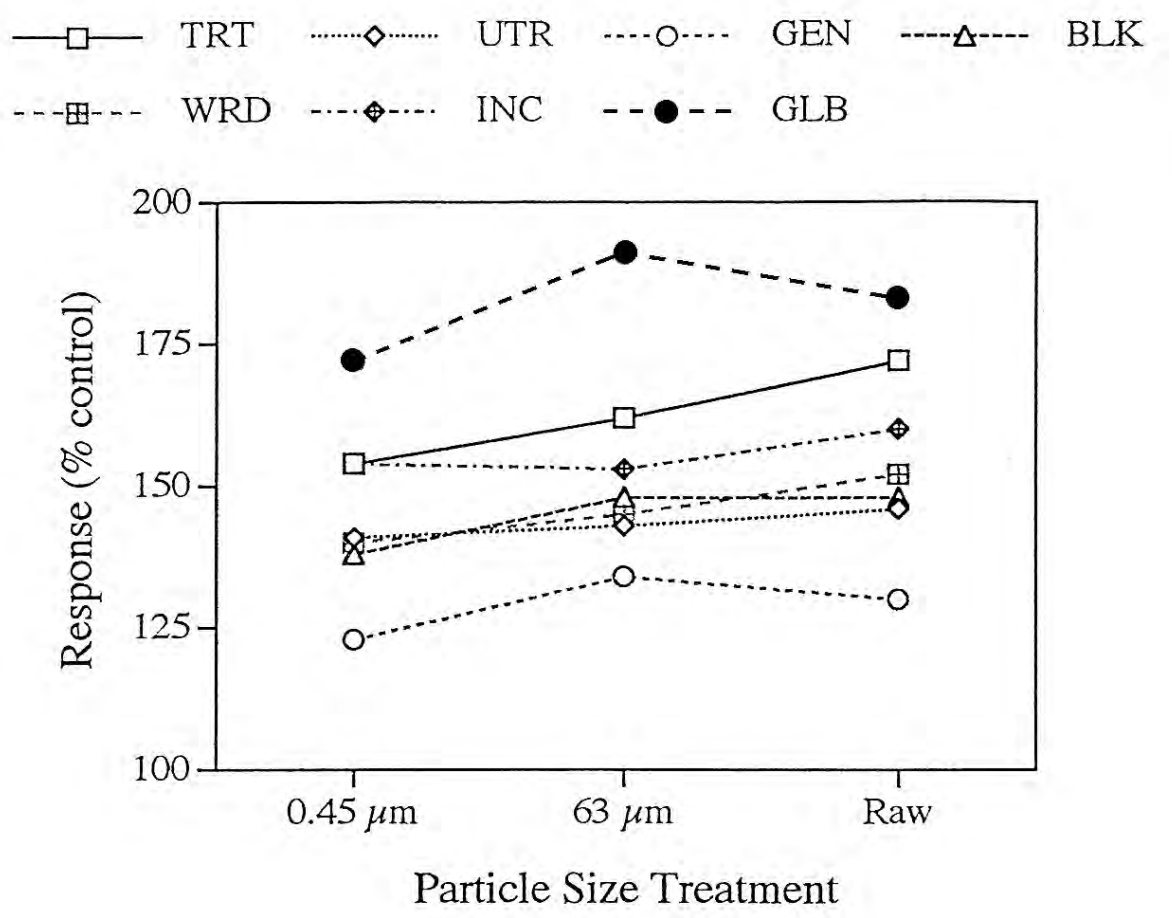


Figure 4-32—Impact of material size class from Lake Tahoe tributaries on lake phytoplankton growth using standard TRG bioassay techniques. The 0.45 μm treatment corresponds to the dissolved fraction; the 63 μm treatment includes all dissolved materials and small particulate matter including silt and clay; the raw treatment includes all dissolved and particulate fractions.

response over the short term, fine particulate-suspended P may add to the bioavailable P over time. However, PP in the sand-sized range will settle relatively rapidly out of the water column in Lake Tahoe and may be removed from potential phytoplankton availability through burial. Additional study of BAP dynamics in the lake is needed.

Limitation by Trace Metals

Iron also may be a contributing factor to algae growth (Goldman and Carter 1965). Several studies have found iron (Iron) to be a limiting factor in some areas of the lake. In their studies, Iron addition increased biological carbon uptake by up to 40 percent. As with phosphorus loading, Iron loading is commonly associated with erosion and sediment transport. Because most Iron loading occurs in particulate form, it is generally considered unavailable for biological uptake. However, mineralization is presumed to make the nutrients available at some point (Elder et al. 1976).

Single Nutrient Versus Multiple Nutrient Control

Reversing the ongoing eutrophication of Lake Tahoe in part depends on reducing the nutrient availability. This is most feasible by controlling sources of nutrients to the lake. Both N and P have been limiting during the past 30 years, with N and P colimitation more prevalent before the early 1980s, and P limitation predominant from the early 1980s

to the early 1990s. Given the current knowledge of nutrient limitation in Lake Tahoe, the most effective strategy for controlling algal growth should be determined.

One strategy is to focus on P control to reduce algal growth under the current condition of predominantly P limitation. P limitation has been more prevalent in recent years, and continued atmospheric deposition of N will most likely drive the lake toward stronger P limitation. Successfully reducing available P by control measures would further increase the N:P ratio. The degree to which atmospheric N loading can be controlled is an important consideration in evaluating this strategy. If it is found that little change in atmospheric N loading can be expected as a result of control efforts, or if N control is otherwise not feasible, the lake N:P ratio will continue to increase, making P control the most effective control strategy.

An alternative strategy would be to focus only on N control. Under conditions of predominant N limitation or N and P colimitation this strategy could be effective. However, the greatest contribution of N loading to the lake is from atmospheric deposition; therefore, controlling N deposition is an extremely important component of a strategy that emphasizes N. As indicated above, information is needed on the extent to which atmospheric deposition of N onto the lake can be controlled. Under conditions of prevalent P limitation, P control would still be necessary.

A case can be made for multiple nutrient control. As mentioned above conditions in the lake probably favor P limitation only marginally. It is conceivable that the lake could undergo a shift back to colimitation as a result of small changes in the N and P balances. Combined N and P control measures may be expected to alter loading; however, the net effect of these changes on lake N:P ratios and nutrient limitation is uncertain. Given the current close balance between N and P and the uncertainty about future nutrient limitation under changing loading conditions, it may not be prudent to discount N control altogether. According to the nutrient budget presented above, 56 percent of the total-N loading to Lake Tahoe comes directly from atmospheric deposition and is related to air quality. On the other hand, 73 percent of the TP entering the lake is derived from the watershed. While a management plan for P control would include such actions as erosion control, revegetation, and purchase of sensitive lands, an N-control strategy must consider both in-basin and out-of-basin sources, such as automobile exhaust and agrochemical residues. N control could be difficult to implement, especially if out-of-basin sources are dominant. Given the current conditions of P limitation in Lake Tahoe and the lack of unambiguous data on sources of atmospheric N, restoration projects that emphasize P control should be a priority at this time. Should continued research on air quality and lake response present a strong case for a need for simultaneous N control, this strategy would require renewed evaluation.

Do the existing long-term data for other biological chemical or physical characteristics of Lake Tahoe show significant trends for other parameters besides algal growth, clarity, and nutrients?

Dissolved oxygen (DO) is one of the most important features of lake water quality. When this critical constituent is too low, a number of beneficial uses of a waterbody are lost. This results from a reduction of habitat available to fish, increased stress to fish and other macrobiota, change in aquatic biodiversity toward more undesirable species, water taste and odor problems, and enhanced released of nutrients from the bottom sediments. DO concentrations should be greater than 6 mg/L to maintain a health salmonid community.

The vertical profile of DO in lakes is largely determined by mixing processes, thermal stratification, and biochemical oxygen demand (BCOD). Typically, the higher the levels of organic matter in the water the higher the oxygen demand and the lower the oxygen concentrations. As bacteria decompose organic matter (including dead phytoplankton), the water's oxygen is consumed. In the mixed layer, the loss of oxygen is often not significant because of reaeration from the atmosphere and photosynthesis by algae. In general, the deeper portions of lakes will experience the most

severe oxygen depletion because BCOD occurs both in the water and at the bottom sediment (sediment oxygen demand or SOD); also, when the lake is stratified or if mixing is not complete to the bottom, reaeration does not occur.

While DO in lakes exhibits distinct daily, seasonal, annual, and interannual patterns, in Lake Tahoe long-term or decadal scale changes are of greatest concern. Specifically, there is a concern that the organic matter produced as algal primary productivity increases is creating a higher BCOD with a concomitant decline in DO. Even if the resulting DO exceeds the recommended 6.0 mg/L value for a coldwater fishery, any progressive decline in the oxygen content of Lake Tahoe is significant because restoring a lake's DO is very difficult, even in smaller and much more manageable waterbodies.

DO concentrations in the deepest portion of a lake largely reflect SOD and provide early insight into changing conditions. As part of the lake's routine monitoring, complete vertical profiles of DO over one of the deepest portions of the lake are made (TRG, unpublished). Monthly measurements are made from the surface to a depth of 450 meters throughout the year. Since 1984, DO concentrations at this depth have been made on over 175 occasions.

A plot of the measurements shows a considerable amount of variation around the line of linear best fit for DO at 450 m (Figure 4-33). The range of values is 6.9 to 11.3 mg/L, with an overall mean of 9.05 mg/L; the median value was 9.0 mg/L (i.e., 50 percent of the concentrations were both above and below this value). Within this range, the values have a normal distribution. For comparison, the range of DO concentrations at 400 m was similar, albeit the normal distribution shifted toward higher values. Both the mean and median at this relatively shallower depth were identical at 9.2 mg/L with a range of 7.1 to 11.4 mg/L. This increase in DO away from the bottom is expected because the direct influence of SOD diminishes. Despite the observed variation when the entire database is considered (partially due to seasonal patterns), there appears to be a downward trend over the 15-year period of record from greater than 9.0 mg/L to less than 9.0 mg/L.

Reducing these data by calculating annual mean values allows a closer evaluation of this decline in DO (Figure 4-34). The linear best fit model shows that DO has fallen by 0.66 mg/L from approximately 9.41 mg/L in 1984 to 8.75 mg/L in 1998. While there still is some variation around the line of best fit, the time variable (i.e., passage of years) explains 45 percent of the observed decrease. Given the well-known link between algal production and loss of DO in lakes and given the long-term increase in primary productivity in Lake Tahoe, the long-term changes in these two parameters are likely related.

Without complete mixing each year, it is valid to question whether the observed decline in annual average DO was related to incomplete mixing and therefore a reduction of reaeration. Years of complete mixing from 1984 to 1998 included 1985, 1989, 1993, 1997, and 1998. Only in 1998 was the annual average DO higher than expected, suggesting no significant impact of deep mixing on the yearly mean value. The higher DO observed in 1998 appears due to increased values during the summer and fall. While an upward trend might be inferred from the 1995 to 1998 segment of the database, primary productivity and Secchi depth data suggest that interpreting temporally truncated portions of the long-term data can lead to erroneous conclusions. Continued monitoring will help clarify this issue.

Analysis of the 450 m DO data by month shows the expected seasonal pattern (Figure 4-35). Regardless of the maximum mixing depth, turnover in Lake Tahoe occurs from February to April, and by May it is complete. From May to September, DO at 450 m remains relatively uniform, between 9.0 and 9.5 mg/L. From September to October, concentrations begin to decline due to increased SOD and presumably because phytoplankton produced in the surface waters during the spring-summer period settle into the deeper waters and decompose. This consumption of DO continues through January when the seasonal minima are observed. The increase between January and March is coincident with turnover and reaeration of the deeper waters.

Because January is the month where minimum DO is measured at depth, it is

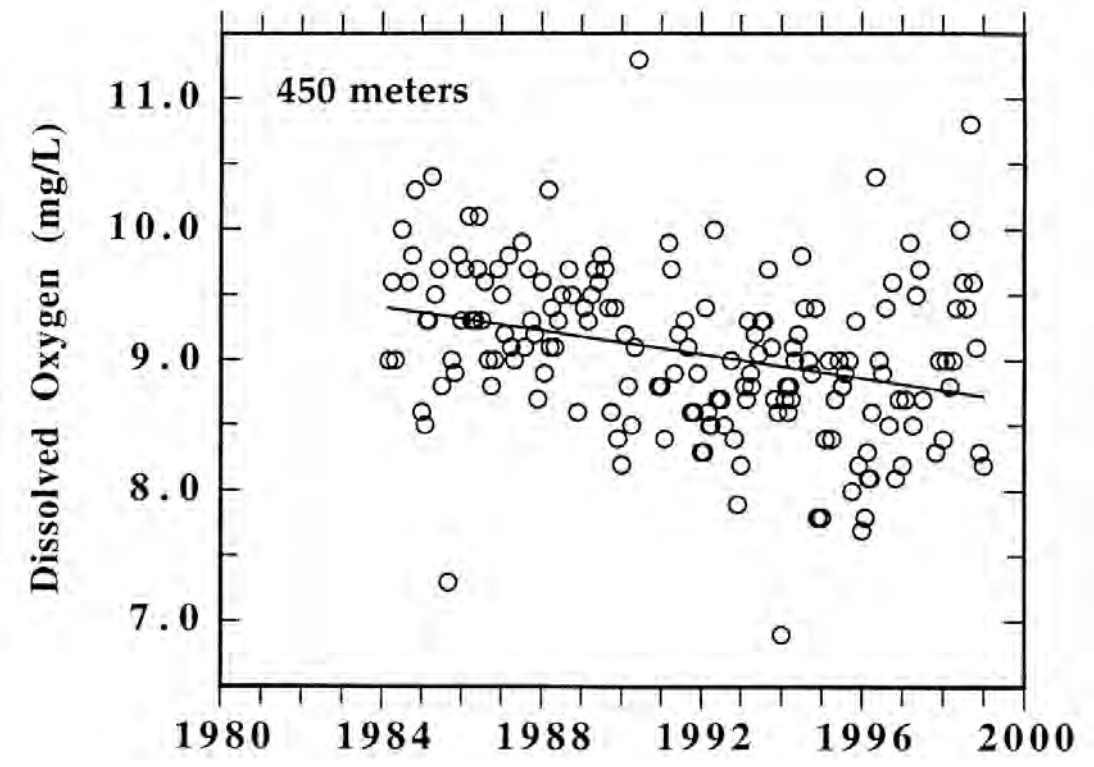


Figure 4-33—Individual measurements of dissolved oxygen at a depth of 450 m below the surface in Lake Tahoe since 1984.

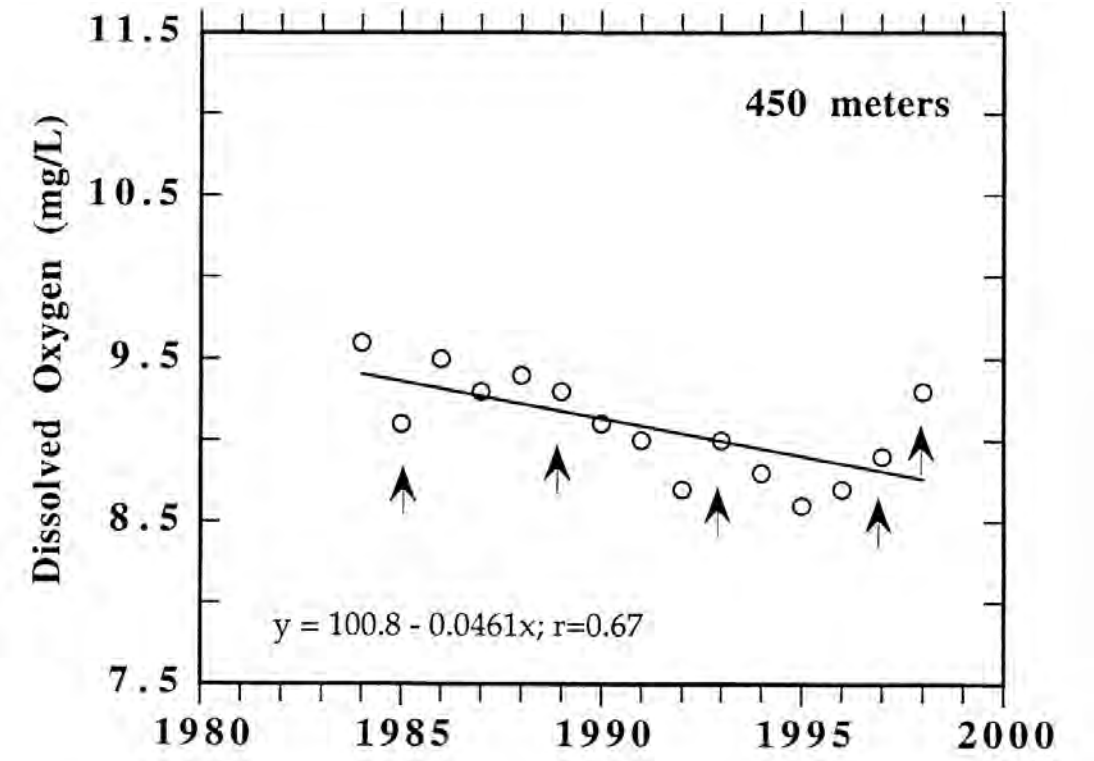


Figure 4-34—Decline in annual average dissolved oxygen at 450 m. Arrows represent years of complete mixing.

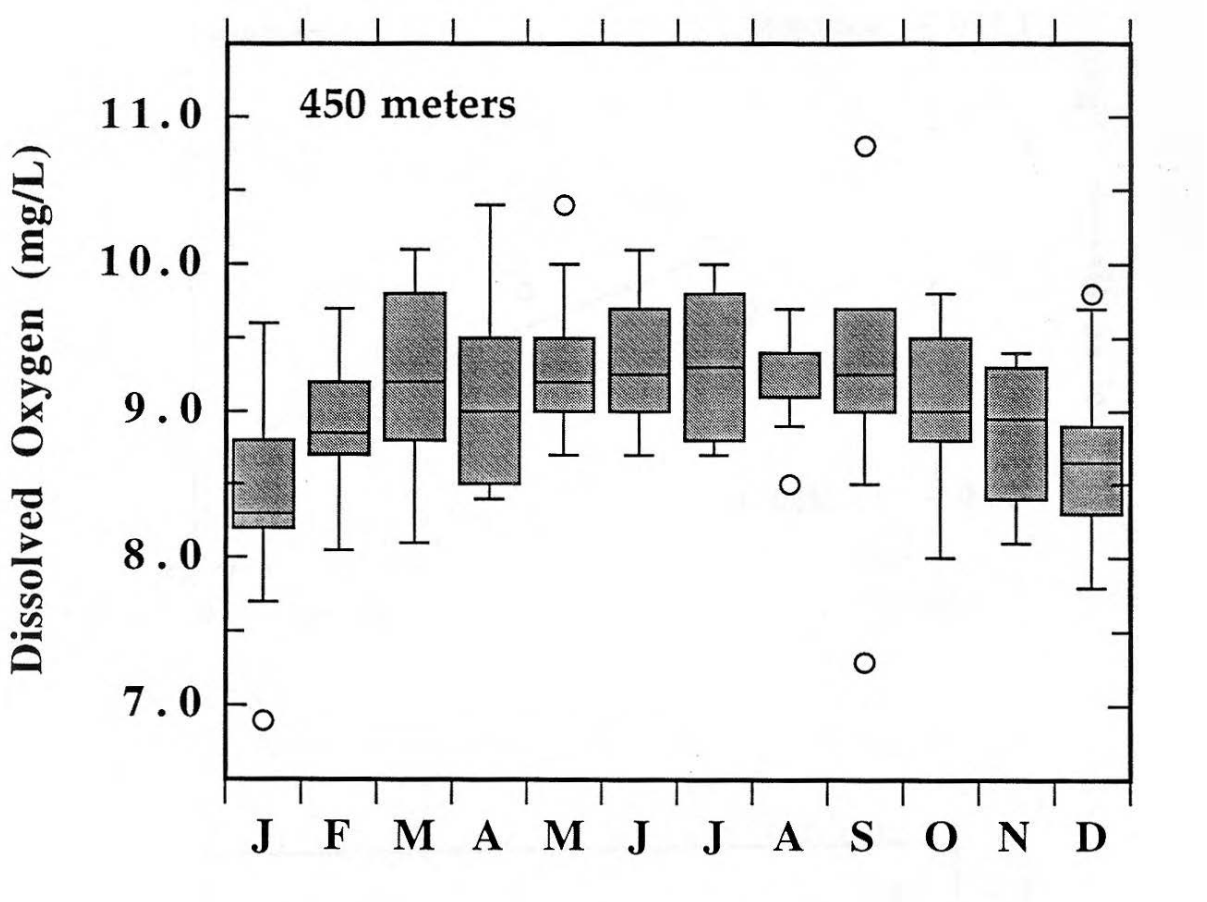


Figure 4-35—Mean monthly values for dissolved oxygen at 450 m, showing the gradual decline in concentration throughout the fall and early winter until mixing during February and March. Solid line in box represents median value. Box ranges from 25th to 75th percentiles, and lines denote maximum and minimum values. Circles are outlying values.

instructive to evaluate the long-term change at this location. The decline in lake DO during January at 450 m is even more pronounced that the change in annual average DO (Figure 4-36). Based on the statistical line of best fit, DO declined by 1.6 mg/L from 9.3 mg/L in 1984 to 7.7 mg/L in 1998 (again, note that specific years may vary from the line of best fit). This represents a 17 percent decline. At this rate, DO at 450 m in January will decline to 6.0 mg/L in slightly more than 10 years (2012). Similarly, if the present rate of decline continues, the average DO concentration for the entire year at 450 m will dip below 6.0 mg/L in 2058.

The observed change to this fundamental indicator is disturbing. Not only is dissolved oxygen critical to maintain fish habitat, an aerobic condition at the sediment-water interface results in the formation of a chemical barrier that largely prevents the migration of phosphorus from the sediments and into the water column. Should dissolved oxygen decline to zero at the bottom, this barrier will break down, resulting in the auto-catalytic release of very large quantities of P to Lake Tahoe. Deep-water dissolved oxygen concentrations should be considered as a water quality Threshold for Lake Tahoe. Formal presentation of a recommended value is premature at this time; however, efforts are underway to make this determination.

Phytoplankton Species Composition

Phytoplankton Response to Ecosystem Changes—Phytoplankton communities are central to many of the environmental issues at Lake Tahoe. Algae are the primary producers, the base of the aquatic food

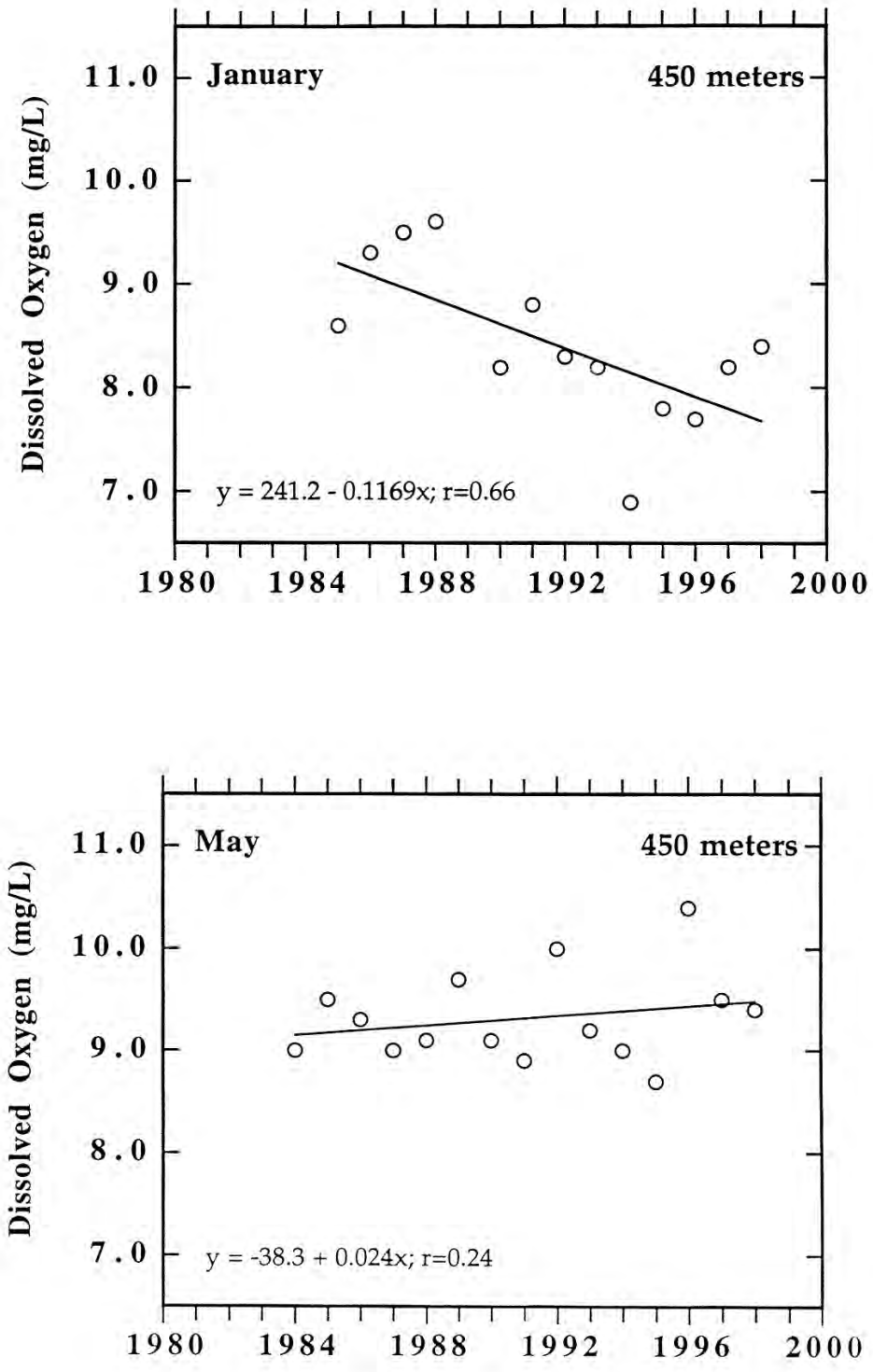


Figure 4-36—Pronounced decline in dissolved oxygen in January prior to lake mixing.

web. Blooms of certain species also can result in taste and odor problems in domestic water supplies. Phytoplankton is very responsive to physical and chemical changes in the aquatic environment. This rapid biological response can be advantageous where managers and scientists have a good understanding of algal community dynamics. Changes observed in the algal community then can be used for predictive purposes and can inform management decisions.

Phytoplankton community changes will directly affect higher trophic levels of the food web. When the algae respond to the fluctuating physical and chemical environment, these changes will affect food quantity and quality. Algal response also will strongly affect lake clarity. Increases in phytoplankton abundance and biomass will increase the overall number of particles in the water column. Light will penetrate to shallower depths because of increasing light scattering and absorption. As a consequence, the eutrophic zone becomes compressed (Goldman 1988; Kirk 1994).

Phytoplankton as Ecosystem Indicators—A useful bio-indicator responds to ecosystem perturbations. The response should be definitive and relatively rapid. Phytoplankton fit these criteria. The algae are easy to sample and easy to assay. Almost 30 years of continuous collections are available for Lake Tahoe from all depths in the euphotic zone. In the last decade, the phytoplankton samples have not been assayed; however, data from the previous two decades suggest that phytoplankton communities are predictable. Changes have occurred in the algal community as a result of changing conditions in the lake (Vincent 1978; Hunter et al. 1990).

Historically, efforts have been made to link the presence and quantity of individual algal species to changing trophic conditions in Lake Tahoe (Byron and Eloranta 1984; Goldman 1988). However, the use of only one or two algal species to prove the case of eutrophication has been unreliable. Individual taxa have varying responses to changing environmental conditions. In addition, there exists an incomplete understanding of what parameters trigger growth changes in individual species.

Even when whole groups of phytoplankton, such as diatoms, are considered, the link to eutrophication has not been dependable. Stockner (1971), working with diatom assemblages, reported that increases in araphid pennate diatoms or decreases in centric diatoms were an indication of increased eutrophication. Similarly, analysis of sediment cores from Lake Tahoe has shown that in the recent past (since 1960) the araphid pennates have increased in abundance in the phytoplankton community, possibly to the exclusion of some centric diatoms (Byron and Eloranta 1984). Nevertheless, these authors and other investigators have cautioned against the use of the ratio of araphid pennates to centrics (A/C) as a sole indicator of eutrophication (Brugam 1979).

While the A/C ratio may not be a valid indicator of eutrophication, the approach of considering changes within the entire community of phytoplankton, rather than individual species, seems to be the most valuable measure of ecosystem change (Reynolds 1980). Indeed, for Lake Tahoe, the phytoplankton community has shifted from diatom dominance to a shared dominance among diatoms, chrysophytes, and cryptophytes (Hunter et al. 1990) (Figure 4-37). Individual species have appeared and disappeared within the phytoplankton, and species diversity has increased. These indications are very reflective of the physical and chemical changes that have occurred in the lake over the same period.

For a large deep lake, like Lake Tahoe, such physical factors as depth of mixing, weather patterns, and surface inputs play an important role in determining the phytoplankton growth response (Goldman 1988). The longevity of the physical perturbations and the ensuing nutrient availability will determine which phytoplankton taxa in the community will dominate. The species whose growth requirements fit best to the current physiological characteristics and ecological conditions will respond with increased growth (Reynolds 1980).

Phytoplankton species respond to seasonal cues with predictable temporal patterns. Often it is not possible to predict algal community dominants

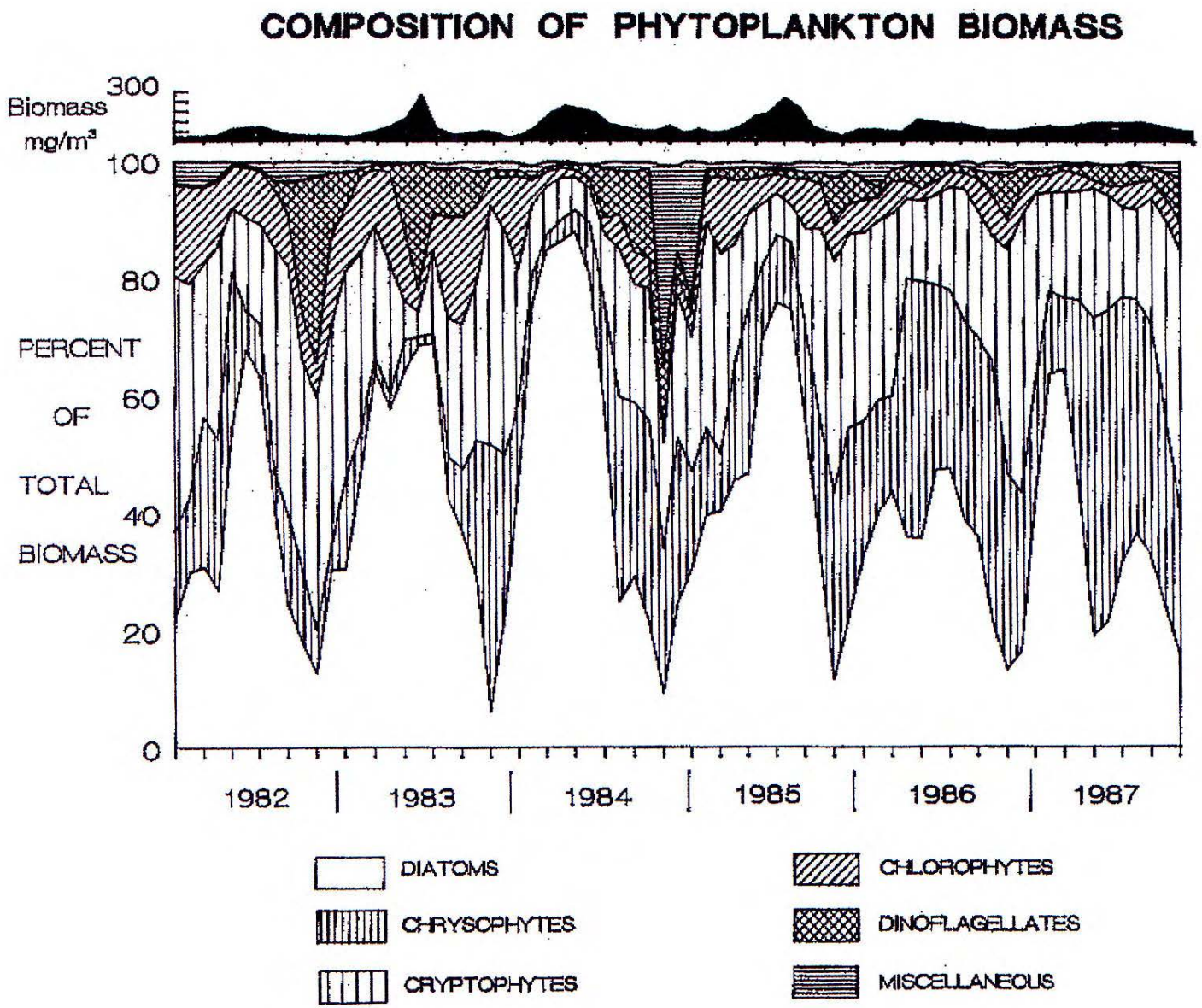


Figure 4-37—Change in the composition of phytoplankton biomass between 1982 and 1987 (from Hunter et al. 1990).

from one season to the next, but the community as a whole has typical seasonal trends. The annual sequence of phytoplankton progression begins the year with a relatively well-mixed euphotic zone. Dominance is shared between diatoms and cryptomonads. As the light duration and intensity increase and nutrient rich waters are mixed into the euphotic zone, the diatoms *Stephanodiscus alpinus*, *Asterionella formosa*, and *Aulacoseira italica* dominate the spring bloom. Generally by May, the surface waters are becoming nutrient depleted. Often chrysophytes dominate above the thermocline. Summer assemblages are marked by the spatial separation of phytoplankton communities with depth. *Cyclotella* spp. dominate in surface waters. *Synedra* spp. and *Cyclotella* spp. and chrysophytes share dominance at deeper depths. Below the thermocline (>60 m depth) cryptophytes, *Cryptomonas* spp. and *Rhodomonas lacustris*, and the green algae *Monoraphidium contortum* dominate. In late September, when the lake is still stratified and the thermocline is still well established, dinoflagellates, such as *Gymnodinium fuscum* and *Peridinium inconspicuum*, along with chrysophytes, dominate the upper water column. Below the thermocline, cryptomonads still thrive. As the thermocline decays in the autumn, more nutrients become available via mixing from deeper waters. Light intensity decreases and the upper water column has the lowest phytoplankton biomass. However, this time of year exhibits the greatest species diversity.

Lake Tahoe phytoplankton communities also exhibit spatial patterns. It has been shown that the lake has relatively homogeneous distributions of phytoplankton in a horizontal direction (Richerson et al. 1975; Eloranta and Loeb 1984). However, because of the lake's clarity and deep light penetration, phytoplankton communities separate vertically. As mentioned above, this is most apparent in summer when the water column is stratified, providing distinct growth niches. Some of the most predictable communities are in the deep chlorophyll maximum, observed during summer thermal stratification, between 40 and 80 m depth. Indeed, the euphotic zone extends beyond 125 m, and viable phytoplankton communities can survive in the aphotic zone (Tilzer et al. 1977; Vincent 1978).

The temporal and spatial predictability of the phytoplankton communities is potentially useful. Although species dominance changes annually and community composition is dynamic seasonally, general patterns remain. As eutrophication progresses, phytoplankton communities will exhibit pattern changes, such as new species introductions or deletions. Also, phytoplankton community dominance will change. Already, over the last three decades changes in the standing stock, species composition and richness, and patterns of dominance have been observed (Byron and Eloranta 1984; Hunter et al. 1990). These changes collectively indicate an alteration from historical phytoplankton data.

Nutrient concentrations of nitrogen and phosphorus in Lake Tahoe have been changing (Goldman et al. 1993). Both of these macronutrients are present in very low concentrations in the lake. Any change in the absolute concentration or in the relationship of one nutrient to another is likely to affect the phytoplankton community. Phosphorus concentrations have been linked to phytoplankton occurrence and periodicity (Lund 1965). Indeed, as Tahoe's phosphorus concentrations have decreased relative to nitrogen and become limiting, the phytoplankton communities have responded. Generally algal species that compete well for phosphorus uptake have become the dominants.

Nevertheless, phosphorus is not always the sole controlling factor. Because nitrogen is also present in such low quantities, it can at times be the limiting nutrient for phytoplankton growth. Researchers have used the ratio of nitrogen to phosphorus to predict phytoplankton community change (Tilman et al. 1982). Use of this ratio to describe Lake Tahoe's changing water chemistry is useful because the ratio takes into consideration concentrations of both nutrients. Nutrient limitation affects algae on a species-specific basis. Algal species have been shown to have different optimal N:P ratios for growth (Rhee and Gotham 1980). Organisms with lower optimal N:P ratios would be dominant in natural environments with lower ratios of available N to P and vice versa. This implies that

knowing the N:P ratio in Lake Tahoe and how it has changed seasonally and interannually would go a long way toward understanding the phytoplankton community changes.

Algal communities adapt to nutrient stress. One of the adaptive strategies, increased efficiency in biochemical uptake of nutrients, has been mentioned. Other strategies include nutrient storage, heterotrophy, phagotrophy, symbiosis, and morphological changes (Vincent and Goldman 1980; Turpin 1988). These adaptations have allowed the phytoplankton to optimize chances for survival in a stressful environment. Nevertheless, species that utilize these adaptations do not follow the predictable patterns based on the N:P ratio.

Historical Evidence for Phytoplankton Community Changes—Some supporting evidence for phytoplankton species response to nutrient change comes from paleolimnological studies. Historical phytoplankton communities have been partially reconstructed from sediment cores. The remains of algal cells with silica structures, such as diatoms and scaled chrysophytes, are found within the sediment. These cells are still identifiable, often to the species level. *Cyclotella ocellata, Aulacoseira italica,* and *Stephanodiscus alpinus* were the historical diatom dominants until approximately 1960. Since 1960 the diatom dominance has changed, with increases in *Fragilaria crotonensis*, *Cyclotella glomerata, Cyclotella stelligera, Fragilaria intermedia*, and *Synedra acus.* Decreases were seen in *Aulacoseira distans* (Byron and Eloranta 1984).

Not surprisingly, 1960 corresponds to the beginning of an era of increased anthropogenic influences affecting the water quality of Lake Tahoe (Goldman 1981). Basin-wide population increases started to have dramatic effects on water quality. Many new homes and roads were built around the shoreline, and the aesthetic appeal of vacations in a mountain location made the Lake Tahoe basin an increasingly popular destination. The Lake Tahoe basin experienced increased recreational use, soil disturbances, and nutrient loading from leaching septic tanks. Both nitrogen and phosphorus additions had an impact on the algal community composition and growth rates.

While nitrogen inputs may have had the most dramatic impact on algal growth rates (e.g., the shift in N-P limitation discussed above), it was the phosphorus loading that was probably responsible for the phytoplankton species shifts. Increased phosphorus input clearly occurs with soil erosion, as phosphorus compounds often attach or become adsorbed to soil particles. Additionally, phosphorus inputs from leaching septic tanks may have been very significant (Collingwood 1978). The sewage effluent was rich in phosphorus from human excrement, but also, notably, very high soluble phosphates came from synthetic detergents used in household laundry. Indeed, this source of phosphorus input to aquatic environments led to bans on the use of phosphates in detergents.

By the early 1970s sewage effluent at Lake Tahoe was no longer a significant issue. A basin-wide sewage system was installed and operational. Untreated effluent was piped out of the basin or sent to tertiary treatment facilities; however, a number of large-scale sewage spills have occurred since this time. In addition, building and road construction within the Tahoe basin was limited by regional governing agencies. Builders were required to employ tactics to reduce soil erosion; as a result, phosphorus loading was reduced.

These years of cultural eutrophication brought many changes to the phytoplankton community. Bioassay enrichment experiments began to show shifting nutrient limitation, with increased response to phosphorus additions (Goldman 1988). Further evidence of a changing chemical regime came from the appearance and then later disappearance of *Fragilaria crotonensis*. Byron and Eloranta (1984) reported that the diatom *F. crotonensis* had very low abundance prior to 1960. However, this species in particular, had enormous increases in abundance after 1960. It clearly dominated the phytoplankton assemblage (Goldman 1974). However, by 1975 its abundance decreased, and by 1980 it virtually disappeared from the lake (Hunter et. al. 1990).

The decrease in phosphorus loading to Tahoe had an immediate impact on populations of *F. crotonensis*. Tilman et al. (1982) reported that *F.*

crotonensis does not compete well in phosphorus-limited environments. Indeed, simultaneous to the *F. crotonensis* decline the phytoplankton community had an increase in the pennate diatoms *Asterionella formosa* and *Synedra* spp. Both of these species have been reported to exhibit more efficient uptake of phosphorus and therefore are better competitors than *F. crotonensis* in phosphorus-poor waters (Tilman et al. 1982).

Cyclotella spp. also has an affinity for phosphate-depleted environments; therefore, it is not surprising that this genus has increased in abundance, especially because phosphorus has become more limiting. Byron and Eloranta (1984) reported decreases in *C. ocellata* and increases in *C. stelligera* and *C. glomerata* since 1960. The decrease in *C. ocellata,* it might be argued, could be due to direct competition among species of the same genera. These species are similar in size and nutrient requirements. The fact that the genus has increased its representation in the phytoplankton community is a rather strong testament to the success of the group.

The chrysophytes also have been reported to be good competitors for phosphorus (Lehman 1976; Reynolds 1980; Sommer and Kilham 1985; Sandgren 1988). Lake Tahoe phytoplankton showed increased abundance of *Dinobryon*, *Chrysochromulina*, *Uroglena*, *Kephrion*, and *Synura* since the early 1980s. Indeed, beginning in the mid-1980s *Uroglena americana* began appearing in blooms that never had been reported before.

Phytoplankton Modes of Nutrient Absorption and Competition—Other phytoplankton assemblage changes tend to favor species with adaptive strategies for success in phosphorus-depleted systems. There have been increases in phytoplankton species that have the ability to internally store limiting nutrients. *Asterionella formosa*, in addition to having an affinity for low phosphorus concentrations, is capable of luxury consumption of phosphorus (Nalewajko and Lean 1980). This species can absorb phosphorus in the dark and in excess of its immediate requirements. Mackereth (1953) reported that *A. formosa* could store 25 times the minimum cell content of phosphorus before spring growth. This strategy for survival is considered secondary to those species that have low half saturation rates for phosphorus uptake (Sommer 1984).

There also have been increases in phytoplankton species that supplement nutrient requirements by phagotrophy, or ingestion of particles. This survival strategy appears to be an important pathway for energy flow in lakes. Phagotrophy has been reported for many of the chrysophytes, such as *Dinobryon*, *Chrysophaerella*, *Uroglena*, *Ochromonas*, *Chromulina*, and *Chrysococcus* (Bird and Kalff 1987). All of these genera have been found in Tahoe waters where the ability to ingest nutritious particles would provide a competitive advantage.

Since 1980 there has been a marked increase in flagellated phytoplankton in Lake Tahoe waters (Hunter et al. 1990). Algae motility has been recognized as an adaptive advantage (Salonen et al. 1984) as motile cells thereby have the ability to move from one space to another for nutrient retrieval or to improve their exposure to light. Algae migrate to deeper depths at night for nutrient retrieval and then move back toward the surface in daylight to proceed with photosynthesis. Some of these flagellated groups of algae have been discussed previously, but the flagellated algal group, the cryptophytes, also has increased in abundance. *Cryptomonas* spp. is especially noted for using motility to improve nutrient acquisition (Rott 1988). Both *Cryptomonas* spp. and *Rhodomonas* spp. dominate the Tahoe phytoplankton assemblage during some parts of the year (Hunter, unpublished).

Another competitive advantage of flagellates is their generally small size. Low nutrient conditions favor cells that have high surface to volume ratios (Grover 1989). Other variables being equal, smaller cells would have faster uptake and turnover of nutrients. The Lake Tahoe phytoplankton community has exhibited a general morphological shift in phytoplankton species. There have been increases in cells with long slender shapes (e.g., pennate diatoms) and overall increases in small cells with an ovoid shape. Interestingly, the biomass calculations of the phytoplankton cannot fully account for the rapid increases in algal growth rates. This increase could, in part, be due to the relatively more rapid metabolism of small cells. The smaller

cells, while more abundant and efficient at nutrient uptake and turnover, do not contribute much to the total biomass of the phytoplankton.

Predictions—Changes in the Lake Tahoe phytoplankton community have accurately reflected changes in the aquatic chemical environment. If nutrient loading continues, where both nitrogen and phosphorus concentrations increase, one or more of the following scenarios might occur:

- **Primary productivity and phytoplankton standing stock will increase**. As nutrient concentrations increase, the primary production and algal standing stock will increase (Schelske et al. 1974). The typical seasonally bimodal production peaks should increase in intensity and length. The periods of low production may become shorter and less pronounced.
- **Species richness of phytoplankton will increase**. When productivity increases, so should species richness. Even small changes in primary productivity should create large changes in species richness (Eloranta 1999).
- **Phytoplankton community dominants will shift**. As the physical and chemical environment changes, the phytoplankton community will respond with increased abundance in species that compete well. Moore (1979) reported that increased nutrient loading favors flagellates at the expense of diatoms. Cells also will tend to be smaller, with an overall increase in surface area to volume ratio.
- **The deep chlorophyll maximum, perhaps the most stable phytoplankton niche, will exhibit changes in species assemblage and distribution**. In thermally stratified waters, the biomass maximum is just below the thermocline (>40 m depth). At this depth there is enough light and nutrients to support algal growth. However, with increasing algal biomass, the clarity of Lake Tahoe will decrease. Light will not penetrate as deeply, and light conditions favorable for the algae will occur at shallower depths. The phytoplankton might have sufficient light to grow only within or above the thermocline, where nutrients are very limited. This change in nutrient conditions may strongly affect the species assemblage.

Most of these changes will happen simultaneously. However, the phytoplankton community dynamics will be the most responsive indicator of change. Efforts to understand these changes can provide strong management criteria for Lake Tahoe's primary production.

One could argue that phytoplankton identification and enumeration do not offer any advantages over the much quicker chlorophyll *a* measurement as a water quality indicator and management tool. The chlorophyll *a* measurement would provide useful information about changes in algal biomass, but it will not detect changes in the species composition of the phytoplankton community, only a relative change in algal biomass. The chlorophyll *a* measurement is an easy rapid method that fails to measure the one component that makes the phytoplankton such a good indicator of change.

In addition, and arguably most importantly in terms of lake clarity, knowing the species assemblage and relative abundance will provide more useful information to models predicting light attenuation contributed by the phytoplankton. Water clarity is strongly affected by the amount of light scattering in the water column, which in turn is closely related to the number and characteristics of particles in the water. However, the chlorophyll assay will not measure light scattering, cell characteristics, or population. It will measure light absorption by the phytoplankton but this parameter may not correlate as well with other measurements of lake clarity (Jassby 1999).

Growth of Attached Algae

Among the first visible evidence of eutrophication of Lake Tahoe was the increased amount of attached algae, or periphyton growth, along the shoreline in the 1960s. Goldman (1967b) indicated that when he first began studying the lake in 1958, the rocks along shore showed only slight growth of attached algae. However, in the spring of 1967, significant periphyton was found in the

shallows on boat hulls, and waves piled up mats of the detached material along the shore. Increased growth of periphyton was apparent to a largely shore-bound populace and provided additional, and very visual evidence that changes were occurring. This increase in periphyton growth coincided with the period of rapid growth and development within the basin during the 1960s and could be attributed to an increased nutrient loading from the surrounding watershed via stream and ground waters (Goldman 1974, 1981; Loeb and Goldman 1979). Widespread periphyton growth in the near-shore during the spring remains a characteristic of the shoreline today. Many studies have been done that have looked at the biology and distribution of periphyton in Lake Tahoe (Goldman and de Amezaga 1975; Loeb 1980; Loeb and Reuter 1981; Goldman et al. 1982; Reuter 1983; Reuter et al. 1983; Loeb and Reuter 1984; Loeb and Palmer 1985; Loeb 1986; Loeb et al. 1986; Aloi 1986; Reuter et al. 1986a, b; Aloi et al. 1988). The following presents some of the findings of these studies with emphasis on factors controlling growth, distribution, and evidence available on long-term trends for periphyton growth in the lake.

Periphyton Community Species Composition

Periphyton grows in the littoral (shore) zone of Lake Tahoe, which may be divided into the eulittoral zone and the sublittoral zone, each with distinct periphyton communities. The eulittoral zone is the shallow area between the low and high lake level (0 to 2 m) and is significantly affected by wave activity. This zone represents only a very small percentage (<1 percent) of the total littoral area. Substrata within this region desiccate as the lake level declines, and periphyton must recolonize this area when lake level rises. The sublittoral zone extends from the bottom of the eulittoral to the maximum depth of photoautotrophic growth. The sublittoral zone remains constantly submerged and represents the largest littoral benthic region of Lake Tahoe.

The eulittoral zone community typically is made up of filamentous green algae and filamentous diatom species. On rock surfaces just beneath the air-water interface (i.e., the uppermost region of the eulittoral), a green filamentous alga, *Ulothrix zonata* is often found. Extending from just below this growth to a depth of approximately 2 m, a brownish or whitish growth of algae covers the bottom of the eulittoral zone. This growth is strongly dominated by one species, the stalked diatom, *Gomphoneis herculeana*. In fact, the growth of this species is so great at times that it resembles a thick shag carpet on the bottom. *Synedra ulna* and various other diatoms are found growing in association with *Gomphoneis*. *Cyanophycean* (blue-green) algae are generally absent from the eulittoral zone.

The upper portion of the sublittoral zone (2 to 80 m) is dominated by blue-green algae capable of nitrogen fixation, including *Tolypothrix*, *Calothrix*, *Nostoc*, and *Scytonema*, which are heterocystous filamentous genera, and *Gloeocapsa*, which is a unicellular, sheathed blue-green algae. These algae firmly attach to the rock surfaces. Filamentous green algae and diatoms also are found in the sublittoral, but they make up a small part of the total biomass. Beneath about 80 meters, blue-green algae species drop out and diatoms and green algae become dominant; below 100 meters, an encrusted green algae may be found. The maximum depth at which periphyton has been found growing on rocks in Lake Tahoe is 198 meters.

Seasonal Patterns of Periphyton Growth—The periphyton in the eulittoral zone is more seasonally dynamic than that of the sublittoral community. Typically, growth of the eulittoral periphyton begins to increase in the late winter, reaches maximum growth in the spring, then decreases in the summer (Figure 4-38). In some years, the eulittoral periphyton also may show a secondary increase in growth during the fall. The range between minimum and maximum annual growth is typically greater for the eulittoral than for the sublittoral community. Following peak growth, the algae may slough off the rocks, and the growth of algae often remains low throughout the fall and winter. Aloi et al. (1988) found that at eulittoral sites with high accumulation of biomass (Pineland and Rubicon Point), sloughing of the entire algal mat occurred after the spring

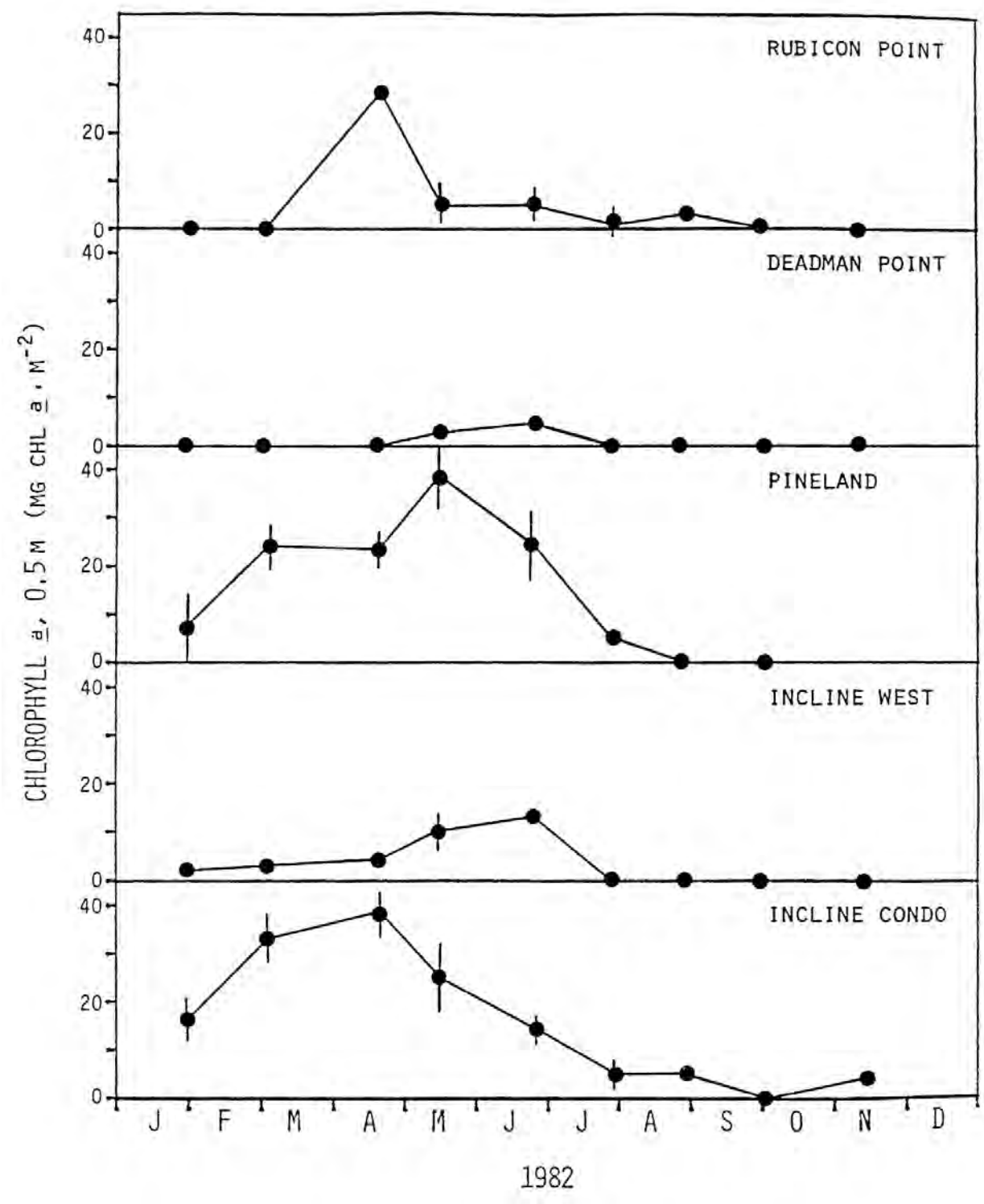


Figure 4-38—Spatial and temporal distribution of periphyton algae at a depth of 0.5 m in Lake Tahoe (from Loeb and Reuter 1984).

maximum. At sites with lesser accumulations of biomass (e.g., Deadman Point and Sand Point), the decrease in algal biomass was a slower process and appeared to be due to a combination of gradual attrition of periphyton biomass, combined with minimal regrowth.

The sublittoral periphyton community generally has less dynamic seasonal biomass fluctuations than the eulittoral community (Loeb et al. 1986). The baseline amount of growth remains more consistent for the sublittoral community. In contrast to the periphyton of the eulittoral zone, this community persists on the rock surfaces and remains viable throughout the year (Reuter et al. 1986a). The seasonal variations of the sublittoral community are generally less predictable than for the eulittoral community (Loeb and Palmer 1985). It was difficult to distinguish a consistent pattern of seasonal biomass for this community from 1982 to 1985 monitoring for three sites studied (Pineland, Deadman Point, and Rubicon Point) (Loeb et al. 1986). In addition, seasonal maxima for chlorophyll biomass at 2 m did not necessarily coincide with seasonal maxima slightly deeper at 8 m at each site.

Spatial Variation in Growth—Several studies have looked at the spatial distribution of periphyton. These studies have included spatial variability of periphyton on natural substrata (Loeb 1980; Loeb and Reuter 1984; Loeb and Palmer 1985; Loeb 1986; Loeb et al. 1986; Aloi 1986; Aloi et al. 1988) and spatial variability of periphyton colonization of artificial substrata (i.e., substrata, such as glass slides placed at sites to specifically measure periphyton growth) in the littoral zone (Goldman and de Amezaga 1975; Loeb et al. 1986; Aloi 1986; Loeb 1987). A consistent finding of these studies has been an association between development and disturbance in the watershed and increased periphyton growth nearshore.

To demonstrate the association between periphyton biomass and land disturbance on adjacent land, Loeb (1986) compared eulittoral chlorophyll *a* biomass data for four stations. Two stations (Pineland and Incline Condo) were adjacent to developed areas, and two stations (Incline West and Deadman Point) were adjacent to undeveloped areas. Greater amounts of periphyton were found at the developed stations than at the two undeveloped stations. The ratios among the maximum amount of biomass at each location (Deadman Point : Incline West : Incline Condo : Pineland) during each of the three years studied showed a persistent spatial relationship: 1982 (1:3:8:8), 1983 (1:1:6:10), and 1984 (1:2:4:13). Available light energy and water temperature did not vary significantly enough to explain the spatial differences in periphyton biomass among sites, especially between Incline Condo and Incline West, which were only 200 meters apart. The most likely cause for the differences among stations was nutrient availability. The Incline Condo station, which had higher periphyton biomass, was adjacent to a condominium development, which Loeb estimated used about 0.13 to 0.16 MT of nitrogen and 0.10 to 0.13 MT of phosphorus in fertilizer per year on a lawn upslope of the station. The Incline West site, which had less biomass, is only 200 meters away, adjacent to an undeveloped area. The Pineland site, which had higher biomass, is adjacent to the developed area of Pineland in the Ward Creek watershed on the west shore. Deadman Point is adjacent to an undisturbed area on the east shore, with the nearest development one kilometer away.

While there is strong evidence of an association between increased periphyton biomass and development or disturbance in the adjacent areas of the watershed, some variations from this pattern do occur. For instance, Rubicon Point is far from significant land-based disturbance, but consistently high biomass was measured at this station from 1983 to 1985 (Aloi et al. 1988). Aloi et al. hypothesize that upwelling of nutrient-rich profundal waters occur here, stimulating algal growth. High chlorophyll *a* biomass of periphyton also was measured near Sugar Pine Point, a relatively undeveloped area. Periphyton grow on isolated boulders at this site, separated by areas of sandy bottom. Aloi et al. (1988) speculated the wide separation between boulders may contribute to decreased competition for nutrients and increased growth of the periphyton.

Periphyton Primary Production—Periphyton primary productivity has been monitored in both the natural eulittoral and sublittoral periphyton communities (Loeb 1980; Loeb and Reuter 1984;

Loeb and Palmer 1985; Loeb et al. 1986; Aloi 1986). Aloi (1986) measured primary productivity in the eulittoral zone at Rubicon Point from January to October 1984 and from February to May 1985. She found primary productivity to be low during the late winter, to increase during the spring, and to decline again through the summer. Productivity ranged from 3 to 10 mg $C/m^2/hr$ during low growth during late winter-early spring and late-summer 1984 and reached a maximum of 203 mg $C/m^2/hr$ in early July 1984.

Primary productivity of the sublittoral zone showed less variability over the same period; at 2 m, productivity ranged from 1.44 to 9.72 mg $C/m^2/hr$, at 8 m, productivity ranged from 0.97 to 13.97 mg $C/m^2/hr$, and at 16 m, productivity ranged from 0.60 to 4.22 mg $C/m^2/hr$. Sublittoral primary productivity measurements were made over a longer period from February 1982 to May 1985 (Loeb et al. 1986) and in general indicated a slightly greater fluctuation, with slightly higher maximum productivity values at 2 m and 16 m in 1982 (14.53 and 10.43 mg $C/m^2/hr$, respectively).

The contribution of periphyton primary production to overall lake primary production is thought to be small, relative to that from the phytoplankton. The littoral zone productivity (phytoplankton plus periphyton production) of Lake Tahoe has been estimated to be about 10 percent of the lake's total annual primary production (Goldman and de Amezaga 1975; Goldman 1981).

Periphyton primary productivity measurements provide a measure of the growth rate of the periphyton (i.e. the production of new organic matter). This new production can be considered detrimental when it produces unaesthetic slimy coatings on rocks nearshore, which also make wading and swimming less enjoyable, when it coats boat hulls, and when decaying mats of periphyton slough from rocks and accumulate along the shoreline. New production by the periphyton also may be utilized by secondary producers, including crayfish, fish, and insects and may be incorporated into the food chain in Lake Tahoe. The crayfish *Pacifastacus leniusculus* has been found to derive 65 percent of its diet from periphyton (Flint 1975).

Factors Affecting Growth of Periphyton—Several physical, chemical, and biological factors may affect the growth of periphyton in Lake Tahoe. The period of maximum periphyton accrual in the eulittoral zone in the spring coincides with increasing flux of solar radiation, lake temperature, and availability of nutrients. Light availability is a fundamental factor affecting photosynthesis and the primary productivity (growth rate) of periphyton. Solar radiation follows a typical cycle of minimum solar radiation in early winter, a rapid increase in the spring to an early summer maximum, and a rapid decrease in the fall back to the minimum. The rapidly increasing solar radiation in the spring may contribute to increased growth of periphyton in the spring. Water temperature is another important factor that could affect productivity of the algae. The slight increases in water temperature that occur in the spring cannot alone account for increases in biomass seen. The increased growth of eulittoral algae in the spring is thought to be largely the result of increased availability of nutrients (Loeb and Reuter 1984). Algal bioassays have shown that addition of nitrogen alone and occasionally phosphorus alone can stimulate periphyton growth and that the combination of nitrogen and phosphorus often causes the greatest growth when significant responses are observed (Loeb 1986; Loeb et al. 1986; Loeb 1987). However, periphyton bioassays have not been run since the mid-1980s, near the time when the dependence of lake phytoplankton on phosphorus was found to increase dramatically. The snowmelt generally occurs from April to June, when much of the annual tributary loading of nutrients occurs. In addition to nutrient inputs from streams, ground water inputs with associated nutrients are thought to be at a maximum during this time (Loeb and Goldman 1979). Lake mixing also contributes nutrients in late winter, which could affect the growth of periphyton in the spring. Reuter et al. (1986b) provided evidence that the eulittoral periphyton, while not having a high physiological affinity for nitrogen, were able to effectively utilize nutrients because the breaking

waves in their shallow environment enhanced the rate of nutrient diffusion into the cells.

Some factors that affect the accrual of the sublittoral periphyton biomass may be generally similar to those that affect the eulittoral periphyton community (Loeb et al. 1986). However, it is also possible that differences in resource availability, physiology, and physical factors in the sublittoral may lead to different growth responses. For instance, the sublittoral periphyton can utilize atmospheric N_2 as a source of nitrogen, which allows these algae to maintain growth when inorganic nitrogen is scarce and which could result in different growth responses than for the eulittoral periphyton under certain conditions of inorganic nitrogen availability. Additional information on factors controlling growth in this community is needed.

Periphyton Nitrogen Fixation—The upper portion of the sublittoral zone (2 to 60 m) is dominated by heterocystous blue-green algae, or algae that are capable of nitrogen fixation. These algae can utilize atmospheric nitrogen for growth, which appears to be a successful adaptive strategy for survival in N-deficient environments, such as Lake Tahoe (Reuter et al. 1986a). This is in contrast to the eulittoral periphyton and lake phytoplankton, which require inorganic nitrogen (NO_3^-, NH_4^+) for growth. Reuter (1983) found that the sublittoral community is perennial and actively fixes N throughout the entire year. Seasonal rates of N-fixation ranged from 4 to 561 $\mu g\ N/m^2/h^1$, with a distinct summer maximum and winter minimum. The seasonal cycle of N-fixation in Lake Tahoe appears to be related primarily to temperature. Factors that have been found to also influence N-fixation in other systems include levels of organic nitrogen, phosphorus and iron (Horne 1978), and their possible effects in Lake Tahoe cannot be dismissed.

During nitrogen fixation, atmospheric nitrogen (N_2) is incorporated into algal biomass, which may later be mineralized to inorganic forms and become available to support phytoplankton production; therefore, it is a source of nitrogen input for the lake. Reuter et al. (1986a) estimated the loading rate of nitrogen resulting from nitrogen fixation was 0.03 kg N/ha (of lake surface)/yr. When this rate is compared to other sources of inorganic nitrogen loading into Lake Tahoe, N loading from periphyton nitrogen fixation is very small, <1 percent of total annual dissolved inorganic nitrogen loading.

Evidence Available for Long-term Trends in Periphyton Growth—Early observations indicate that a significant change from relatively small amounts of periphyton growth in the past to increased amounts of growth took place during the 1960s. As discussed above, Goldman (1967b) indicated that when he first began studying the lake in the late 1950s, the rocks along the shore showed only slight growth of attached algae. However, in the spring of 1967, he observed much periphyton growth in the shallows, on boat hulls, and mats of the detached material piling up along shore. Goldman and de Amezaga (1975) studied periphyton growth around the lake in 1971 and found that in the spring and early summer inshore areas were visibly green due to periphyton growth, with particularly heavy growth found in the vicinity of some stream mouths.

Goldman and de Amezaga (1975) compared the growth of periphyton on artificial substrata (Pyrex cylinders) at many sites around the lake in 1971 and discerned a trend of increased periphyton growth associated with human activity in the watershed. They found that the highest growth rates were recorded near stream mouths where human activity is the greatest, such as Ward Creek and Incline Creek, and that in general, lower growth was found in areas of least tributary influence, such as along the sparsely populated east shore. As indicated above, many subsequent studies have confirmed a trend of increased periphyton growth adjacent to areas of developed or disturbed portions of the watershed. This increased periphyton growth is thought to be largely due to the increased nutrient loading associated with the land development or disturbance in the watershed and represents a change from the expected natural growth pattern.

Quantitative data for periphyton biomass and primary productivity are available for certain years from 1971 to 1992, which should provide additional information on trends; however, a

thorough statistical analysis of these data has not yet been made. Only very general observations were attempted here, based on the available biomass data. Only recently has funding been reinstated to carry on periphyton monitoring.

Comparative data are available for periphyton biomass on natural rock substrata in the lake for 1978 (Loeb 1980), 1982 to 1985 (Loeb and Reuter 1984; Loeb and Palmer 1985; Loeb et al. 1986), 1986 to 1987 (Loeb 1987), and 1989 to 1992 (TRG, unpublished). Chlorophyll biomass data for the Rubicon Point 2-meter and 8-meter sites are available for several of the above periods. Sublittoral chlorophyll *a* biomass in 1978 (February to November) at 2 meters ranged from about 5 to 15 mg/m^2, from 1982 to 1985 it ranged from 7 to 52 mg/m^2, and from 1989 to 1991 it ranged from 12 to 37 mg/m^2. At 8 meters, chlorophyll biomass ranged from about 14 to 35 mg/m^2 in 1978, from 12 to 73 $mg\ m^{-2}$ from 1982 to 1985, and from 10 to 37 mg m^{-2} from March to June of 1992. These data indicate variability in the sublittoral chlorophyll *a* has occurred, but no long-term trend of either increase or decrease in biomass is apparent from these ranges.

Chlorophyll *a* biomass data is available for Pineland eulittoral (0.5 m) periphyton growth from 1982 to 1985 (Loeb et al. 1986), from 1986 to 1987 (Loeb 1987), and from 1989 to 1992 (TRG, unpublished). This data indicates that substantial year-to-year variability in seasonal maximum biomass has occurred. However, it is difficult to discern any long-term trend in overall annual growth from 1982 to 1992. This observation is not inconsistent with the more general finding that periphyton biomass in Lake Tahoe has increased over time. In the studies cited above, periphyton at a single location was assessed over time. The data imply that more of the shoreline may be now experiencing periphyton growth.

A noteworthy trend from these observations is the consistent presence of the blue-green algae in the sublittoral zone from at least 1971 to 1992, when sampling was terminated. It is possible that this community has existed at some level of growth in Lake Tahoe for a long time. Studies of other oligotrophic lakes, including pristine Crater Lake in Oregon, have shown similar sublittoral blue-green algal communities (Loeb and Reuter 1981). The presence of filamentous green algae and diatoms in the eulittoral zone of Lake Tahoe is similarly a characteristic of other oligotrophic lakes. Changes in the *amount* of growth of the eulittoral community in Lake Tahoe have been a visible indicator of eutrophication in the lake.

What is known regarding phosphorus and nitrogen in Lake Tahoe and regarding the long-term behavior of these nutrients?

Jassby et al. (1995) examined the long-term change in Lake Tahoe's water chemistry for nitrate (NO_3^-) and THP. These nutrients were selected because of their importance to algal growth and eutrophication and because of the availability of an extensive database from which a statistical evaluation of long-term trends could be made. A significant portion of the discussion below comes directly from that analysis.

Due to the vagaries of funding sources and the varying interests of the many TRG researchers over the past three decades, the water chemistry data set for Lake Tahoe varies depending on the specific nutrient species in question. The longest records are for nitrate ($NO_3^- + NO_2^-$) and THP at the mid-lake station, which have been measured since 1973. Ammonium (NH_4^+) measurements are available since 1983, TKN since 1990, and SRP, TDP, and PP since 1992 at the mid-lake station. Although these latter series are inadequate for studying long-term variability, they enable an estimate of lake nutrient reservoirs. The TRG mid-lake station overlies the deepest point in the lake (505 m) and allows estimates of whole-lake nutrient content. Samples are collected monthly at depths of 0, 10, 50, 100, 150, 200, 250, 300, 350, 400 and 450 meters.

Nutrient Reservoirs

Data from 1992 and 1993 allows an examination of the size of the reservoir or pools for various forms of nitrogen and phosphorus in Lake Tahoe. By definition, total-N (TN) and TP contain both dissolved (<0.45 μm) and particulate (>0.45 μm) components. Typically, water clarity is most affected by the particulate fraction; however, there may be significant transformation between particulate and dissolved material through biological uptake, mineralization, dissolution, and other

processes. These processes occur on a multitude of time scales extending from seconds to years. Many of the individual forms of nitrogen and phosphorus show significant seasonal and interannual variability depending on the degree of input from the airshed and watershed and lake biogeochemistry. This section is focussed primarily on the annual, interannual, and decadal patterns of Lake Tahoe's nitrogen and phosphorus content.

Nitrogen

The mean whole-lake concentration of TN for Lake Tahoe in 1992/1993 was 65 μg/L. Monitoring and research data summarized by Marjanovic (1989) indicates that particulate-N (PN) comprises nearly 15 percent of TN, or in this case 9 μg/L. The majority (85 percent) of TN occurs in the dissolved form either, as dissolved organic-N (DON) or dissolved inorganic-N (DIN). DIN consists of nitrate (15 μg/L) and ammonium (1-2 μg/L) and accounts for approximately 25 percent of TN. At a mean concentration of approximately 40 μg/L, DON constitutes the largest N-fraction at 60 percent. Nitrate and ammonium are known to be readily and directly available for algal growth; however, the bioavailability of DON, not only in Lake Tahoe but in the world's lakes and oceans in general, is not well understood.

DON includes a wide array of chemical compounds, ranging from some of the more labile, or easily broken down, compounds, such as certain amino acids, to more refractory N-containing compounds, which resist bacteria breakdown. Lake Tahoe is similar to most other lakes that also contain large portions of their TN pool as DON. The ratio of organic-N (as PN+DON) to DIN during the 1992/1993 period was on the order of 4:1. From 1984 to 1989, this ratio in Lake Tahoe was 5:1 (Marjanovic 1989). Because the PN+DON pool is large, relative to DIN, even a relatively small conversion could have a major effect on DIN. For example, a mineralization rate that is only 10 percent higher than the current rate (unknown at this time) would result in a 50 percent increase in biologically available DIN. Moreover, mineralization of only one to two percent of the DON pool in Lake Tahoe in roughly equal to the annual DIN load from atmospheric deposition and stream runoff combined. This underscores the importance of considering nutrient cycling and bioavailability in any discussion of lake nutrient dynamics. Difficulties in methodologies make quantification of the mineralization of PN+DON to DIN unreliable; highly sophisticated research is needed to address these questions. Presently only a limited number of oceanographers are working on this issue.

Based on the preceding data, the approximate whole-lake content for various N-fractions are as follows:

Fraction	Metric Tons*
NH_4^+	219
$NO_3^- + NO_2^-$	2,344
PN	1,409
DON	6,216
TN	10,188

In comparison to the estimated TN load of approximately 350 MT per year (see nutrient budget), this corresponds to a specific loading rate of $0.034 \cdot yr^{-1}$. Viewed in a different light, this also means that in the absence of any loss (e.g., outflow, sedimentation, denitrification) and no change in loading, it would take approximately 30 years of input to double the existing lake TN content. Clearly, the response time for nutrient concentrations in Lake Tahoe is long as a result of its large volume (156 km^3), great depth (505 m), slow hydrologic flushing rate (650 to 700 years) and relatively low loading rates relative to these hydrogeological features.

Phosphorus

Mean, whole-lake TP concentration in 1992/1993 was 6.3 μg/L. PP, at a calculated concentration of 0.6 μg/L, was approximately 10 percent of this larger pool. As observed for nitrogen, most of the lake's P is in the dissolved form; TDP was determined at 5.7 μg/L. Further dividing TDP, ortho-P ($PO4^{-3}$ or SRP) was 2.1 μg/L, and dissolved organic-P (DOP) was 3.6 μg/L. Total acid-hydrolyzable $PO4^{-3}$ (THP) represents that P-pool converted to ortho-P following a relatively mild acid

* One metric ton = 1,000 kilograms, or 2,204.6 pounds

digestion during chemical analysis. This is intended to represent the potentially bioavailable-P. THP from 1992 to 1993 was 2.6 μg/L, and, as expected TP<THP>PP.

Typically, when algal growth is active ortho-P is rapidly incorporated into phytoplankton and bacterial biomass. Hatch et al. (in press) tested the response of Lake Tahoe phytoplankton to stream water additions of various particle size classes. Over the one week course of these experiments, the dissolved fraction of stream water contributed most (75 to 90 percent) of stimulation to Lake Tahoe phytoplankton. Within the DP-pool, algal response was best related to ortho-P ($p=0.005$) and less related to DOP ($p=0.051$).

The approximate whole-lake content for various P-fractions are as follows:

Fraction†	Metric Tons
SRP	340
TDP	901
DOP	561
THP	403
PP	91
TP	992

In comparison to the estimated TP load of approximately 42.6 MT per year (see nutrient budget), this corresponds to a specific loading rate of $0.043 \cdot yr^{-1}$. In the absence of loss and with no change in loading, it would take approximately 23 years of input to double the existing lake TP content.

Spatial Variation

A comparison of the mean annual concentrations of nitrate and THP in the euphotic zone at the TRG's mid-lake and index stations provides evidence that the mid-lake location, in general, is representative of most of the lake. The index station is positioned on the lake's western shelf, approximately two kilometers off-shore. It overlies 150 m of depth and is just south of Blackwood Creek. In this analysis, the euphotic zone is taken to be 0 to 100 meters, which approximately corresponds to the depth where light transmission is one percent of surface light; most of the lake's phytoplankton growth occurs in this region.

For the period 1985 through 1993, nitrate at the index station was 4.9±0.8 μg N/L and slightly higher than the average concentration of 4.5±1.0 μg N/L at the mid-lake station (average of mean annual concentrations). The largest annual difference in nitrate between these two locations was in 1992, when NO_3^- at the index station was 3.6 μg N/L as compared to 2.8 at mid-lake. THP was virtually identical at these two stations, with the average of the mean annual concentrations equal to 2.9 μg/L for mid-lake and 3.0 μg/L for the index station. As for nitrate, the largest difference between these two stations occurred in 1992, when the index THP concentration was 20 percent greater (i.e., 2.4 μg/L vs. 2.0 μg/L).

Long-term Chemistry Records

According to Jassby et al. (1995), the monthly series of mean whole-lake NO_3^- displays considerable variability at the scale of months and years but only a weak long-term trend that is due to a rise prior to 1977 (Figure 4-39). To assist in the statistical analysis of this data, a 12-term moving average was calculated; because there were too many missing data points prior to 1980, data earlier than this date were not included. The moving average helps to filter out much of the seasonal variability and focus on interannual and long-term changes. The average data shows persistence in the form of quasi-cyclical behavior; for example, between 1980 and the mid-1990s, NO_3^- appeared to peak on a somewhat regular three- to five-year interval. Thiel slopes were calculated from the time series and were used as indicators of long-term trend. For NO_3^-, the Thiel slopes were positive for every month but were only statistically significant for August. These data indicate that over the period of record, there was an increase in NO_3^- concentration in Lake Tahoe during each of the 12 months but that this rise was significant ($p<0.05$) for August. However, the occurrence of a positive Thiel slope during every month is highly unlikely due to chance alone ($p=0.0002$).

† By definition, TP = PP +TDP and TDP = SRP + DOP

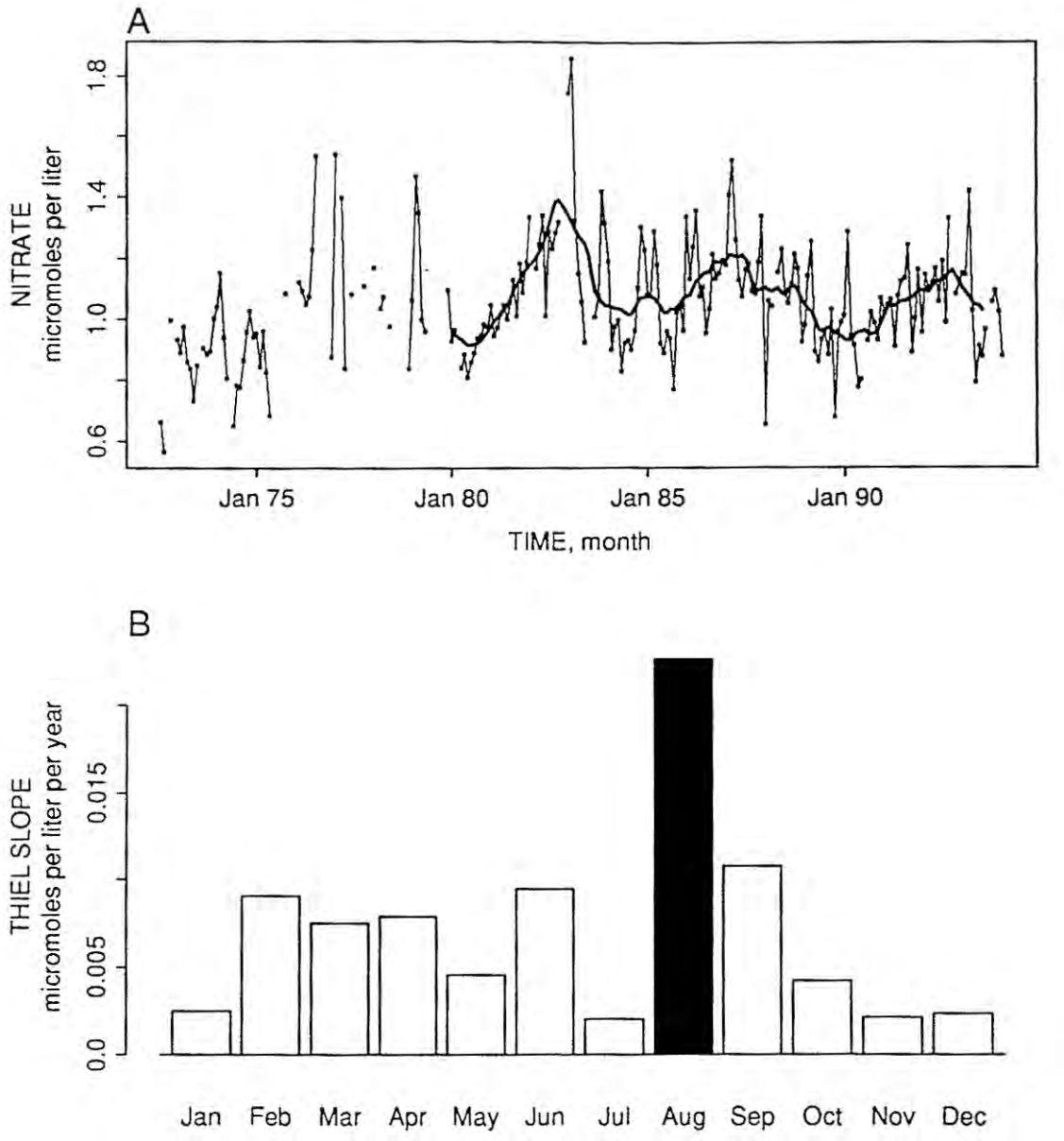


Figure 4-39—Presentation of long-term nitrate water chemistry data from Lake Tahoe. Thiel slopes show an increase in concentration during each month; however, this increase is only statistically significant in August. 1 micromole per liter = 14 μg per liter (from Jassby et al. 1995).

As in the case for NO_3^-, the monthly THP time series exhibits much seasonal variation but no unequivocal long-term trend (Figure 4-40). Between 1980 and 1993, the 12-term moving average even suggests some downward movement for whole-lake THP. Nine months exhibit a negative Thiel slope, but only two of these slopes—March and April—are significant ($p<0.05$).

Given the statistically significant change in algal primary productivity and water clarity since continuous measurements began in 1968, it is important to ask why the time series for NO_3^- and

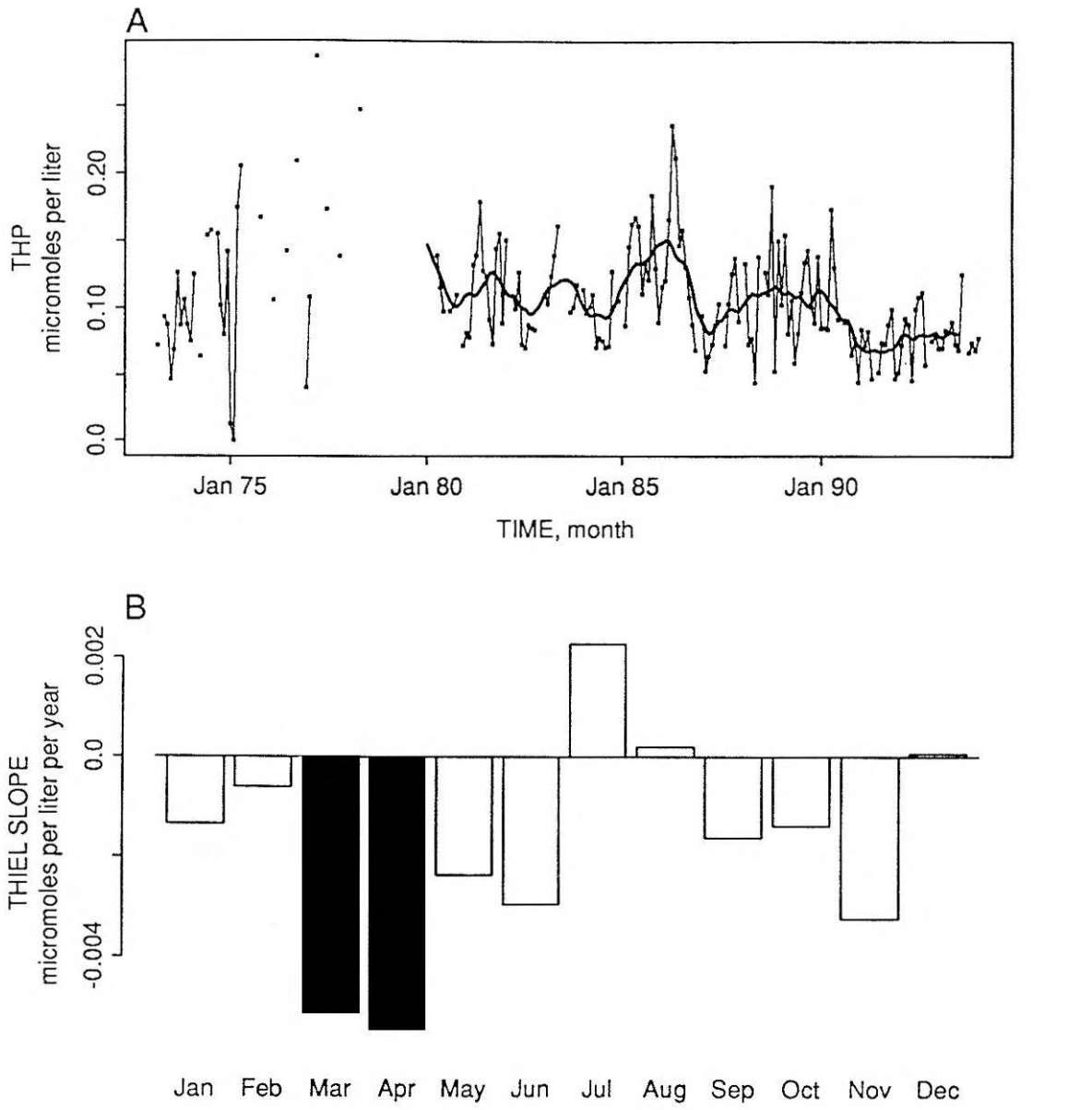


Figure 4-40—As in Figure 4-39, except for total hydrolyzable phosphorus. Thiel slopes indicate a reduction in THP concentrations over the period of record (from Jassby et al. 1995).

THP show only weak evidence for a long-term change in lake water chemistry? Jassby et al. (1995) offer a number of possible explanations.

First, NO_3^- and THP may not represent the total biologically available N and P pools. If this were the case, a change in bioavailable N or P could occur and affect lake response but still not be reflected in the NO_3^- and THP series. The bioassay data (see discussion above) indirectly suggest such a lack in correspondence between the measured NO_3^- and THP series and the true biologically available pools. Despite the large interannual variability in NO_3^- and THP, P-limitation has been remarkably consistent since about 1982, indicating a more stable supply of bioavailable N and P than implied by the time series measurements.

Second, it is possible for increased loading to induce an increase in primary productivity with no significant change in the concentration of dissolved nutrients. Studies of P-cycling within the open water

regions of lakes indicate that phosphate is very rapidly incorporated into phytoplankton and bacteria (Lean 1973). The dynamic movement of P among phosphate ($PO4^{-3}$), particulate-P (algae), low molecular weight-P and colloidal-P affects the pool of bioavailable-P. Phosphate uptake and turnover has been found to be extremely rapid during times of high demand (active algal growth) and low loading inputs. During these periods, newly loaded $PO4^{-3}$ is likely to be consumed within a period of minutes to just a few hours at most (Wetzel 1983). Phosphate turnover is more rapid under oligotrophic conditions where P-deficiency exists (Peters 1979), e.g., Lake Tahoe. P-cycling in lakes is regulated not only by biological transformations but by abiotic processes, such as complexation or dissolution from inorganic particulate matter (e.g., eroded soils). Monitoring and research efforts on the P-content of Lake Tahoe or P-inputs have not focused on the question of bioavailability; however, given that TRP was 84 percent of the whole-lake THP pool in 1992/1993 but only 45 percent and 41 percent of the TOP and TP pools, respectively, a large portion of lake THP may be bioavailable. As a consequence of its potentially rapid turnover, THP would not be expected to accumulate over time. Clearly, the understanding of lake response to nutrient loading requires a much more thorough understanding of P and N bioavailability, both as a function of loading and the nutrient reservoirs in Lake Tahoe.

A third possible explanation for the apparent lack of a long-term change in water chemistry despite a clear signal in lake response is that trends in nitrate and THP could be disguised by the strong interannual variability and that measurements are too near the analytical limits of detection. Jassby et al. (1995) point out that the whole-lake nitrate pool during summer stratification (June through August) is, on average, about 20 percent lower during years of deep spring mixing. Deep mixing occurs on the average of once in three years, during which time nitrates and other nutrients released by decomposition in deep waters are delivered to the euphotic zone where they can be taken up by phytoplankton. While this process does not affect whole-lake TN, it will change whole-lake $NO3^-$. Jassby et al. (1995) calculated that the difference in $NO3^-$ during summer stratification between deep- and shallow-mixed years is on the order of 3 μg N/L but that a $NO3^-$ increase of only half that amount (1.4 μg N/L) hypothetically could result in a whole-lake doubling of phytoplankton. Given that the analytical reporting limit for nitrate is approximately 1 μg N/L, long-term changes in Lake Tahoe phytoplankton may not be readily discerned from the nitrate reservoir, despite the fact that nitrate is readily bioavailable. Similar concerns exist for phosphorus in Lake Tahoe.

Fourth, in the most recent analysis of the origin and scale dependence of temporal variability in Secchi depth transparency in Lake Tahoe, Jassby et al. (1999) suggest that mineral suspensoids from eroded watershed materials may contribute to the documented decline in lake clarity. To the extent that these materials contribute to the decline in Secchi depth, the relationship between THP and $NO3^-$ will not be unambiguous.

Finally, the possible downward trend in THP suggested by the post-1979 time series, while intriguing, should not be overinterpreted. While it could be argued that erosion control measures in the Tahoe basin over the past 20-plus years have had an effect on P-loading, the observed trend in THP (arguably, more closely related to soluble-P than total-P) also could be the result of increased phytoplankton uptake of lake-P, which would result from the continued atmospheric deposition of nitrogen directly to the lake surface. Indeed, this would be consistent with algal bioassay results that show an enhanced response to additions of N and P simultaneously and with the observed increase in primary productivity of Lake Tahoe.

Changes in Lake Nutrient Content

Mass Balance Considerations—For the reasons presented above, evaluation of the long-term nitrate and THP series may not yet be adequate for the purpose of determining long-term change in the nutrient content of Lake Tahoe. Using the 1992/1993 estimates of lake nutrient pools and applying a mass balance approach (change in lake nutrient content = inputs/outputs), Jassby et al. (1995) addressed the question: Are estimates of the doubling times for TN and TP pools compatible

with the time course of measured change in Lake Tahoe's primary productivity and nutrient limitation; that is, in order for nutrient loading from atmospheric deposition and watershed runoff to drive the changes seen in lake response from the instrument record, the TN pool must have changed significantly during the past 30 years.

Taking nitrogen (N) as an example, mass balance for TN in lake water requires that:

$$\frac{\partial N}{\partial t} = \frac{LN}{H} - (r + sN)N$$

where:
$\frac{\partial N}{\partial t}$ = change in TN over time
N = average whole-lake concentration (mg/m^3)
LN = external loading rate ($mg\ N/m^2/yr$)
H = mean depth (m)
r = flushing rate constant (1/yr)
sN = rate constant for loss other than outflow (1/yr)

Based on studies of nutrient loss rates at other lakes, the doubling time for the TN pool was estimated as 52 years; the calculated lower limit was 30 to 35 years. These values are consistent with the time scale of change in the record for primary productivity. In other words, at current rates of TN loading, lake content can double on the time scale of three to five decades. It is noteworthy that in the absence of atmospheric TN loading, the TN doubling time would have been much slower, at 220 years. Doubling time for the TN:TP ratio in Lake Tahoe is on a similar time scale, or 30 years (Jassby et al. 1995).

What is the magnitude of nutrient loss from Lake Tahoe and what is the importance of loss processes on mass balance and nutrient accumulation?

Mechanistic water quality models and nutrient budgets are based on the principle of mass conservation. By definition, therefore, one would expect that mass balance equations balance when all terms for the nutrient pools, sources, and sinks have been correctly specified. Unfortunately, it is often impractical or cost prohibitive to measure each of these terms individually for any particular system. Therefore, at least one term generally is specified in the mass balance equation by forcing a fit to the equation or by extracting a coefficient value from cross-sectional studies, where data from a spectrum of cases (lakes) have been analyzed for a general empirical specification of the relevant parameter or coefficient.

Clearly, accurate specification of nutrient loss coefficients is an essential step in the construction of mass balance models that are used to better understand a system and its response to mitigation. Most easily measured of these loss coefficients are the nutrient outflows that occur with hydraulic discharge. Other nutrient loss processes, however, may be more important; especially when the system has a long hydraulic residence time. At Lake Tahoe the hydraulic residence time is about 650 years (Marjanovic 1989). Data on nutrient loss from surface discharge to the Truckee River indicate that flow out of the lake represents less than five percent of total nutrient loss. Loss of nitrogen resulting from denitrification was measured in a preliminary fashion in the early 1980s. Because of the extremely low concentration of nitrate in the sediment porewater, rates were below detection in unamended samples.

Accurate specification of the sedimentary loss rate, therefore, is a critical parameter for mass balance models of Lake Tahoe. The coefficient of sedimentary loss can be expressed as a sedimentation coefficient, σ (Vollenweider 1969, 1975), as a settling velocity, v_S (Chapra 1975), or as a retention coefficient, *R* (Dillon and Rigler 1974). Although these coefficients are not easily measured directly, their general values and some criteria for specification have been derived from empirical relationships observed in several cross-sectional studies. The coefficients also are intrinsically related (Chapra 1975), so they can be converted from one form to another within a specific system, depending on the data available and the question at hand.

At Lake Tahoe, Heyvaert (unpublished) recently has measured nutrient settling velocities (v_S) for phosphorus from the accumulation rates in

several mid-lake sediment traps, according to the equation:

$$v_S = J / P$$

where:
J = downward flux of phosphorus to the sediment (mg m^{-2} y^{-1})
P = lake phosphorus concentration (mg m^{-3})

Values for this coefficient were directly determined from two distinct hydrologic periods in recent lake history, thereby representing a range of values likely to be encountered within this system. The phosphorus settling velocity for a two-year period during the drought of 1987 to 1994 was 10.3 m y^{-1}. During the post-drought interval from 1995/1996 this coefficient was 22.5 m y^{-1}. The long-term average is likely to be some intermediate value, which is defined at this time simply as the mean (16.4 m y^{-1}). For Lake Tahoe, with a mean depth of 313 m and a maximum depth of about 500 meters, the phosphorus settling time to these depths would be on the order of 19 years to 31 years, respectively.

These results compare favorably to coefficient values derived from several commonly cited cross-sectional studies. In one analysis from the Canadian Shield Lakes, for example, Chapra (1975) found the best empirical fit to phosphorus retention data was provided by a phosphorus settling velocity of 16 m y^{-1}. This is remarkably similar to the estimate from Lake Tahoe. Other cross-sectional studies have reported somewhat lower values. Larsen and Mercier (1976) fit a phosphorus settling velocity of 11.7 m y^{-1} to data from a similar study but with a different set of lakes. DePalma et al. (1979) found that literature values reported for this coefficient ranged from 0.7 to 37.9 m y^{-1}, with a mean of 9.5 m y^{-1} among 50 temperate lakes. Results from Lake Tahoe fall within this range, although somewhat above the typical average. While the downward flux of phosphorus at Lake Tahoe may be relatively efficient, compared to other systems, its overall settling time is longer because of the great depth of this lake.

Assuming that the value for the coefficient of phosphorus settling velocity in Lake Tahoe is reasonable, it is possible to estimate a system response time to changes in phosphorus loading rates. Dillon and Rigler (1975), for example, suggested using a half-life time change, which is the time required to achieve a new concentration that is midway between the initial concentration and the final concentration, after a step decrease in loading. Based on the coefficient of phosphorus settling velocity (16.4 m y^{-1}) and some additional parameters describing the volume, depth, and hydraulic input rate for Lake Tahoe, the 50 percent response time to changes in phosphorus loading is about 13 years. Dillon and Rigler (1975) also suggested that three to five times the half-life, representing 87.5 to 96.9 percent of the time required to reach a final steady-state, could be used as a reasonable estimate for a lake's complete response. For phosphorus in Lake Tahoe this would be 39 to 65 years.

Although application of these sedimentation coefficients could be refined in a dynamic model of lake nutrient cycling, fundamentally the principle would remain the same, and results are likely to be quite similar. That is to say, a 50 percent phosphorus response time of between nine and 20 years is to be expected for Lake Tahoe, based on the range of coefficients obtained from sediment trap analyses to date. Similarly for nitrogen, a 50 percent response time of between 14 and 22 years is to be expected from nitrogen settling velocities of 9 and 15 m y^{-1}, measured during the drought and post-drought intervals, respectively.

Now, for the first time, it is possible to make an independent estimate of the annual nutrient loading necessary to sustain observed sedimentary loss rates. In this case, the sedimentary nutrient loss coefficients are applied to a mass balance equation, with the assumption that hydraulic outflow is the only other significant loss term for nutrients in Lake Tahoe (Jassby et al. 1995).

$$dc / dt = (W / V) - (Q / V)c - (v_S / H)c$$

where: c = lake concentration of nutrient (mmol m^{-3})
W = total loading of nutrient to lake (mmol y^{-1})
V = volume of lake (m^3)
Q = hydraulic input (m^3 y^{-1})
v_S = nutrient settling velocity (m y^{-1})
H = mean depth of lake (m)

Under steady-state conditions, this equation can be rearranged to yield:

$$W = cV(\rho + \sigma)$$

where: $\rho = Q / V$ = hydraulic flushing rate (y^{-1})
$\sigma = v_S / H$ = sedimentary loss coefficient (y^{-1})

For these calculations, the average lake nutrient concentrations were obtained from Jassby et al. (1995). Mean settling velocities for phosphorus and nitrogen were 16.4 and 12.0 m y^{-1}, respectively, as shown above. The volume of Lake Tahoe was taken as 156 km^3, with a flushing rate of 0.00154 y^{-1}.

Under these conditions, the annual lake loads necessary to sustain nutrient sedimentation losses are 401.7 metric tons N y^{-1} and 52.8 metric tons P y^{-1}, equivalent to areal loading rates of 57.3 and 3.4 mmol m^{-2} y^{-1} for nitrogen and phosphorus, respectively. These are both within about 10 to 20 percent of total annual loading rates calculated from the most recent nutrient budget for the lake presented at the beginning of this chapter. This relative congruence between independent methods is encouraging. However, the loading rates estimated from sedimentation velocities are greater than loading estimates from field measurements, which suggests that some nutrient sources in the budget may have been underestimated slightly. The inverse explanation, that nutrient sedimentation rates have been overestimated, seems unlikely since sediment trap data (0.25 m^2 and 0.5 m^2 baffled cones of Soutar oceanographic design) tend to underestimate the true sedimentation rates by 10 percent or more (Bloesch and Burns 1980). Natural variation in water column nutrient concentrations, as well as changes in the lake volume, hydraulic flushing rates or loading rates also could account for a portion of this small discrepancy. As discussed above, the current estimates of lake-wide N and P inputs are preliminary at this time; additional investigation is required, especially regarding the contribution of urban runoff.

As one final example of the potential benefit to be realized from this approach, a preliminary baseline phosphorus concentration for Lake Tahoe was calculated. This estimate is a hindcast of the long-term average predisturbance (prior to 1850) total water column phosphorus concentration, based on sediment core analyses and the phosphorus settling velocities. As derived from the previous equation for settling velocity:

$$P = J / v_S$$

Where J now represents the baseline flux of phosphorus, determined as the product of deep core sediment phosphorus concentrations and the average predisturbance mass sedimentation rate (Heyvaert 1998). This result is only as good as estimates for the flux term and the historical phosphorus settling coefficient, which is assumed to be equal to the average modern value. With those provisions, however, the results suggest that baseline concentrations would have been in the range of 3.9 ti 8.5 mg m^{-3}. Surprisingly, this is comparable to the 1992/1993 average whole-lake total phosphorus concentration of 6.3 mg m^{-3}. Perhaps small changes in the nutrient concentration of this historically ultra-oligotrophic lake cause big changes in its biomass, which are visible today. This is a reasonable hypothesis given that for every milligram of phosphorus used by algae in the formation of biomass, 41 mg of carbon are fixed and that small changes in particulate matter affect the relative clarity of oligotrophic waterbodies more than eutrophic waterbodies. In other words, the clarity of Lake Tahoe should be more sensitive to small changes in biomass relative to similar changes in a more productive lake.

In any case, the settling velocity is clearly a dynamic function for nutrients in Lake Tahoe. It may respond to changes in loading rates and matrix composition, as well as to shifts in relative nutrient concentration and to changes in lake biology. The continued joint analyses of whole lake nutrient concentrations and sedimentary loss rates will help define the nature of this function for Lake Tahoe and ultimately will improve models and their predictive accuracy for lake response to mitigation efforts and watershed restoration.

What has been the lake response during historical periods of disturbance and recovery?

Reconstructing Sedimentation Rates using Paleolimnological Techniques

Lake sediments constantly accumulate material derived from the watershed and from the overlying water column. Over time a physical record accrues. The biogeochemical analysis of this record can provide useful information about lake response to natural changes in environmental condition and to anthropogenic watershed disturbance. Sediment core analyses facilitate examination of ecosystem processes at longer and more relevant time scales than usually can be attained from any existing monitoring database. When used in conjunction with process-oriented research that includes both modeling and analyzing long-term data, this approach can significantly improve efforts to forecast ecosystem response to contemporary watershed disturbance. The following review comes from (Heyvaert 1998).

There have been two major episodes of watershed disturbance in the Tahoe basin since it was first located and described by John Fremont in 1844. The first event was clear-cut logging that began in the 1860s and continued into the 1890s; the second event was rapid urbanization in this watershed since the late 1950s. Of particular interest are effects on the lake function and its response to late 1800s logging in the Tahoe basin. This historical information could be instructive for evaluating modern environmental impacts from urbanization.

Over the years, several sediment cores have been extracted from various points within Lake Tahoe to determine spatial and long-term patterns of sediment composition and accumulation (Heyvaert 1998). These cores have been analyzed for many chemical and biological constituents and for characterization of their physical attributes. The specific goals of this project have been to identify biogeochemical markers that indicate lake and watershed response to ecological stress, to establish the baseline predisturbance condition of these markers and natural background variability, to assess watershed response to historical periods of fire, drought, and timber harvest, to determine lake response to urbanization since the late 1950s, and to establish a database for calibrating and verifying watershed-lake models in the Tahoe basin.

An early key step in this study was to establish a relatively reliable geochronology for the Tahoe sediments, constructed from ^{210}Pb and ^{14}C data. These data indicate that significant basin-wide changes have occurred in mass sedimentation rates over the last 150 years. Specifically, high sedimentation rates were associated with clear-cut logging in the Tahoe basin from 1860 to 1900, followed by a three-to five-fold decrease in mass sedimentation rates during the early twentieth century. These lower rates persisted until urbanization began in the Tahoe basin after World War II.

From ^{210}Pb data, the average mass sedimentation rate (with a 90 percent confidence interval) during the Comstock logging era from 1860 to 1900 was 0.043 ($\pm$ 0.011) g cm^{-2} y^{-1}. By comparison, the average mass sedimentation rate for the recent period from 1970 to 1990 was 0.027 ($\pm$ 0.006) g cm^{-2} y^{-1}. Both these rates are significantly higher than the average sedimentation rate of 0.009 ($\pm$0.004) g cm^{-2} y^{-1} that was determined for the intervening period from 1900 to 1970 (Table 4-6).

Predisturbance sedimentation rates were estimated from ^{14}C measurements in several deep sections of two cores. The long-term average rate was 0.006 ($\pm$ 0.002) g cm^{-2} y^{-1}, which is slightly less than the sedimentation rate that was estimated for the intervening period between Comstock logging and urbanization. Because these rates are comparable, it would appear that landscape recovery was rapid after clear-cut logging ended and that sedimentation rates dropped to nearly predisturbance levels.

Reconstructing Historical Primary Productivity Rates

Diagenesis and organic decomposition preclude a quantitative reconstruction of historical primary productivity (PPr) from the carbon record. However, diatom frustules are composed of biogenic silica, which is relatively persistent in these sediments. Since diatoms represent greater than 80 percent of phytoplankton biomass in Lake Tahoe,

Table 4-6—The ^{210}Pb dates and sediment accumulative rates, with 90 percent confidence intervals, for Lake Tahoe sediment cores.

LT - Core	81-1	91-1	91-2	91-3	91-4	Mean	90% ±
Recent	1971	1969	1972	1973	1966	1970	2.5
(rate 1)	(.035)	(.026)	(.032)	(.021)	(.020)	(.027)	(.006)
Intervening	1901	1892	1901	1909	1902	1901	5.9
(rate 2)	(.007)	(.007)	(.012)	(.007)	(.014)	(.009)	(.004)
Historical	1864	1862	1878	1848	1854	1861	10.9
(rate 3)	(.060)	(.050)	(.042)	(.029)	(.035)	(.043)	(.011)
Baseline	LT-H-9	LT-91-1	--	--	--	<1850	--
(^{14}C rates)	(.009)	(.004)	--	--	--	(.006)	(.002)

Notes:
Mass sedimentation rates (g cm^{-2}y^{-1}).
Baseline sedimentation rates are from ^{14}C data.

the accumulation rate of biogenic silica should provide a useful proxy for algal productivity. Heyvaert (1998) calibrated the biogenic silica content of recent sediments to modern PPr measurements and then reconstructed PPr for premonitoring periods from the biogenic silica content of Lake Tahoe's historical sediment record. On average, this reconstructed PPr for the interval from 1900 to 1970 was 28 g C m^{-2} y^{-1}, which is about 25 percent less than the earliest ^{14}C PPr measurements conducted at Lake Tahoe in 1959 (39 g C m^{-2} y^{-1}). PPr reconstructed for the historic period of Comstock logging gave an average annual rate of about 176 g C m^{-2} y^{-1}, which is comparable to the annual average PPr measured in 1993 (183 g C m^{-2} y^{-1}). The estimate of baseline predisturbance PPr in Lake Tahoe before 1850 was 27 g C m^{-2} y^{-1}. Apparently, the lake nearly returned to this baseline PPr rate during the intervening period, after logging ended.

The fact that mass sedimentation rates and biogenic silica flux decreased shortly after the logging disturbance ended is testimony to rapid landscape stabilization with second growth forest. It also indicates that Comstock logging produced a pulse disturbance. By contrast, the disturbance from urbanization could persist as a chronic perturbation for considerable time. These data also suggest, however, that effective mitigation of the watershed erosion caused by urbanization could directly improve water quality over a relatively short period, probably on the order of about 20 years, plus or minus a decade. This corresponds to the 50 percent response times calculated independently from sediment trap data for nitrogen and phosphorus settling velocities.

At this time, the Tahoe basin sediment chronology and research estimates of mass and nutrient sedimentation rates continue to be refined. Work also has begun on the interpretation of additional sediment markers for understanding other disturbance patterns, including drought and forest fires, over longer baseline periods.

How does predictive modeling of lake response allow better strategies for restoration and management efforts at Lake Tahoe? What is the scientific basis behind the proposed TRG Clarity Model to be selected?

Role of Thresholds and Standards in Protecting Lake Tahoe Water Quality

TRPA currently has six water quality thresholds designed to protect the beneficial uses of Lake Tahoe. These are as follows:

- WQ-1—Shallow waters of Lake Tahoe (nearshore turbidity);
- WQ-2—Deep waters of Lake Tahoe (pelagic water clarity); includes WQ-2a, Capital Improvement Program, and WQ-2b, BMPs;

- WQ-3—Water quality (phytoplankton primary productivity);
- WQ-4—Tributaries (stream water nitrogen and phosphorus);
- WQ-5—Stormwater runoff quality (discharge to surface water); and
- WQ-6—Stormwater runoff quality (discharge to ground water).

Two of the most critical lake water quality thresholds, pelagic water clarity and phytoplankton primary productivity, are based on the historical database. The numeric value for clarity states that the average Secchi depth from December to March shall not be less than 33.4 meters. For phytoplankton growth, annual mean primary productivity shall not exceed 52 g $C/m^2/yr$. In both cases, these thresholds were not being achieved at the time they were established; however, in the spirit underlying the water quality standards sections of the federal Clean Water Act, the intended purpose was to set goals for desired water quality. For each of these parameters, threshold values represent levels measured from 1967 to 1971.

Numerical values for the tributary inflow and stormwater runoff thresholds are based on the Lake Tahoe Basin 208 Plan and the specific water quality criteria adopted by the states of Nevada and California under their water quality standards programs. For example, the numerical criteria or standards for surface water in the California portion of the Tahoe basin reflect historical (often pre-1975) conditions, and often the specific criterion is chosen so as not to exceed the 90^{th} percentile concentration. According the Lake Tahoe Basin Water Quality Plan, even if the standards set for the streams are achieved, further reductions in the nutrient concentrations in the stream may be required to prevent lake deterioration. Given that nutrients accumulate in Lake Tahoe for longer periods than in other lakes, (i.e., Lake Tahoe has an unusually long hydraulic and nutrient residence time) and that direct atmospheric deposition of nutrients to the lake surface and ground water discharge are important components of the nutrient budget, this assumption is not likely to be completely applicable.

Combined, the thresholds for the lake and surface runoff express the desire for lake clarity to return to the period from 1967 to 1971 when quality was significantly better. While this is an appropriate conceptual goal, and one that was warranted when the thresholds were first established in 1982, it no longer provides the most adequate framework for lake and watershed management in the next century. Within this simplified approach, the complex limnologic, hydrologic, biologic, and social factors that interact to affect lake clarity and water quality are not considered, vis-a-vis, specific management strategies. A considerable amount of research and monitoring has been completed since 1981; both the thresholds and future watershed policy require that this science-based knowledge be incorporated into the decision-making process.

In addition, the federal Clean Water Act requires states to develop TMDLs for impaired waterbodies. In concept, TMDLs are best viewed as watershed attainment strategies to ensure that water quality standards are attained. It is most likely that TMDLs, along with the state mandated TMDL implementation program will be critical in water quality plans, regulatory programs, and remedial plans and monitoring at Lake Tahoe.

For effective lake management, methods need to be established for answering the following:

1. What are the specific sources of sediment and nutrients to the lake and what are their respective contributions?
2. How much of a reduction in loading is necessary to achieve the desired thresholds and TMDLs for Lake Tahoe (i.e., lake response)?
3. How will this reduction be achieved?

Combined long-term research and monitoring in the Tahoe basin by a number of universities and agencies provided considerable information related to the first topic; in fact, much of this assessment is an attempt at an integrated presentation of this understanding. However, a number of critical pieces of information are still needed, and these areas are highlighted throughout this document. At the same time, TRPA's Capital Improvement Program, the wide range of interagency BMP and restoration projects (e.g., EIP), and other efforts in the basin are facilitating the conceptualize of factors that may be relevant to the

third topic—how is a reduction of load achieved and which projects should be given priority. Indeed, while the EIP goes a long way toward identifying the needed restoration projects, this list is not complete. This issue is still far from being adequately understood well enough to implement the most ecologically and economically efficient management strategies. The second topic—how much of a reduction is required to achieve the desired thresholds—is critical but not known at this time. The TRG clarity model presented below attempts to address this issue in a quantitative and predictive manner.

Completion of watershed mitigation in the basin may take 10 to 15 years. Because the lake has such a long retention time for nutrients (decade time scale), the direct effect of this complete mitigation on lake clarity by monitoring alone will probably not be measurable for many years. Watershed and lake modeling provides an appropriate tool to overcome this long response time. Without this approach the results of watershed management actions today will not be known until much of the implementation resources are spent. With techniques that forecast the effect(s) of various management strategies on stream and lake water quality, the large amounts of financial resources and staff time that is anticipated for the Tahoe basin can be used in the most productive manner.

Need for a Watershed-based Lake Water Quality Model

Investigations from 1962 to the present have shown that multiple factors, such as the stress of land disturbance, habitat destruction, atmospheric pollution, erosion in disturbed watersheds, and extensive road network, have all interacted to degrade the basin's air quality, terrestrial landscape, and streams, as well as the lake itself. Inputs of nitrogen from atmospheric pollution and, in particular, accelerated erosion from natural and disturbed sections of the drainage, along with its associated phosphorus load, are considered major factors contributing to the decline of the lake's ecological health. Continued sediment and nutrient loading is a critical factor that reduces the long-term sustainability of this ecosystem (CTC 1987; Sierra Nevada Research Planning Team 1994; Jassby et al. 1994). Both water clarity and algal growth are parameters that reflect the long-term health of the lake; however, since their original adoption, neither threshold has been met, and no specific science-based tool exists for predicting the effect of current or proposed land use and watershed management policies on these parameters.

As human use in the basin increases, the effectiveness of natural pollutant control mechanisms, such as wetland and riparian treatment of runoff, ground water infiltration, and ground cover protection of erosion, has declined. Coupled with the well-documented increases in anthropogenic loading from the surrounding watershed and the atmosphere (Jassby et al. 1994) these conditions have led to artificially high nutrient and sediment delivery rates (Byron and Goldman 1989). Serious concerns about the ecological health and long-term sustainability underscore the urgent need to identify and conduct the highest quality science to link scientific understanding, policy, and watershed management. A critical component for long-term planning at Lake Tahoe is a water quality model, based on the lake's assimilative capacity to receive and process sediment and nutrients, which can be used to assess such future lake conditions as clarity. By knowing the level of loading required to return the lake to conditions defined in the thresholds, state standards, and TMDLs, responsible agencies will be better able to plan in a more quantitative and progressive manner.

The overall goal of the lake modeling effort is to link environmental policy and management in the basin to expected lake response. A clarity model for a Lake Tahoe model should define the relationship between land use in the surrounding watershed(s) and sediment/nutrient loading to the tributaries, between sediment/nutrient loading and algal growth, and between algal growth and sediment (silt) loading and clarity. By mathematically linking these variables (based on empirical data and limnologic and hydrologic principles) one can describe water clarity in terms of nutrient loading from both the watershed and atmosphere. Furthermore, the model should include a subcomponent that considers sources and transport

of sediment and nutrients from both natural and urban activities in the watershed. The benefits to the TRPA and other basin agencies can be substantial. Ultimately such a model should be able to identify the total amount of nutrient loading per year required to achieve the Secchi depth threshold. Coupled with a nutrient budget, regulators can establish targets for reduction, which is precisely what is expected of a comprehensive TMDL program. Planning documents, proposed projects, BMPs, and restoration/erosion control work then could be assessed on the basis of their ability to meet these target loads.

Using Models to Predict Lake Water Quality

Water quality models are used both in diagnosing lake problems and in evaluating alternative solutions. The models define the cause-effect relationships that control water quality in quantitative or mathematical terms. Formulas used in these models typically come from limnological and hydrological theories and from literature case studies from other lakes. Much can be learned about Lake Tahoe by incorporating actual data from observations and studies of processes and responses in the lake. The long-term database for the lake and atmospheric deposition, coupled with the LTIMP database for many of the major tributaries, affords an invaluable background for these models. Because Lake Tahoe is unique in such qualities as its size and depth, mixing patterns, hydraulic residence time, nutrient cycling, biota, and subalpine watershed characteristics, dependence on theory or case studies from much smaller and shallower lakes is inadequate.

When used in the diagnostic mode, water quality models allow limnologists to assess what is going on in the lake, especially in reference to other similar waterbodies. At Lake Tahoe this is not of critical importance. Largely because of the long-term commitment to monitoring and evaluation, a good understanding of changes in Lake Tahoe and its tributaries exists. As discussed above, many of the symptoms of the on-going decline in lake water quality have been identified, and monitoring continues to assess trends. However, lake and watershed managers, environmental planners, and policy-makers need to know "what will happen to the lake if we do this, that, or the other thing" (US EPA 1988).

In the predictive mode, models can be used to forecast how lake water quality (or some particular aspect of water quality) will change in response to changes in nutrient loading or other controlling factors. Rarely do aquatic scientists have the ability to assess lake response based on whole-lake experimentation. And clearly, the purposeful addition of nutrients and sediment to Lake Tahoe to study its response threatens the very resource to be protected. While the combination of monitoring and research data allows a view of lake response over time, in the sense of a natural experiment, this approach is slow (only one new annual data point is added each year), it cannot be scientifically or statistically controlled (six consecutive years of drought provide little insight regarding lake response over a normal range of years), and the lake further degrades during the long observation process. However, models allow scientists to test hypotheses and various management scenarios and alternatives on the computer over a relatively short time scale.

Application of Published Models to Lake Tahoe

In the absence of a fully developed model at this time, and solely for the purpose of example (not for management decisions), some very basic and broad-based phosphorus loading model equations are being applied. These equations are empirically based, utilizing the observed mathematical relationships observed in a series of lakes. Often, these empirical models are regionally specific (Buiteveld 1995; Tilzer 1988). These models generally follow the framework that P-loading controls lake P-concentration, which in turn regulates chlorophyll or primary productivity and ultimately clarity. Application of these empirical models to Lake Tahoe is not advised for the purpose of strategic management planning. This is because Lake Tahoe is unique in terms of its very long hydrologic residence time, great depth, and oligotrophic nature, because phosphorus can be co-limiting with nitrogen at certain times of the year, and because fine inorganic sediment from the watershed also may be important in regulating clarity. When Lake Tahoe has been included in

models of this type, it usually occupies a position on the outer edge of the relationship because of its relative pristine nature. Unfortunately, this is also the portion of the statistical regression curve where variation in the predicted parameter (e.g., chlorophyll and algal growth) is maximum. As discussed above, because the chlorophyll concentration is so low, even a relatively small variation could result in a 200 to 300 percent variation in lake response.

Used as an educational tool, however, these models can provide an order of magnitude estimate of lake response. For example, Vollenweider (1968) proposed a P-loading criterion in one of the first attempts to translate limnologic relationships regarding P-loading and lake chlorophyll into a form useful for lake quality management planning (Reckhow and Chapra 1983). Based on lake trophic status, P-loading ($g/m^2/yr$), and lake flushing for a wide cross-section of northern, temperate natural lakes, Vollenweider (1975) established P-loading criteria defined as permissible (oligotrophic) and dangerous (eutrophic). Using estimates for P-loading presented in the nutrient budget portion of this assessment, Lake Tahoe would be below but very close to the calculated permissible level.

Another example of using existing empirical models as guides is demonstrated by the very simple chlorophyll response model developed by Carlson (1977). Using a subset of northern temperate lakes, Carlson found the following relationship:

$$\text{Chl } (\mu g/L) = 0.068\ P^{1.46}$$

where P = lake TP concentration. Assuming a TP doubling time of approximately 40 years (based on discussion above related to nutrient mass balance), the lake concentration of TP could be expected to double (2X) by 2040 and triple (3X) by 2080, if inputs and outputs remain steady). If the current lake P-concentration is taken as 6 μg/L, Carlson's relationship would predict a 2.7-fold increase in chlorophyll by 2040 and a 4.9-fold increase by 2080, relative to current conditions. Further, Carlson's (1977) empirical model between chlorophyll and Secchi depth suggests that the 2.7-fold rise in chlorophyll could reduce Secchi transparency by a factor of 2; i.e., in 2040 Secchi clarity could be 50 percent of its current value. This first approximation is quite intriguing because the linear regression model based on the 30 years of Secchi depth measurements in Lake Tahoe predicts a 54 percent decline in Secchi depth by 2040.

Marjanovic (1989) used an empirical model developed by Smith (1982) that accounted for both nitrogen and phosphorus to predict Lake Tahoe chlorophyll. Marjanovic further combined this approach with a preliminary nutrient budget he developed for Lake Tahoe to evaluate a set of alternative N and P loading scenarios on the response of chlorophyll. While he stated that these analyses are qualitative only and should not be used as the basis for specific management policy, a number of suggestive conclusions are made. These include the following:

- Because nutrient loading to Lake Tahoe is only a small percentage of the total lake nutrient content, it will take many decades to discern the long-term effects of different management scenarios;
- A rapid implementation of measures to reduce nutrient loading may be a better alternative than slow stepwise nutrient loading control;
- Nutrient loading control strategies, while focusing on phosphorus, should not exclude the reduction of nitrogen inputs; and
- Accurate quantitative predictions of the fate of eutrophication in Lake Tahoe will be difficult; however, qualitative predictions of lake response based on different management and nutrient loading strategies are possible and should be sufficient for making sound and reasonable decisions.

In conclusion, a model of Lake Tahoe water clarity is needed as a tool to assist in watershed management. However, selection and naive use of an inappropriate model can lead to both unwarranted and unwanted results. Every lake is unique, and therefore each will respond to nutrient inputs in a slightly different manner. This is not to imply that lakes and their watersheds do not share certain features; indeed, the empirical lake response models described above attempt to exploit these areas of commonality. Scientists and planners alike must be

aware of where the commonalty ends and uniqueness begins (Reckhow and Chapra 1983).

Simple application of any of the dozens of published empirical models or more complex process-based mechanistic models, which are focused on general applicability, will be of limited use at Lake Tahoe. Despite the fact that application of the Carlson (1977) equations to Lake Tahoe may yield "reasonable results," there are many such predictive equations in the literature (Buiteveld 1995). For many of the reasons previously stated—extreme depth and volume, long nutrient and hydrologic residence times, incomplete mixing from year to year, high susceptibility to atmospheric nutrient loading, proximity of many nutrient species to the analytical reporting limit—Lake Tahoe is more unique than common.

A number of factors contribute to uncertainty in quantitatively predicting the response of Lake Tahoe to management strategies to control nutrient loading. These include but are not necessarily limited to the following:

- Specific sources of nutrients and sediment to Lake Tahoe;
- BMP and restoration effectiveness;
- Proximity of many forms of N and P to the reporting limits;
- Biological availability of N and P both in the chemical sense of what organisms can utilize and the immediate fate of nutrient inputs;
- Relative contribution of organic (algae) and inorganic (watershed sediment) to lake clarity; and
- Effect of particle size on lake clarity.

As modeling efforts progress and as these models are fine-tuned, research and monitoring should be providing the answers to these and other questions.

Tahoe Research Group Clarity Model

The purpose of this model is to identify the total amount of nutrient and/or sediment loading per year required to achieve the Secchi depth threshold. Coupled with a nutrient budget, regulators then would establish targets for reduction. Planning documents, proposed projects, BMPs, and restoration/erosion control work then could be assessed on the basis of their ability to meet these target loads.

The overall conceptual framework for this model is presented in Figure 4-41; additional details will be incorporated as work continues. Water clarity or Secchi depth, is the primary response variable. This is reasonable given that thresholds for nutrients and primary productivity are all intended to stem the loss in transparency. In addition, given the importance of atmospheric deposition to nutrient loading at Lake Tahoe, this component will be considered.

Major model components include the following:

- Sediment, nutrient and water budgets;
- Sediment and nutrient loading-land use relationships;
- Nonpoint source pollutant transport model;
- Lake hydrodynamic and quality model; and
- Lake response model.

These components represent more focused models on their own. When mathematically linked into a larger more comprehensive model, they will provide new insight on predicted lake response based on various management and loading scenarios.

Model Components

Secchi depth is directly related to the amount and characteristics of suspended particulate matter (SPM) and, to some extent, of dissolved organic matter, in the upper portion of the lake's water column. In turn, SPM is composed of both living and dead organic matter (primarily from in-lake algal growth) and inorganic silt, which is transported from the watershed. Dissolved organic matter consists of humic substances from the watershed and breakdown products from algae. As shown in Figure 4-41, silt enters Lake Tahoe via surface runoff from tributaries and intervening areas and from direct on-lake deposition from the atmosphere. In addition, surface runoff and stream loading are regulated by climate and hydrology.

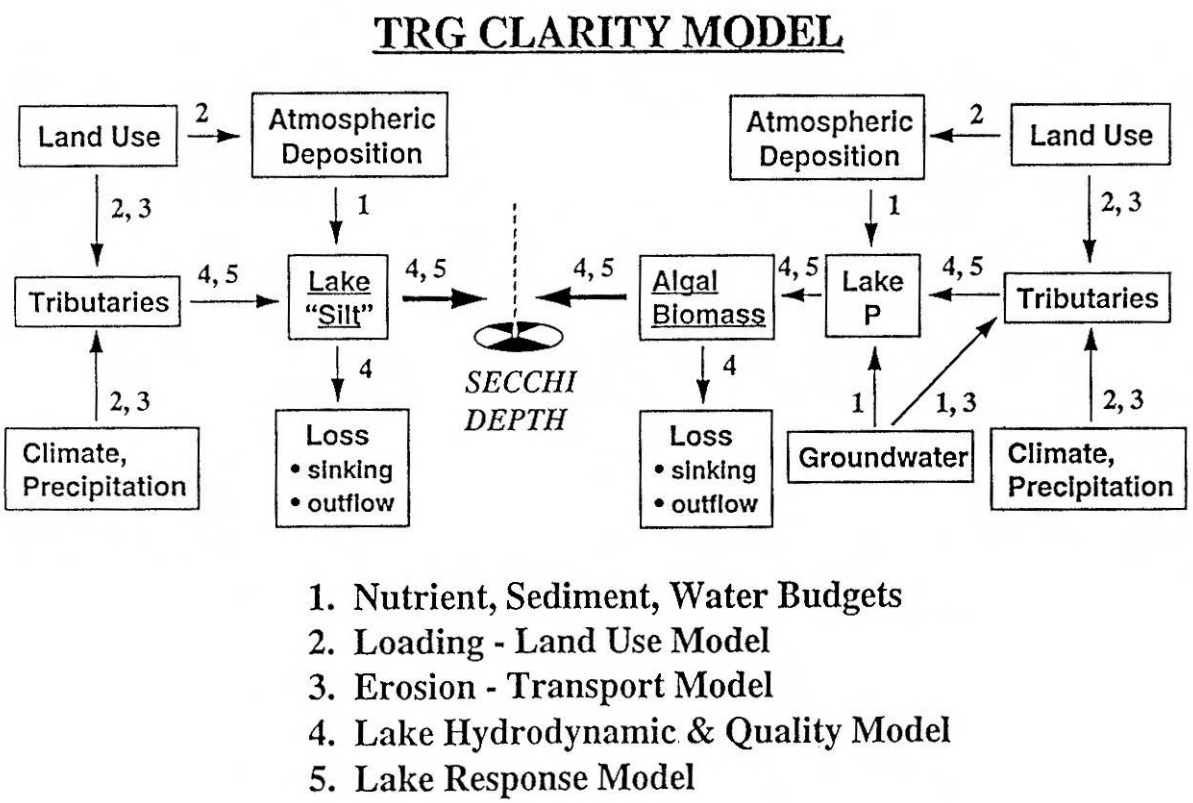


Figure 4-41—Conceptualization of TRG clarity model (from Reuter et al. 1998b).

The contribution of silt to the long-term decline in clarity has not received sufficient attention to determine its overall contribution to the loss of transparency. It is known that phosphorus loading to Lake Tahoe results from direct deposition of atmospheric fallout on the lake's surface and from surface runoff. The load associated with surface runoff again is dependent on land use and geomorphology. While silt can directly affect clarity as a result of an immediate increase in turbidity, phosphorus must first be incorporated into growing phytoplankton algae.

An important first step in lake modeling is to establish a water budget. Flows and direct precipitation carry sediment and nutrient into and out of lakes, and modeling efforts such as those described below require a quantitative understanding of lake hydrology. Not only does the amount of total precipitation affect sediment and nutrient loading, but the timing and conditions of rainfall and snowmelt also provide energy that contributes to the erosion and transport processes. Nutrient budgets identify sources of nutrients and sediments to lakes and define the balance between inputs and outputs. Given the conceptual model presented above for nutrient loading and algal growth, and assuming a steady state condition, lake quality would be expected in improve over time when outputs and inputs are balanced. The lake's assimilative capacity is exceeded at some point after inputs are greater than outputs. The proposed clarity model permits quantitative definitions of these relationships and to evaluate management alternatives that would lead toward a sediment and nutrient balance. A detailed sediment and nutrient budget also allow management policies to focus on the most important sources of these pollutants.

Understanding the relationships between land use in Tahoe's mountainous watersheds and the degradation of stream and surface runoff quality is an important component of effective watershed management policy. In order to predict loading, an understanding of how land use affects total phosphorus loading from both stream flow and

surface runoff and from the atmosphere is needed. The sediment and nutrient loading/land use relationships address this in much the same way the TRG did in its evaluation of land use and water quality in Lake Tahoe tributary streams using only a four year database. Now that the LTIMP database has expanded to up to 19 years for some streams, this analysis will be extended and refined. The nonpoint source pollutant transport model applies a newly developed model, by the Department of Civil and Environmental Engineering at UC Davis, to describe the flow dynamics of nonpoint source pollutants over mountainous terrain. Simulation modeling of surface runoff, erosion, and transport of nonpoint source pollutants is a necessary approach in watershed assessment research.

The lake hydrodynamic and quality model employs an existing limnological model to determine the interactions among suspended particulate matter, chlorophyll, transparency and the physical mixing environments in Lake Tahoe. This component of the overall model will make it possible to quantitatively explore the effects of a variety of watershed management strategies designed to reduce transport of sediment and nutrients to the lake. The lake response model is the important link between nutrient and sediment loading, and change in clarity. The relationships among nutrient (phosphorus) loading, lake concentration, primary productivity, chlorophyll, and transparency are mathematically determined in this component of the model. The lake response model also accounts for loss processes, such as sinking and deposition on the lake bottom, outflow, and zooplankton grazing in the case of algal biomass.

In concert, these components will allow TRPA and other basin agencies to assess watershed and lake management alternatives on water clarity. As with all models, calibration and verification will be part of the effort. Additional background information on the nonpoint source pollutant transport model, lake hydrodynamic model, and lake response model is necessary.

Simulation modeling of surface runoff and erosion and transport of nonpoint source pollutants is a necessary component in watershed and lake water quality models. Along with estimates of atmospheric deposition and ground water flow, the Nonpoint Source Transport Model not only will be used to assess differences in various watershed management alternatives, it also will supply loading data for the Lake Hydrodynamic and Quality Model and the Lake Response Model. Despite the recent availability of models intended to predict watershed behavior, their applicability to the complex, mountainous landscapes of the Tahoe basin is questionable. Consideration of landscape complexity in mountainous environments at multiple scales (i.e., < 50 m x 50 m, hundreds of hectares, many square kilometers) becomes fundamental in evaluating alternative strategies within an integrated watershed context.

The nonpoint source pollutant transport model described in this section is a mechanistic model that utilizes a new technique developed by faculty in the Department of Civil and Environmental Engineering at UC Davis (Dr. M. Levant Kavvas and collaborators). When used as part of the overall TRG Clarity Model, this component will be applied at the subwatershed and watershed levels. Based on a wide variety of watershed characteristics, including weather, microtopography, and urbanization, the results of this model will provide input data on sediment and nutrient loading to the lake. These data subsequently will be incorporated into the Lake Hydrodynamic and Quality Model and the Lake Response Model. The versatility of this model is that land use alternatives, including development scenarios and BMP mitigations, can be quantitatively evaluated for effects on loading.

Historically, erosion and runoff estimates have been predicted for agricultural areas using empirically derived equations, including the Universal Soil Loss Equation and the SCS curve number method (ARS, USDA 1965). More recent approaches consider continuity equations for such components as water conservation and sediment (Foster 1982). The approximation of hillslopes by kinematic cascades was one of the first successful attempts to consider landscape features in combination with a physical-based approach (Woolhiser et al. 1990). Although the large number of commercially available erosion and nutrient transport models, such as AGNPS, ANSWERS, CREAMS, EPIC, EUROSEM, KINEROS,

SHESED/SHETRAN, SWAM, and WEPP, have significantly improved knowledge regarding the process of soil erosion, they have limitations and deficiencies that restrict their practical use in locations with highly variable surface structures.

These limitations include the following:

- The use of point-scale equations to describe spatially occurring processes requires too many simplifications to maintain the applicability of the overall model;
- Due to high spatial variations of the hillslope topography, the assumptions of gradually varied flow in the currently utilized point-scale technology do not hold unless one smoothes the important microtopographic flow controlling features;
- Quantitative input requirements (thousands of computational nodes) are very difficult to obtain; and
- The current point-scale technology considers conservation of mass and momentum only at the point-scale of a computational node and cannot account for mass/momentum conservation over the heterogeneous area that surrounds each node.

To overcome these deficiencies, Kavvas and co-workers introduced spatially averaged conservation equations into a newly developed hydrologic watershed modeling system with successful application at the hillslope scale (Kavvas and Govindaraju 1992). This modeling approach will be applied to the watershed scale to describe overland flow, soil erosion, and the transport of related sediment and nutrients.

On typical terrestrial landscapes, discharge occurs both in small-to-large channels or rills and as overland sheet flow. Most flow on hillslopes is found in rills; however, much of this flow comes from overland flow in interrill areas. The Nonpoint Source Pollutant Transport Model mathematically considers movement of overland flows and was derived from local averaging of the two-dimensional flow equations for sheet flow, based on the principles of mass and linear momentum conservation (Kavvas and Govindaraju 1992; Tayfur and Kavvas 1994). Combined rill (channel) and interrill (sheet) flows are treated in a single, spatially-averaged flow equation, with an additional flow interaction term (Govindaraju and Kavvas 1991, 1994a, 1994b). As natural surfaces have a large number of rills into which water flows from neighboring interrill areas, flow and sediment transport equations are averaged on a large-scale. Similar equations for overland transport of nutrients have been developed and applied by Kavvas and Govindaraju (1992). Using existing data on phosphorus/sediment relationship(s) in channelized flow (historic and ongoing stream monitoring) and overland flow (existing BMP monitoring database), watershed yield of this critical nutrient can be modeled.

The obtained combined rill flow-sheet flow equation and the averaged sediment transport equation, with their areal-average parameters and areal-average inputs enable the modeler to overcome the difficulties in estimating overland-flow and transport parameters. The Nonpoint Source Pollutant Transport Model is comprised of an interacting series of model subcomponents. As discussed above, the mathematical structure and computational framework have already been established. However, application of the model within the Tahoe basin requires collecting and incorporating a calibration data set for conditions in a selected watershed.

Calibration of each subcomponent requires quantitative estimates of the following components:

- *Overland flow*—areal averaged roughness coefficient both for rills and interrill surfaces, areal averaged bedslope both for rills and interrill surfaces and, rill cross-sectional geometry areal averaged dimensions;
- *Interrill area erosion/sediment transport*—areal averaged soil detachment rate from rainfall impact, mass density of the sediment, soil erodibility, critical shear stress for the interrill surfaces and, first order reaction coefficient for the computation of areal averaged soil detachment rate due to sheet flow;
- *Rill erosion/sediment transport*—first order reaction coefficient for the computation of areally averaged soil detachment rate, critical shear stress within rills, mass density of sediment particles, areal averaged dimensions of the rill geometry;

- *Stream flow*—bedslope, roughness coefficient, and dimensions for the stream channel;
- *Snowmelt*—snow depth, specific heat, density and thermal conductivity of snow cover, and snow albedo;
- *Stream sediment transport*—first order reaction rate for soil detachment from the stream bed, critical shear stress within the stream channel, mass density of sediment particles, and stream channel dimensions; and
- *Computation of phosphorus load*—requires the first-order kinetic coefficient that relates the sediment concentration to the phosphorus concentration.

After the calibration stage, the model will be validated on the basis of site-specific sampling in selected streams and the use of several historical events that were not considered during model calibration.

Once erosion, runoff, and other related hydrologic mechanisms in the watershed deliver sediment and nutrients to the inflowing tributaries and ultimately the lake, physical, chemical, and biological processes interact to determine its bioavailability and effect on clarity. The lake hydrodynamic and quality model will investigate the interaction(s) between ecological and hydrodynamic factors in the lake. The fate of organic (algae) and inorganic (silt) material in the water column is important when predicting the impact of this SPM on transparency. What is the residence time of the various forms of SPM within the upper waters where Secchi transparency is measured, and how does this change with season, year-to-year, and over longer periods? Existing research on rates of settling and changes in the chemical composition of this material (sediment trap data) will be used to validate this model. In addition, new research, which is providing direct measurement and characterization of inorganic and organic SPM at both a nearshore and pelagic station, allows for a direct determination of the biogeochemical nature of SPM and an assessment of its influence on long-term and seasonal changes in the lake's photic environment.

To understand the processes that control the temporal variability of transparency in Lake Tahoe, UCD will use an existing mechanistic dynamic, one-dimensional, process-based hydrodynamic model (Imberger et al. 1978), combined with a particle settling model (Casamitjana and Schladow 1993), and a set of submodels for phytoplankton production, dissolved oxygen, and nutrient cycling (Schladow 1998). This model, termed DLM (Dynamic Lake Model), allows accurate prediction of vertical temperature stratification without calibration. This means that the level of process description, including the temporal and spatial scales in the model, is fundamentally correct for situations where a one-dimensional description is appropriate (Patterson et al. 1984). The freedom from calibration allows identification of the specific hydrodynamic processes that influence water quality. This approach also enables the interactions between ecological and hydrodynamic processes to be examined at a more fundamental level because only the ecological component needs to be calibrated.

Preliminary numerical model runs using DLM have demonstrated excellent agreement with the measured temperature profiles in Lake Tahoe for three years (Schadlow unpublished). Despite its size and the complexities of the local meteorology, the lake's thermal structure was well represented as a one-dimensional system. Future model runs are expected to include the full 20- to 30-year historical record and to include previously developed algorithms for the settling of inorganic suspended particulate matter and chlorophyll production. The extremely long water quality record available for Lake Tahoe allows an extensive calibration and validation to be performed. Using this modeling approach, it also will be possible to quantitatively explore the effects of a variety of watershed management strategies designed to reduce sediment and nutrients being transported to the lake.

Once sediment and nutrient budgets are determined and characteristics of transport and loading are known, a lake response model can be used to evaluate existing conditions and to predict

changes in phosphorus, chlorophyll, and transparency resulting from changes in phosphorus loading. The Lake Response Model can be used as a management tool to estimate total allowable phosphorus and fine inorganic particle loading to the lake (in the sense of a TMDL) or to predict water quality consequences of development and watershed management alternatives. However, it is important to keep in mind that for a lake as large as Lake Tahoe, no lake response model will be sensitive enough to predict the impact at the level of a new single-family dwelling. Because of the many uncertainties associated with a model of this large a scale, it is to be viewed as a management tool best used at the watershed and subwatershed level.

The framework for the typical phosphorus loading model used for northern temperate lakes is as follows (US EPA 1988):

Inflow -->Phosphorus (1) -->Chlorophyll (2) -->Transparency (Secchi) (3)

This framework is based on limnological principles with the relationship between parameters defined in quantitative terms, using mathematical equations typically obtained from existing empirical models for other lakes. For example, estimates for step (1) above were presented in an early model by Vollenweider (1976), which related hydraulic residence time (lake volume÷outflow) and inflow total phosphorus concentration to predict lake concentrations. This model was intended to define the typical north temperate lake and indeed was based on data collected from dozens of systems. As discussed earlier, conditions at Lake Tahoe are unique and warrant the formulation of site-specific relationships for each of the processes above. When a site-specific clarity model is developed, both empirical and mechanistic features must be included. For example, the long-term loading and lake water quality data provide important answers in an assessment of lake response to sediment and nutrient loading. However, specific processes related to suspended particulate matter, such as zooplankton grazing, rates of sedimentation, decomposition and changes in biochemical composition, permanent burial on the bottom, and nutrient release from the sediment, will affect clarity. When important, these processes also must be incorporated into the overall model.

Figure 4-42 provides a simplified outline of the optical quality model. The DLM will provide values for organic and inorganic particle concentrations. These will be used to derive the inherent optical properties (light absorption and scattering characteristics) of the water. The results will, in turn, be used to calculate the overall light attenuation, appearance of the water, and the predicted Secchi depth.

What is the current status of macroflora (submerged aquatic plants) and macrofauna (benthic invertebrates, crayfish, zooplankton, and fish) in Lake Tahoe?

The current assemblage of macroflora and macrofauna in Lake Tahoe is largely the result of human influence in the Tahoe basin. Since Europeans began settling around the lakeshore, exotic species have been introduced both intentionally and accidentally. Many of the intentional introductions were planned by wildlife management agencies to increase the production of top predators for recreational harvest by the expanding human population. Species introduced accidentally is a common occurrence wherever human populations live in close proximity to recreational waterbodies. Plants and animals often are transferred from one location to another by trailered watercraft, either attached to the vessel itself or contained in bilge water.

The result of these introductions has been dramatic for Lake Tahoe. The historic native game fish, Lahontan cutthroat trout (*Oncorhynchus clarki henshawii)*, is no longer present within the confines of the lake. The only known location within the basin where the species exists is in a remote stream where strict management preserves a reintroduced population. This once great fishery produced many fish in the ten- to twenty-pound range and a record trout weighing 31 pounds. It was the introduction of an exotic predator, lake trout (*Salvelinus namaycush*), and human disruption of the native fish habitat that led to the species' demise in Lake Tahoe.

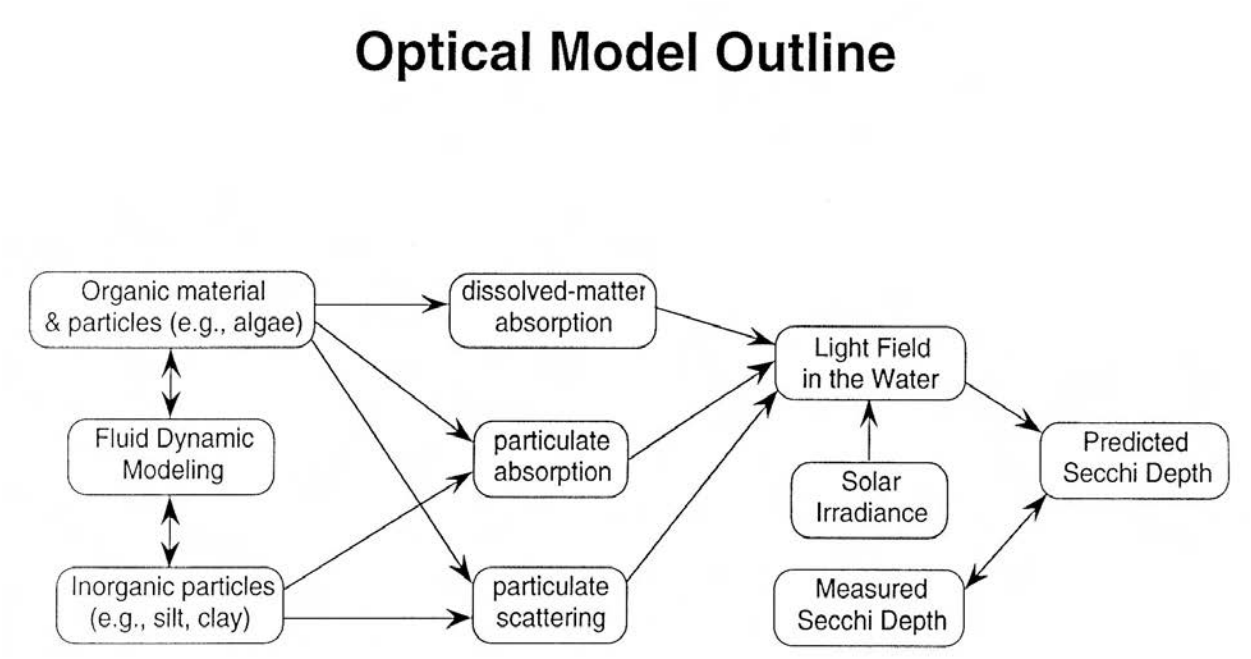


Figure 4-42—Conceptual model showing the relationship among material in Lake Tahoe, absorption and scattering of light, and Secchi depth.

The displacement of species was not limited to the fish community in Lake Tahoe. An intentionally introduced zooplankter (*Mysis relicta*) brought about the near elimination of three native zooplankters, *Daphnia rosea*, *D. pulicaria*, and *Bosmina longirostris*. These species remain weakly represented in the lake through seeding from other basin lakes via tributaries.

There are possibly other native species near extinction or that have gone extinct within Lake Tahoe as a result of exotic introductions or habitat degradation. However, without recent inventory studies, the status of much of Tahoe's macrobiotic populations remains unknown. It is clear that biotic introductions to the lake have greatly influenced the way the aquatic ecosystem functions. It is possible that in spite of well-intended efforts to increase Lake Tahoe's production of recreational species, the current assemblage is less efficient at energy transfer through the food web, resulting in a lower biomass of the top predators.

Current Assemblage of Macroflora in Lake Tahoe

While nutrient loading to Lake Tahoe continues to increase, many of these nutrients are stripped from the water column by the lake's phytoplankton, leading to the rapidly accelerating primary production rates. These same bioavailable nutrients therefore are not well transferred from the water column to the benthic milieu where they would be available to higher order aquatic plants. The only two areas in the lake where nutrients in the sediments can increase are the protected coves (both naturally occurring and human engineered) and the area below the zone of wave disturbance. Because Tahoe has a very steeply sloped littoral zone, there remains a relatively narrow area around the lake where plants might experience adequate nutrient levels in the sediments and a suitable sediment texture (fine silts) and still be shallow enough to receive the light intensity necessary for photosynthesis (Frantz and Cordone 1967). This

was confirmed by a shorezone mapping project (Beauchamp et al. 1994b). During visual surveys, sand was found to be the most common substrate in the offshore zone, comprising over 80 percent of the habitat below 8 meters depth. Despite the lake's inhospitable conditions for colonization and growth, a diverse community of aquatic plants exists in the depths of Lake Tahoe. However, the greatest abundance of flora occurs in the shallow coves around the shoreline. These typically are associated with tributary inlets or marinas where sediments and nutrients accumulate.

Deep-water Plant Community

A study conducted during the 1960s included an inventory of Lake Tahoe's deep aquatic vegetation (Frantz and Cordone 1967) (Table 4-7). Plant collections did not produce any higher vascular plants but did reveal species of mosses, liverworts, and stoneworts. These plants were in greatest abundance between 61 and 107 meters deep, with a rapid decrease in density below 100 meters. Investigations into the health of the nonvascular macrophyte, *Chara delicatula*, collected from depth, found it to be exhibiting stress as a result of low light

Table 4-7—List of deepwater aquatic plants collected in Lake Tahoe, 1962 to 1963 (from Frantz and Cordone 1967).

Plant	Collection Depth
Green Algae	
Cladophora glomerata	194-411
Zoochlorella parasitica	127
Stoneworts	
Chara contraria	127
C. delicatula var. *annulata*	23-150
C. delicatula var. *barbata*	200
Yellow-green Algae	
Vaucheria sp.	175-362
Blue-green Algae	
Schizothrix calcicola	100
Mosses	
Fissidens adiantoides	244
F. granifrons	244-400
Brachythecium sp.	342
Eurhynchium sp.[1]	329-400
Hygrohypnum molle[1]	225-299
H. palustre[1]	290
Leptodictyum riparium	100-408
L. riparium forma *fluitans*	251
Porothamnium bigelovii	329-392
Fontinalis nitida	400
Liverworts	
Blepharostoma arachanoideum	329-362
Chiloscyphus fragilis	199-400

Note:
[1]Identification not certain.

levels. Tahoe's deep water plant species may suffer a loss of habitat, forcing communities shallower, as light penetration decreases in Lake Tahoe from further effects of cultural eutrophication. If shallower substrates (3 to 30 meters) outside embayments are not suitable for plant growth, as suggested above, species loss could be expected.

Link between Deep-water Hydrophytes and the Invertebrate Community

The agency study conducted in the 1960s also found a strong correlation between these deep plant communities and a variety of benthic invertebrates. Invertebrate samples collected within the plant zone showed densities an order of magnitude higher than those samples collected where plant material was not present (Frantz and Cordone 1996).

More recent investigations have found a connection between deep plant beds (*Chara delicatula*) and lake trout spawning (Beauchamp et al. 1992). Tahoe's top predator was utilizing the *Chara* as spawning substrate at a depth of 50 meters. Eggs were retained within the strands of *Chara* thus were protected from predatory juvenile lake trout. The study area was an underwater mountain and represented a refuge from other predators (crayfish) that would have less difficulty extracting eggs from the *Chara*. As a result, this area may be one of the most productive for lake trout recruitment. Further loss of lake clarity, resulting in decreased light transparency, could eliminate one of Tahoe's most productive spawning areas.

There are a few deep plant communities still existing in Lake Tahoe today, but the extent of their distribution is unknown. Further studies into the habitat requirements of these species and their link to the benthic invertebrate community would help managers predict future conditions based on water transparency models.

Shallow Plant Community

The shallow plant communities in Lake Tahoe were surveyed in 1995 to establish the extent of watermilfoil (*Myriophyllum* sp.) around the lake and to identify other plant species encountered (Anderson 1995). Eight species and their collection locations were identified (Table 4-8) in areas of stable nutrient-rich sediments, as discussed above.

Table 4-8—Shallow water plants collected from Lake Tahoe (from Anderson 1995).

Common Name	Scientific Name
Milfoil	*Myriophyllum spicatum*
Elodea	*Elodea canadensis*
Coontail	*Ceratophyllum desersum*
Spikerush	*Elocharis* sp.
Richardsons Pondweed	*Potamogeton* sp.
Horned Pondweed	*Zannichellia palustris*
Leafy Pondweed	
Chara	*Chara* sp.

Note: Plants were collected from the surface to a depth of 15 feet. Only common names were given in survey. Scientific names have been added for this text.

There appears to be little connection between the shallow vascular plant communities and the deep nonvascular plants described by Frantz and Cordone (1967). While the deep vegetative communities may be hindered by the increasing eutrophication of Lake Tahoe (decreased water transparency), the shallow plant communities could benefit.

Increased sediment load and nutrient-rich substrates accumulating in protected areas would favor the expansion of the shallow plant species.

Special attention should be given to the introduced Eurasian watermilfoil (*Myriophyllum spicatum*). This vascular macrophyte has demonstrated its ability to rapidly expand and eventually dominate the plant communities of other oligotrophic lakes. Watermilfoil propagates by seed, rhizome, and fragmentation, making the establishment of new communities readily possible. A single plant node can settle on suitable substrate and begin a new plant. Additionally, the seasonal senescence (growth phase from maturity to death) of the standing crop during winter helps bolster the organic content of the sediments for the following year's growth. This is an important advantage in Lake Tahoe, where much of the littoral zone is composed of coarse sand with a low organic content. Because watermilfoil grows to be quite tall, with a great density of stems, it is effective at decreasing water flow. This creates the potential for trapping sediments and further enhancing the plant community's prospects for expansion.

There is evidence that watermilfoil is increasing its distribution at Lake Tahoe (Anderson 1995). During the 1962/1963 study conducted by the California Department of Fish and Game and the Nevada Department of Wildlife, *Myriophyllum* sp. were identified in the shallow protected fringe of the lake (Frantz and Cordone 1967). While the propensity of this plant for rapid expansion raises concern, there does not appear to be the wide distribution at Lake Tahoe that might be expected, given the presence of *Myriophyllum*, for at least 25 years. Dr. Anderson and, separately, the Tahoe Research Group have observed propagules (plant fragments capable of regeneration) in the open lake. These propagules presumably would have established colonies along the open lake shoreline if substrate conditions were adequate. The lack of open lake watermilfoil communities may be due to the unstable, nutrient-poor sand substrate that dominates Tahoe's shallow (0 to 30 meter) shoreline.

Current Assemblage of Tahoe Macrofauna

The macrofauna of Lake Tahoe is composed of three primary communities, the benthic invertebrates, zooplankton, and fish. Much is known about the fish and zooplankton communities and the changes that have occurred at the hands of humans; however, Tahoe's benthic invertebrates have received relatively little study. Aside from an inventory list and some distribution data, virtually nothing is known about the ecology of the community.

Benthic Invertebrate Community

The most comprehensive information available on Lake Tahoe's benthic biota comes from a study that was completed by the early Frantz and Cordone work in 1963. Almost 400 bottom grab samples were collected from various locations and depths around the lake. The macrofauna from each grab were identified and used to make density and distribution estimates for Lake Tahoe. The following summarizes the findings of this study (Frantz and Cordone 1996).

The survey collected and identified 95 species from the bottom of the lake, representing seventeen major taxonomic groups (Table 4-9). Ten species were believed to be endemic to Lake Tahoe. It remains possible that some of these species also may have extant populations in other lakes in the Lahontan region. However, a lack of benthic invertebrate studies from other waterbodies does not allow for verification. There was a dramatic decrease in species diversity with increasing depth. Nearly 50 percent of the taxonomic groups were no longer present in samples below 150 meters. Oligochaetes numerically dominated the benthic invertebrate community and were collected from all depths sampled (5 to 500 meters). The calculated standing crop of all species of benthic invertebrates totaled 2,500 individuals/m^2 (6 g/m^2 wet weight), with oligochaetes comprising 40 percent by number and 65 percent by weight (Frantz and Cordone 1996). When compared to other North American oligotrophic lakes, the standing crop of benthic invertebrates was higher than eighteen of the twenty-one lakes listed. Based on Tahoe's low productivity and limited littoral zone, the abundant standing crop appears unique. The researchers conducting the study suggested that this may have been due to Lake Tahoe's lack of deep invertebrate predators, famed water clarity, and high dissolved oxygen concentrations throughout the water column.

The same study found relatively high densities of Tahoe's endemic wingless stoneflies (*Capnia lacustra*) between 60 and 90 meters deep, with 38/m^2 and 80/m^2 in 1962 and 1963, respectively. Later studies conducted in the mid-1980s, employing similar collection techniques, were not able to locate the deep living invertebrate (Nelson and Baumann 1989). Only a few individuals of this species have been collected since the original state agencies' study in the early 1960s. Specimens were collected in 1993 from a depth of 55 meters near Tahoe City (Allen unpublished). Efforts are underway to see if additional stoneflies can be collected from the deep waters of Lake Tahoe. Recent efforts have failed to capture any of the deep living stoneflies. *C. lacustra* serves as a good example of how little is known about Lake Tahoe's unique benthic organisms.

The most visible and perhaps best-known species in the benthic invertebrate community at Lake Tahoe is the signal crayfish (*Pacifastacus leniusculus*). It was first introduced to

Table 4-9—Macrobenthic organisms collected from Lake Tahoe, 1962-1963 (from Frantz and Cordone 1996).

Class: Tubellaria
Phagocata tahoena
Dendrocoelopsis hymanae
Class: Adenopherea
Cobbonchus pounamura
Hydromermis sp. or *Gastromermis* sp. (or perhaps a new genus)
Class: Clitellata
Rhynchelmis rostrata
Kincaidiana freidris
Spirosperma beetoni
Limnodrilus hoffmeisteri
Varchaetadrilus minutus
Ilyodrilus frantzi typica
Rhyacodrilius brevidentatus
R. sodalis
Arctionais lomondi
Uncinais unicinata
Haplotaxis sp.
Class: Hirudinea
Helobdella stagnalis
Erpobdella punctata
Class: Crustacea
Latona setifera
Daphnia rosea
D. pulex
Simocephalus serrulatus
Bosmina longirostris
Drepanothrix dentala
Ilyocryptus acutifrons
Eurycercus lamellatus
Camptocercus rectirostris
Acroperus harpae
Alona quadrangularis
Pleuroxus denticulatus
Chydorus latus
C. sphaericus
Candona tahoensis
Epischura nevadensis
Leptodiaptomus tyrrelli
Acanthocyclops vernalis
Macrocyclops albidus
Hyalella azteca
Stygobromus tahoensis
S. lacicolus

Table 4-9—*(continued)*

Class: Arachnoidea
Lebertia sp.
Hydrovolzia sp.
Hygrobates sp.
Limnesia sp.
Piona sp.
Class: Insecta
Capnia lacustra
Utacapnia tahoensis
Nemoura sp.
Acroneuria sp.
Siphlonurus sp.
Callibaetis sp.
Centroptilum sp.
Heptagenia sp.
Choroterpes sp.
Paraleptophlebia packi
P. bicornuta
P. zayante
P. heinae (possibly new species as well)
Tricorythodes fallax
Gomphus kurilis
Hydroptila sp.
Limnephilus sp.
Hydroporus striatellus
Agabus disintegratus
Columbetes rugipennis
Tropisternus ellipticus
Laccobius ellipticus
Palpomyia sp.
Conchapelopia monilis
Apsectrotanypus (possibly *florens*)
Psilotanypus bellus
Pseudodiamesa pertinax
Monodiamesa bathyphila
Heterotrissocladius oliveri
Paratrichocladius sp.
Orthocladius obumbratus
Cryptochironomus near *fulvus*
Paracladopelma near *nais*
P. sp.
Polypedilum near *scalaenum*
P. near *parascalaenum*
Pseudochironomus pseudoviridus
Endochironomus near *nigricans*
Stictochironomus sp.

Table 4-9—*(continued)*

Phaenopsectra near *profusa*
Dicrotendipes near *modestus*
Cladotanytarsus sp. No. 1
C. sp. No. 1
Rheotanytarsus sp.
Tanytarsus sp.
T. near *guerlus*
Class: Pelecypoda
Pisidium sp.
Class: Gastropoda
Fossaria bulimoides
Physella virgata
Helisoma newberri
Vorticifex effusus
Ferrissia fragilis

the Tahoe basin in 1895 (Abrahamsson and Goldman 1970) as an early attempt to bolster the production of introduced game fish. The crayfish has become widespread throughout the littoral region of the lake, with mean density estimates of 10 individuals per square meter (Flint 1975). Crayfish have appeared in the stomachs of rainbow trout (*Oncorhyncus mykiss*), mountain whitefish (*Prosopium williamsoni)*, brown trout (*Salmo trutta*), and lake trout (*Salvelinus namaycush*) in Tahoe studies (TRG unpublished). While little is known about their importance to the other salmonid species, crayfish were calculated to represent over 13 percent of the annual lake trout diet by weight (Beauchamp et al. 1994c). It is unclear how well crayfish transfer biogenic energy to the lake trout population, but transfer is expected to be relatively inefficient due to the trout's difficulty in digesting and assimilating the crayfish carapace. The future for crayfish in Lake Tahoe appears to be sound. It is present in all habitat areas of the lake's littoral zone and has been observed to depths of 100 meters (TRG unpublished). While the crayfish are preyed upon by several fish species, birds, and various mammals, including humans, the population appears stable.

Flint (1975) conducted a study of crayfish life history in Lake Tahoe. He found that aquatic vegetation and attached algae made up over 65 percent of the adult crayfish diet. In controlled experiments in the lake, the ability of crayfish to depress the standing crop of aquatic macrophytes (*Myriophyllum* sp.) depended on the density of crayfish. Flint found that crayfish densities greater than 69 g/m^2 were capable of decreasing the standing crop of higher aquatic plants. Lower densities were found to stimulate vegetative growth.

Experiments were conducted in laboratory enclosures to determine if crayfish could effectively control the growth of Eurasian watermilfoil (*M. spicatum*). Initial experiments investigated the dietary preference of crayfish when exposed to three higher aquatic plant species from Lake Tahoe, *M. spicatum*, *Ranunculus aquatilis*, and *Elodea nuttalli*. Crayfish were found to feed on watermilfoil in the presence of the other species but selected watermilfoil second to *R. aquatilis* (Panayotou et al. 1996). During the experiment, grazing crayfish were observed creating floating propagules of watermilfoil. In order to ensure equal feeding opportunities on all plant species these propagules were collected daily and anchored to the bottom. In a lake situation, crayfish actually may promote the spread of watermilfoil by generating free-floating propagules.

During the lake trout spawning study, observations of *Chara delicatula* growth patterns were made. On the South Lake Tahoe mounds where spawning was confirmed, *Chara* grew to a height of 15 to 30 cm (Beauchamp et al. 1992). No crayfish were collected from this area, and it is suspected that the crayfish do not exist on the sea mounts because of the great depth from these mounts to the lake bottom (up to 105 meters). Therefore, *Chara* was able to grow in the absence of grazing. *Chara* on the shoreward slope in the vicinity of Camp Richardson Resort were found to have significantly reduced plant heights. Where *Chara* was observed above a depth of about 40 meters, plant height was estimated to be less than 10 cm. Taller plants were found at greater depths in the same location (TRG unpublished). Crayfish have been collected to depths of 100 meters in Lake Tahoe, but 90 percent of the population is found above 40 meters (Abrahamsson and Goldman 1970). Crayfish are suspected to be successful grazers on *Chara*, limiting overall plant height where the two species overlap.

Frantz and Cordone (1996) suggested that a lack of deep-living predators, the renowned water

transparency, and high dissolved oxygen concentrations might be responsible for Tahoe's diverse and relatively high standing crop of benthic invertebrates. Since the comprehensive 1963 study (Frantz and Cordone 1996), the following changes have arisen that may have influenced Tahoe's benthic invertebrate community:

- The introduction of *Mysis* shrimp
- The decreasing water transparency due to cultural eutrophication; and
- The slow decrease in deep-water dissolved oxygen.

Prior to the introduction of *Mysis relicta* to Lake Tahoe, the species was thought to be a detritivore, feeding on organic matter on the lake bottom. While this scavenging strategy is utilized by mysids, they are also effective predators within the water column. Mysids have been shown to prey on amphipods and benthic cladocerans while on the bottom (as summarized by Northcoat 1991) and on other pelagic zooplankton species, including *Daphnia* sp. and *Bosmina* sp. (Threlkeld et al. 1980). It is unknown what effect the mysid introduction has had on Lake Tahoe's benthic community; however, the implications for species loss are strong. The 1963 benthic invertebrate survey discovered two deep-living endemic amphipods and referred to eight of the fifteen species of cladocerans as scarce (Frantz and Cordone 1996). These samples were taken prior to mysid abundance in the lake. If over the past thirty years mysids have been as successful preying on these benthic invertebrate species as they were on the pelagic species *Daphnia* and *Bosmina*, it is possible that several species have been eradicated from the lake. In fact, Frantz and Cordone (1996) state, "it is likely major changes in the Lake Tahoe macrobenthos have resulted from the combination of cultural eutrophication and the introduction of *M. relicta*."

The decreasing transparency of Lake Tahoe and its potential for limiting the deepwater plant community has been discussed above. This has important repercussions for the benthic invertebrate community as well. The California/Nevada study of the benthic community showed that a ten-fold increase in invertebrate density was associated with samples that contained plant fragments (Frantz and Cordone 1996). Investigations using a remotely operated underwater vehicle (ROV) and an occupied submersible found little benthic macroinvertebrate habitat, other than open silt, on the deep (> 60 m) lake bottom, except for a few isolated boulder escarpments (TRG unpublished). The primary structure associated with this profundal region of the lake is believed to be the plant communities. ROV surveys during lake trout spawning studies revealed only two deepwater plant locations (the South Lake Tahoe Mounts and lakeward of Camp Richardson Resort; Tahoe Research Group [TRG unpublished]). Efforts to revisit areas described by Frantz and Cordone (1967) failed to produce observations or collections of deep hydrophytes. The apparent attraction of these plant beds for benthic invertebrates creates an increased risk to their species diversity and abundance with decreasing water clarity.

The long-term record collected by the TRG has shown a slight, albeit steady, decrease in Lake Tahoe's dissolved oxygen concentration. While even the deepest lake waters remain saturated with oxygen year-round, the noticeable decrease warrants concern. It may be that the oxygen-rich deep water of Tahoe is partly responsible for the higher than expected standing crop of macrobenthos found by Frantz and Cordone (1996). If the trend toward decreased oxygen concentrations were to continue, further pressure would be put on the macrobenthic community.

Management strategies for preserving Tahoe's macrobenthos should include a detailed survey of the organisms present and continued efforts to halt the cultural eutrophication. Future studies designed to evaluate the macrobenthos should include sampling techniques that would allow comparisons to the data collected by Frantz and Cordone. It is important to know how species assemblages have changed over time and how the total standing crop has adjusted to the decline in water quality.

Macrozooplankton Species Composition

The crustacean plankton (zooplankton) community of Lake Tahoe and its environs has received a fair amount of study over the past three and a half decades. The Lake Tahoe plankton food web is discussed in Richards et al. (1991) (see Figure 4-43). Research into specific questions related to zooplankton ecology (e.g., life histories, community interactions, and population trends) has waxed and waned over the years, depending on research interest and funding availability.

Initial studies around the early part of this century were mainly short-term surveys (Ward 1904; Kemmerer et al. 1923) and were followed by a long period of almost no work until the late 1960s. Beginning with a doctoral thesis on the lake's plankton community structure and ecology (Richerson 1969), 15 years of zooplankton-related research has produced a half-dozen doctoral and masters theses and more than 20 peer-reviewed journal papers. Most of the work was completed by the mid-1980s, but a few papers were published on special projects as late as the early 1990s (Burgi et al. 1993). In addition to the zooplankton research, yearly and seasonal changes in populations have been monitored since 1967. Samples have been collected at the TRG's index station over 30 times annually since inception of the routine monitoring program. However, over the last 10 years, most of the collected samples have been simply archived for future analysis.

Because zooplankton sample counts and data analysis are so far in arrears, it is difficult at this time to determine whether significant changes in biomass, seasonal timing of population peaks and declines, or species composition have occurred. Zooplankton, as other living components of any ecosystem, can be indicator organisms, or early warning systems of impending or current change. This was illustrated by the changes that occurred in the zooplankton population (and subsequently are occurring in such other organisms as fish in the Tahoe food web) after the introduction of the

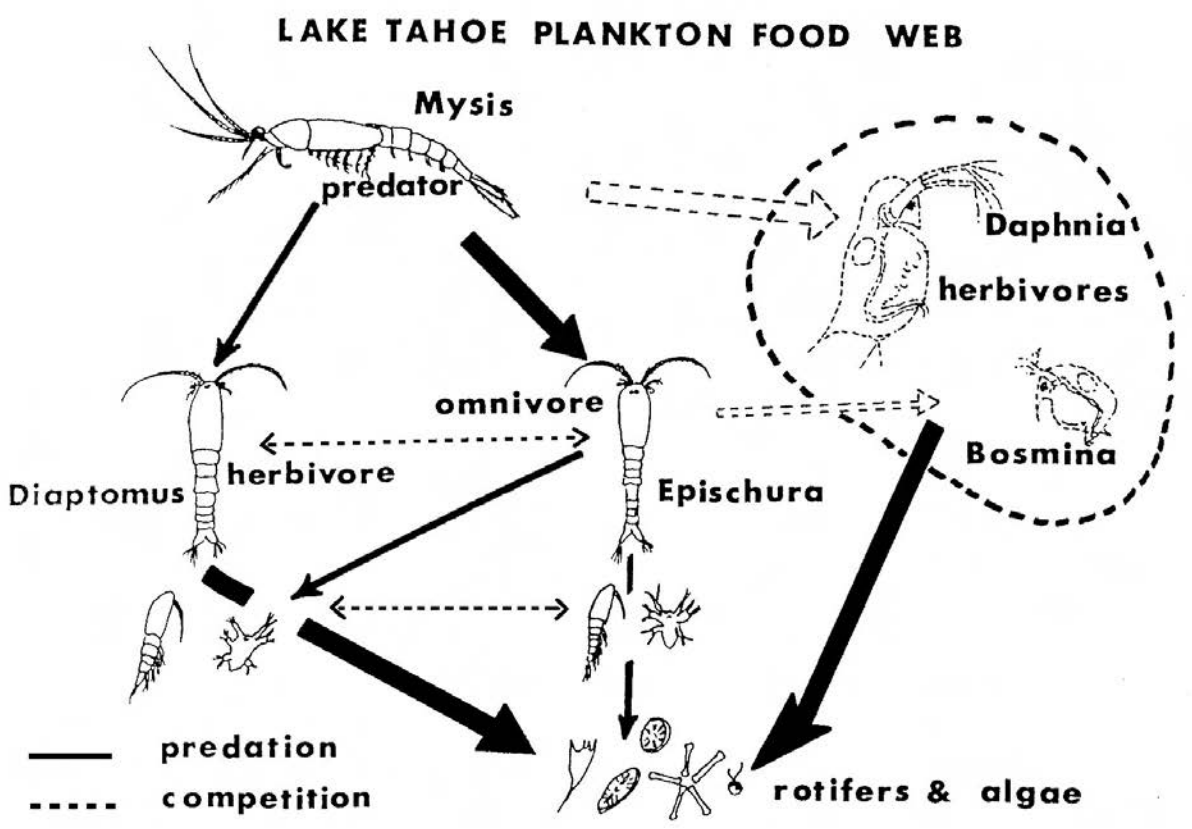


Figure 4-43—Lake Tahoe plankton food web (from Richards et al. 1991).

opossum shrimp, *Mysis relicta* in the early 1960s (Linn and Frantz 1965; Hansen 1966; Richards et al. 1975, 1991). Because of the sensitivity to change exhibited by this crustacean zooplankton and its importance within the food web as a major vehicle for transfer of energy from one trophic level to another (as a primary food source for fishes), it is advantageous to include them in future lake monitoring activities.

Since the analysis of the plankton community structure in 1969 by Richerson, much has changed to alter that community through the process of increasing lake eutrophication and other intentional or unintentional human-induced manipulations. Many fish and invertebrate species have been introduced, most with limited success. Undoubtedly, the most important recent introduction was that of the omnivorous opossum shrimp in the early 1960s by California and Nevada fish and game officials. *Mysis* was brought into the lake over a three-year period with the hope that it would supplement the food supply for kokanee and lake trout and that it would produce better sports fishing for the Tahoe angler. It was also introduced into many other waters in California and throughout the western United States.

This introduction was of limited success and was responsible for dramatically changing the makeup of the Lake Tahoe zooplankton food web (Richards et al. 1975; Morgan et al. 1978; Threlkeld et al. 1980; Morgan et al. 1981; Richards et al. 1991). This resulted from the lack of knowledge by zooplankton ecologists at that time in understanding the full dietary role of the shrimp in large and deep oligotrophic lakes and how shrimp behavior (e.g., diurnal vertical migration) modified their utilization by fishes. Incomplete life history information led to the premature introduction. While the introduction of this organism was successful in a few lakes, this was not true at Lake Tahoe. Although the shrimp was known to prey on other zooplankton, this role was underestimated for shrimp living in an infertile lake like Tahoe, where alternate food sources for such a large omnivorous invertebrate are limited (Sawyer 1985).

Fortunately, some of the highly affected species apparently have enough plasticity to rebound to some extent and make sporadic reappearances in the lake (Goldman et al. 1979; Threlkeld 1981; Byron et al. 1984, 1986). Additionally, it may have allowed for natural introductions of replacement or alternative zooplankton species into the lake's marginal environments, such as Tahoe Keys (Byron and Saunders 1981). Part of the ability of the major zooplankton species to respond to increasing predation rates by opossum shrimp lies in their varying capabilities for predator avoidance, their ability to remain in physical refuges, such as temperature barriers, or in geographical refuges, such as embayments, their adaptation to differing birthrates to keep pace with increased mortality, and their ability to maintain population densities relative to those of other available prey through competition mechanisms effective enough to ensure survival (Threlkeld 1979; Folt and Goldman 1981; Folt et al. 1982; Byron et al. 1986).

Many questions exist about the interactions among zooplankton, mysids, and the fish that depend on them for food. These questions provide a fertile field where much more research could be done to unravel relationships that are continuing to change in response to other environmental changes in progress in the Tahoe basin.

Much of the present status of the shrimp already has been covered in the previous section because its ecology is so interwoven with the smaller zooplankton species. Early research indicated that mysids were voracious predators on zooplankton (Rybock 1978) and that they were fully capable of causing near-extinction of prey species (Cooper and Goldman 1980, 1982) or at least effective in altering the zooplankton prey community composition more or less permanently (Folt et al. 1982). Indeed, the previously "simple" Lake Tahoe zooplankton community, which was dominated by four genera (two calanoid copepods [*Diaptomus* and *Epischura*] and two cladocerans [*Daphnia* and *Bosmina*]) before the mysid introduction has been simplified even further to a community dominated by only the two calanoid copepods (Figure 4-44).

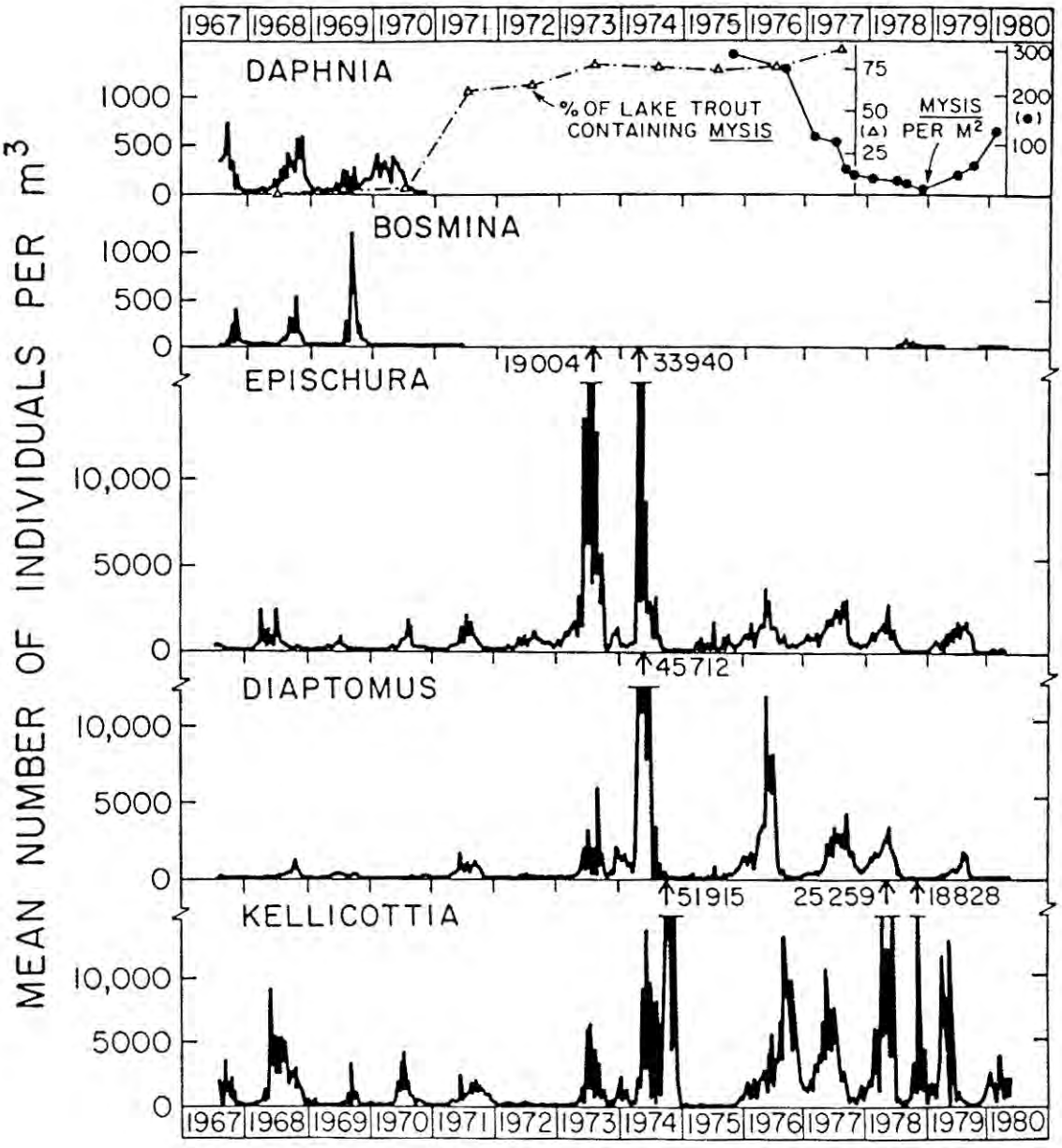


Figure 4-44—Change in Lake Tahoe zooplankton community following introduction of *Mysis* in the late 1960s (from Goldman 1981).

As with the zooplankton research and monitoring, emphasis has shifted away from intensive efforts to answer questions about how the shrimp are continuing to interact with and respond to the fluctuations in the Lake Tahoe environment. This decline in effort is unfortunate and should be remedied. A similar case could be made for including routine sampling for the opossum shrimp population at regular intervals because they also are good indicators of changing lake conditions and play a role not yet well understood in the transfer of energy through the food web from algae to fish. However, there is some speculation that *Mysis* might not be a very effective method of this transfer and actually are an ecological "bottleneck" for the flow of energy. Because of this unknown factor (which could be

determined through appropriate research), opossum shrimp may or may not be a good indicator of change when considered as a potential environmental threshold species.

Up until the middle of the 1990s the TRG sampled mysids three to four times a year to characterize their population changes, despite a lack of funding or a directed program to document the annual and interannual trends. Recently, samples have been collected sporadically for other research purposes. Casual observations do show that an abundant number of shrimp are in the lake, and they do not appear to be fluctuating widely from population levels of the past.

Morgan et al. (1981) did a comparative study on the abundance, life history, and growth rates of the opossum shrimp in Donner Lake (outside the Tahoe basin) and Fallen Leaf Lake. In both lakes, mysids reached sexual maturity in one year due to higher fertility (greater algal production) than that found in Lake Tahoe, where maturity was at three to four years of age. Morgan also noted that these lakes exhibited algal growth rates similar to that found in Emerald Bay. During the period of study, Lake Tahoe was about a third as productive, with Secchi depth averaging nearly twice that of the other two lakes and the bay. Interestingly, although mysids were abundant in both these lakes in the 1970s, there was not nearly the total loss of the cladoceran zooplankton population as in Lake Tahoe. Emerald Bay, which has a fertility level similar to these lakes, maintains a coexistent population of the shrimp and the cladoceran *Bosmina* (Threlkeld et al. 1980).

Current Assemblage of Tahoe's Fish Community

The fish community in Lake Tahoe has received a great deal of attention for the past hundred years. Since early Europeans became year-round residents in the basin, humans have been attempting to enhance the productivity of Tahoe's top aquatic predators. These efforts have focused on introductions of exotic species near the top of the relatively short food chain. Despite repeated attempts, there is evidence that the production of top predators has actually decreased over time. The only certain product of human intervention in the lake ecosystem is a dramatically different assemblage of species.

Exotic Introductions

The introduction of exotic species to Lake Tahoe can be separated into three periods, 1875 to 1920, 1920 to 1965, and 1965 to the present. While the species and strategies varied during each period, the desired effect was always the same: find species that will increase Lake Tahoe's yield of game fish.

The Lahontan cutthroat trout (*Oncorhynchis clarki henshawii*) once dominated Lake Tahoe's waters and produced individual fish over twenty pounds within a thriving population. Due to human activities in the basin, which included logging, commercial fishing, water management practices, and exotic species introductions, the Lahontan cutthroat trout is no longer present in the lake. It has been replaced as the apex predator by lake trout, which were imported originally from the Great Lakes shortly before the turn of the 20th century (Dill 1997). The introduction of lake trout dealt the final blow to the already suffering cutthroat trout. Construction of Derby Dam in the lower reaches of the Truckee River and the dam at the outlet of Lake Tahoe in Tahoe City effectively cut off historic cutthroat migrations between Pyramid Lake and Lake Tahoe. This isolated the Tahoe population of cutthroat trout, requiring it to become self-sustaining entirely within the basin. At about the same time, clear-cut logging operations were causing heavy siltation in Lake Tahoe's tributary streams, making them unsuitable for cutthroat spawning. It is thought that this resulted in decreased recruitment to the isolated population. Commercial fishing for cutthroat trout continued all through this period. Adult fish were harvested for local consumption and were sent to markets in the Midwest. Around the turn of the 20th century, nearly 75,000 pounds of cutthroat trout were commercially harvested from Lake Tahoe (Roush 1987). The heavy fishing pressure significantly depleted the adult population in Lake Tahoe, reducing overall recruitment. The introduced lake trout are believed to have extirpated the dwindling cutthroat population by preying on many

of the year classes remaining in the lake. Today's lake trout have been found to feed on individuals of the same species up to eighteen inches in length (TRG unpublished). This is the equivalent of about a two-pound fish, the size of the average cutthroat caught in Lake Tahoe in the early 1900s (Roush 1987).

Lake trout were only one of at least nine species of fish introduced to the lake between the late 1800s and about 1920. These introductions included chinook salmon, Atlantic salmon, golden trout, Arctic grayling, Great Lakes whitefish, brook trout, brown trout, and rainbow trout (Cordone 1986). In addition to the lake trout, brook trout, rainbow trout, and brown trout were able to establish self-sustaining populations either in the tributaries to Tahoe or in the lake itself. All other introduced fish species failed to thrive in the Tahoe environment. It was during this period that crayfish were introduced, presumably to provide forage for fish and for a growing human population. By the end of the 1920s Lake Tahoe's fishery was dominated by deepwater lake trout. A viable population of rainbow trout added to the recreational fishery. However, Lake Tahoe's vast volume and the pelagic nature of these fish resulted in a diluted population. The status of the native nongame fish in the lake during this period is unknown. It is believed to have been stable as all the species continue to have self-sustaining populations today.

A second series of introductions starting in the 1940s again were meant to increase the biomass of top predators. These attempts showed a shift in focus; rather than simply adding apex predators to the system, managers also introduced both zooplankton and lower trophic level fish.

The intentional introduction of *Mysis* shrimp from 1963 to 1965 (Linn 1965) resulted in the greatest change in the aquatic community since the loss of Lahontan cutthroat trout. The mysids established a thriving population by the end of decade (Goldman et al. 1979; Morgan et al. 1981). Their success was due largely to their exploitation of other zooplankton species, nearly eradicating three cladocerans from the system.

Kokanee salmon (*Oncorhyncus nerka*) were added to the lake in hopes of both providing forage for the piscivorous lake trout and of creating their own shallow recreational fishery. The recreational goal of this strategy was achieved initially, but it later was undermined by the expanding mysid population. Kokanee salmon is the land locked equivalent of the sockeye salmon. It has a four-year life cycle in Tahoe, growing from fry to adult in the open lake and feeding on zooplankton species. During the fall of their fourth year, adults return to spawn in the tributaries where they hatched. Both males and females stop feeding, undergo dramatic morphological changes, then spawn and die. In 1973 a California state record fish was caught, weighing just under five pounds. This phenomenal growth rate at Lake Tahoe was possible because kokanee were feeding on the then-abundant cladoceran populations in the pelagic regions of the lake. However, this success was short-lived because the mysid population soon began competing directly with the kokanee. By 1970/1971 (Goldman et al. 1979; Morgan et al. 1981), the mysids and kokanee had successfully depleted the lake of their preferred prey, *Daphnia rosea*, *D. pulicaria*, and *Bosmina longirostris*. The kokanee were unable to shift their diet to take advantage of the abundant mysids due to the mysid aphotic response. Mysids make a daily vertical migration away from light. This can be a descent of as much as 300 meters in Lake Tahoe (Rybock 1978), effectively removing them from the sight-feeding kokanee. The loss of the three zooplankton species mentioned above left two smaller more evasive zooplankton species, *Diaptomus tyrelli* and *Epischura nevadensis*, as the primary prey items for both kokanee and mysids. In a study of Lake Tahoe's kokanee, it was shown that individual kokanee size depended on the size of the population. This indicates that there is a limited food resource available within the lake (Beauchamp 1994a). It is unlikely, based on the current kokanee and mysid populations and their preference for *D. rosea*, *D. pulicaria*, and *B. longirostris* as prey, that these cladoceran species will ever regain strong populations within Lake Tahoe.

During this same period of introductions the California Department of Fish and Game and the Nevada Department of Wildlife attempted to reestablish populations of Lahontan cutthroat trout

in Lake Tahoe. Three separate plantings of catchable size fish (> 20 cm estimated) were released into the lake between 1962 and 1965 (Dill 1997). Although the fish were marked prior to release, recapture efforts produced only about a one percent return. Within a few years the cutthroat trout had disappeared from Lake Tahoe once again. The state agency biologists concluded that the plantings of cutthroat trout had not been successful due to predation by lake trout.

The last series of exotic species introductions has been dominated by illegal introductions by individuals, presumably attempting to establish angling opportunities. Largemouth bass (*Macropterus salmoides*), smallmouth bass (*Micropterus dolomieui*), black crappie (*Pomoxis nigromaculatus*), and white crappie (*P. annularis*) all have been identified in the Tahoe Keys, a dredged harbor connected to Lake Tahoe (California Department of Fish and Game, unpublished observation, 1999). While all of these are considered warm water fish species and are expected to do poorly in Lake Tahoe's cold environment, there is evidence that even isolated populations could have significant impacts on the existing fish community.

Largemouth bass were first reported in the Tahoe Keys about twelve years ago. The highly productive, warm waters in the keys and the seasonally abundant aquatic vegetation (*Myriophyllum spicatum*) likely benefited all life stages of bass. As the population within the keys grew, bass began leaving the confined harbor. Fisheries investigations by the TRG in Taylor Creek, a tributary to Lake Tahoe, found summer resident bass. A survey conducted by fisheries biologists from UC Davis, TRPA, California Department of Fish and Game, and the Nevada Department of Wildlife identified largemouth bass during the summer in marinas at the north end of Lake Tahoe. Unless humans transported these fish, one can assume that the original population of bass from the Tahoe Keys has had the opportunity to occupy all suitable habitats around the lake. It appears that new populations of largemouth bass are locating in areas of the lake where they experience elevated summer water temperatures and aquatic vegetation. These areas are associated with marinas, large private piers, and creek mouths. While it is somewhat unlikely that largemouth bass will ever succeed in the open lake, even small, isolated populations of bass could have a dramatic effect on the current fish assemblage in Lake Tahoe.

A study of the ecology of nearshore fishes showed a correlation between rock crib piers in the Tahoe shorezone and increased fish density and diversity (Beauchamp et al. 1994b). Later work by Allen and Reuter (1996) demonstrated the attraction of spawning Lahontan redside shiners (*Richardsonius egregious*) to rock crib structures adjacent to shoreline spawning gravel. Because most marinas and large private piers are constructed of rock cribbing, there is an overlap of preferred bass habitat and habitat selected by aggregations of spawning nongame fish. The habitat preference of these species overlaps again at the mouths of Tahoe's tributaries. At least some portion of each of Tahoe's fish species, with the exception of lake trout, is known to utilize the tributary streams for spawning. The spatial overlap of a top predator (bass) and juvenile and adult prey species could have a devastating effect on the current fishery.

The eventual effect of having largemouth bass in Lake Tahoe is unknown; however, evidence suggests that even a limited distribution of these predators could eliminate one if not more of Tahoe's few remaining native fish species. A study assessing the potential for bass distribution and their impact on other fish species is strongly recommended. Control options for undesirable, nonnative fish species at the lake appear limited. There are strict prohibitions against the use of pesticides and herbicides within the Lake Tahoe basin. Mechanical methods of fish control (gillnets, traps, fishing) are not an effective means of reducing fish populations unless the fish are commercially valuable. Historical evidence indicates that the fish species humans place in Lake Tahoe will remain in the lake as long as they are able to establish self-sustaining populations.

Lake Tahoe's Trophic Cascade

The historic food chain in Lake Tahoe was very short and efficient. Phytoplankton were

consumed by the grazing species of zooplankton, which fed the native minnows and subadult Lahontan cutthroat trout. Adult cutthroat ate the native minnows. There was a direct flow of energy through the system, with only three to four steps necessary to reach the apex predator. This allowed the cutthroat trout to achieve an exceptional biomass for the very limited production of Lake Tahoe.

It is ironic that all human attempts to increase the yield of top predators have most likely hampered the ability of resident fish populations to take advantage of the increased primary production that Lake Tahoe has experienced during the last three decades. Today the food chain in the lake is much less efficient than it was historically, with poor energy transfer between trophic levels. Primary production has increased three-fold in the past thirty years (Byron and Goldman 1986). Due to the loss of the historic zooplankton species *D. rosea*, *D. pulicaria*, and *B. longirostris* that were very efficient phytoplankton grazers, there is poor transfer of primary production to the zooplankton community. The remaining zooplankton species, *Diaptomus* and *Epischura*, being less efficient grazers, expend more energy while consuming the same amount of algae. It has been shown that these two species are more adept at avoiding predation than *Daphnia* and *Bosmina* were (Cooper and Goldman 1980). This implies that there is further energy loss today than within the historic food chain at the next trophic level. Native minnows and kokanee must expend more energy to capture the same amount of food energy in these zooplankton species. This is shown by the decreased kokanee size, which coincides with the loss of the original zooplankton assemblage (Beauchamp et al. 1994a).

The presence of mysids in the system further decreases the trophic efficiency. Mysids are a long-lived zooplankton species, requiring up to four years to reach adulthood (Morgan 1980). Also, they expend large amounts of energy maintaining their daily migratory strategy. Mysids may make daily vertical migrations of 300 meters to avoid light (Rybock 1978). This results in a 600-meter round-trip during every 24-hour period. Based on this consumptive life style, *Mysis* are expected to transfer very little energy from zooplankton prey to lake trout, which prey on *Mysis*. It has been suggested that lake trout are not able to control mysid biomass through predation (Beauchamp et al. 1994c). If this is the case, and mysids are high-level consumers of energy, they can be considered a bottleneck in the transfer of trophic energy.

Lake trout are a deepwater, bottom-oriented fish species. As adults, they are morphologically adapted to prey on fish with their widely spaced sharp teeth and short stubby gill rakers. Investigations at Lake Tahoe found that mysids dominated the lake trout diet during all seasons of the year for all sizes of lake trout (Beauchamp et al. 1994c). Because the species is not adapted to feed on zooplankton, it is probably relatively inefficient when feeding on mysids. This would be yet another trophic interaction that is expected to be less efficient than that which existed historically at Lake Tahoe.

Strong evidence exists that flow of energy through the food chain at Lake Tahoe today is very inefficient. Attempts to increase the yield of apex predators by introducing fish, zooplankton, and benthic invertebrate species probably have had the opposite effect. The current food chain is longer than that which existed historically, and the assemblage of species does not transfer energy efficiently due to limitations of life history strategies and morphological characteristics. Based on this information, it is not surprising that although Lake Tahoe has three times the primary productivity it did in the 1960s, there is no apparent increase in top predator biomass.

Management and Restoration Strategies for Tahoe's Macro Biota

Due to historical and recent exotic species introductions, there is little hope of the biological assemblage of species ever returning to native conditions. Reintroduced native species today would face dramatically different conditions in the lake and would not be expected to thrive as they once did. Plant species would face decreased light levels due to eutrophication, pressure from grazers, and competition for habitat from other introduced macrophytes. Reintroduced benthic invertebrates would face comparable difficulties, with lower

dissolved oxygen concentrations and predation pressure from introduced species. Attempts by fish and game agencies to reestablish cutthroat trout in Lake Tahoe already have failed. These efforts were unsuccessful before mysids were fully established in the lake and before new fish predators (largemouth bass) were introduced.

Lake managers must therefore decide what species are desirable within the Tahoe basin and create strategies for their success. It is important to recognize that all nonnative species presently in the lake were desirable to somebody at some time. An optimal assemblage of species surely would inspire great debate among the scientific community, environmentalist groups, and private citizens. When and if this discussion occurs, special attention should be given to energy transfer through the food chain. Lake Tahoe continues to be an oligotrophic lake, with very low annual productivity. Anyone attempting to create thriving biotic populations needs to recognize that energy transfer between trophic levels is the limiting factor in a given species potential biomass.

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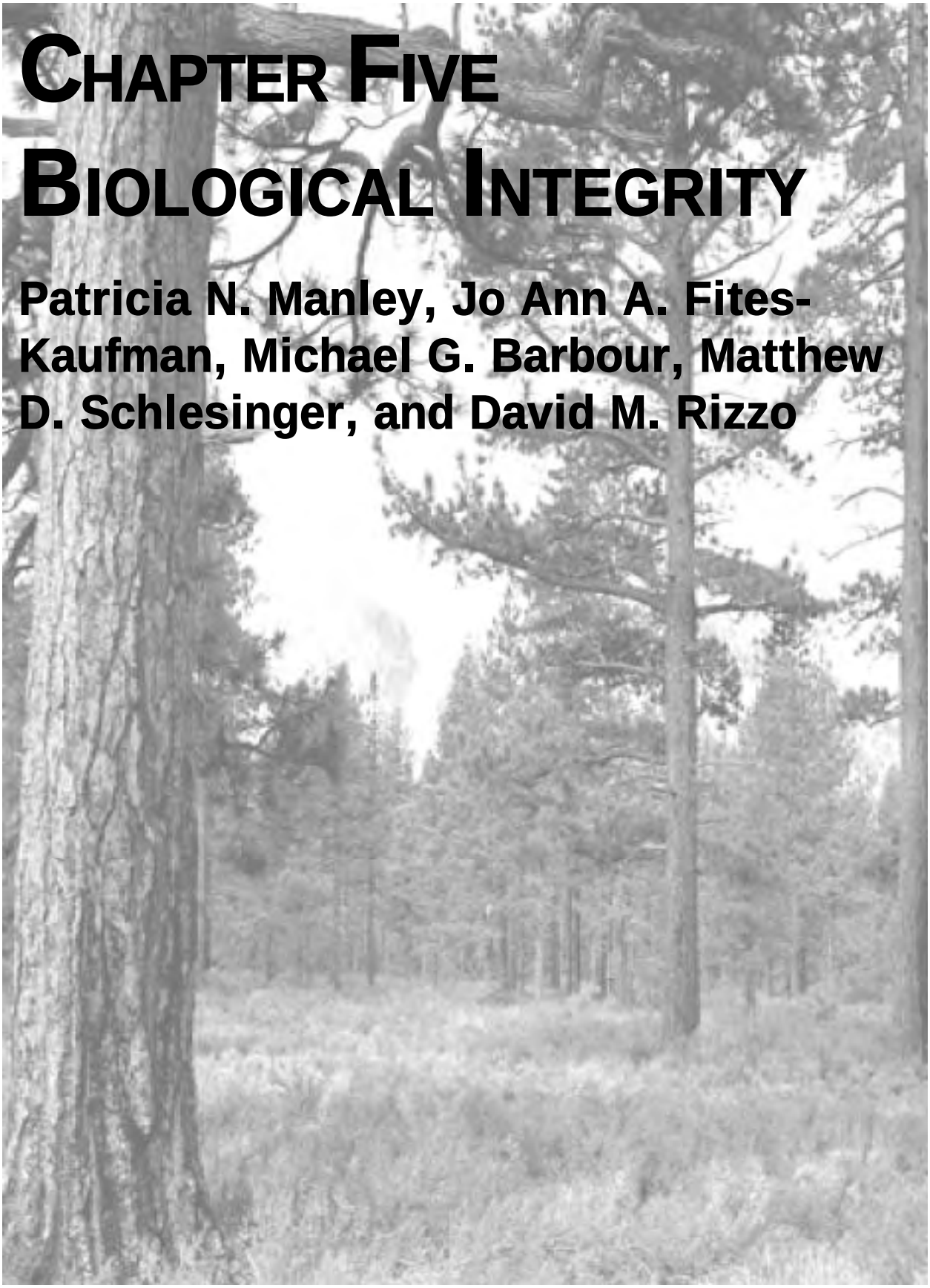
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CHAPTER FIVE
BIOLOGICAL INTEGRITY

Patricia N. Manley, Jo Ann A. Fites-Kaufman, Michael G. Barbour, Matthew D. Schlesinger, and David M. Rizzo



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CHAPTER FIVE

BIOLOGICAL INTEGRITY

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Introduction

"As the wind howled outside my window, heralding the onset of winter, the local band of coyotes sang their evening chorus as they roamed the rich hunting grounds where the wet meadow and forest meet in the backyards of my neighbors. Drifting off into a cozy slumber, pleased with myself for living in a place where I can experience the pulse of the natural world, where coyotes and bears visit my backyard, I bolted out of bed, realizing I had forgotten to bring my cat inside for the night!"

So says a long-time Lake Tahoe resident. The Tahoe basin offers many natural splendors to its residents and visitors, several of which appear in the opening quote. Natural experiences in the basin are defined not only by characteristic landscape features, such as Lake Tahoe and the majestic mountain ranges surrounding the basin, but also by less dominant features, such as frequent sightings of wildlife from one's doorstep, the ability to enjoy beautiful forests and meadows, and the sound of coyotes howling in the night. Even the fact that coyotes occasionally prey on domestic cats left outside at night is something that most residents accept as part of living in an ecosystem that still supports a diversity of living creatures. Many of the natural features that have come to be expected as part of the "Tahoe experience" are a reflection of and depend on the biological integrity of ecosystems in the basin.

Biological integrity is "the capability of a landscape or ecosystem to support and maintain a balanced, integrated, adaptive community of organisms comparable to that of natural habitat of the region" (Karr and Dudley 1981). Biological diversity and the ecological and evolutionary processes inherent in natural systems are essential elements of biological integrity and ecological sustainability (Angermeier and Karr 1994; Hunsaker et al. in preparation). Biological diversity refers to the variety of living organisms in an area, encompassing a hierarchy of biological organization—genes, populations, species, communities, ecosystems, and biomes (Angermeier and Karr 1994; Noss and Cooperrider 1994). We can view biological diversity as building blocks and natural processes as architects and engineers determining how the blocks are shaped and arranged, together resulting in biological integrity.

Approaches to the conservation of biological integrity focus both on the needs of individual species and on conserving entire ecosystems and their fundamental processes. As the science of conservation matures, it is increasingly recognized that both approaches not only have merit but that attention to communities and ecosystems, as well as to species and populations, is important to the success of large-scale conservation efforts (Noss 1990), such as the conservation of biological integrity in the Lake Tahoe basin. Our assessment addresses both levels of biological organization.

The biological integrity of ecosystems in the basin has been altered and perhaps permanently compromised by human land use over the past 150 years (see Chapter 2). Three facets of biological integrity have experienced substantial changes over the past 150 years, and they form the central topics of this assessment of biological integrity: community structure and composition, fire as an ecosystem process, and species composition and population characteristics. The topics addressed in this chapter do not constitute a comprehensive treatment of the considerations in conserving and restoring biological integrity; rather, they are a combination of points of

greatest concern and factors significantly affecting biological diversity and integrity in the basin.

Communities are composed of species that occur together in space and time, whereas ecosystems include interactions of biological components (plants, animals, and fungi) with all the physical and chemical components of the immediate environment (Begon et al. 1990). Although we can define communities conceptually, in practice they are difficult to identify and classify. Communities are dynamic collections of species in which each species responds independently to environmental variation (Whittaker 1975; Krebs 1978; Levin 1992). However, classification schemes facilitate taking stock of the quantity, quality, location, and diversity of communities. Common descriptors of communities include species richness, disturbance regimes, and the composition, age, and physical structure of the community. The distribution, abundance, and diversity of community types are also informative descriptors. Aquatic ecosystems usually are differentiated by both their physical and biological features and include a wide variety of flowing and standing water systems (Moyle and Ellison 1991). Physical features of aquatic ecosystems commonly include their size, shape, depth, volume, gradient, shade cover, temperature, water chemistry, and substrates.

Fire is recognized as a keystone process in Sierra Nevada ecosystems. Fire is a natural part of the Sierran environment, and it significantly influences the distribution and abundance of native plant and animal species, as well as the physical structure of vegetation communities. The arid summers typical of Mediterranean-type climates, such as California's, cause dead plant material on the ground to dry rapidly. Lightning strikes frequently in late summer and fall. If these events are not followed by rain, if there is sufficient dry fuel on the ground to carry flame, if the air is dry enough, and if wind conditions are right, then a surface fire results. In the Lake Tahoe basin, sediment cores from Lake Tahoe (Davis 1997) and nearby Osgood Swamp (Adams 1967) show that charcoal was continually deposited in the Lake Tahoe basin and vicinity in the past, indicating frequent fires. This historical pattern of fire represents a combination of wildfire and prescribed burning conducted by the Washoe tribe to manage vegetation, similar to many other Native American tribes (Anderson and Moratto 1996).

Characteristics of species and populations are considered primary attributes of biological diversity (Noss 1990). Although it is generally accepted that biological diversity in the basin has been altered in the past 150 years, the degree of alteration and its implications for species persistence have not been described previously. Populations typically are described by their distribution, species frequency of occurrence, and abundance (Noss 1990). Species can be described further in terms of their life history characteristics, habitat associations, and exotic or endemic status.

Factors Influencing Biological Integrity in the Basin

Factors influencing biological integrity become relevant when attempting to understand its current condition, how this condition came to pass, and how it may change in the future. The primary factors influencing biota are divided into physical and biological factors and are discussed below.

Physical Factors

A myriad of physical factors affect species, communities, and ecosystems. Some of the most influential physical factors include such major environmental gradients as elevation, precipitation, and latitude (Schluter and Ricklefs 1993). All of these gradients affect the productivity of an area and have been shown in numerous studies to have significant relationships with biological diversity and the distributions of species and communities (Rosenzweig 1995). In the basin, elevation and precipitation vary greatly for such a small geographic area and may exert a stronger influence than expected. Variation in precipitation is largely a function of basin's location in a transition zone between Mediterranean and continental climates. The Sierra Nevada and Carson Range crests, which flank Lake Tahoe west and east and create its basin, and provide the elevational variation that demarcates

the transition between the two very different climatic regimes.

Biological Factors

Innumerable biological factors influence biological diversity and integrity in most systems. It is difficult, and perhaps inappropriate, to attempt to identify a few key factors that shape biological systems. Here, we discuss a limited set of biological factors that are of interest in the basin and are known to significantly influence biological diversity and integrity: fire and succession, interspecies interactions, and biogeographic dynamics.

Fire and Succession—Paleoecologists such as Axelrod (1986) believe that a fire-prone climate has existed in California for at least the past four to six million years; therefore, we can assume that Californian vegetation has evolved with fire, not only tolerating it but also, in the case of many species, requiring it to stimulate certain phases of their life cycle. In terms of community structure, fire is a dominant agent (along with human activities) that stimulates and alters secondary succession in vegetative communities in the Sierra Nevada. For example, researchers have shown how particular herb, shrub, and tree species in mixed conifer forests reproduce, regenerate, and grow better in the presence of periodic low to moderate intensity fires than in the absence of these fires (Rundel et al. 1988; Barbour and Minnich 2000). Further evidence is provided by Skinner and Chang (1996), who reported that white fir (*Abies concolor*) is more often dominant in forests with less frequent fires, whereas Jeffrey pine (*Pinus jeffreyi*) and lodgepole pine (*Pinus contorta*) are more often dominant in forests with higher fire frequency in upper montane and subalpine environments. Shifts in species composition as the result of fire exclusion is apparent in the Lake Tahoe basin.

Interspecific Interactions—The biological processes of competition among species for food and other resources and predation of one species on another are known to shape the composition and structure of communities, as well as to influence species distributions and local abundance (Begon et al. 1990). Changes in species composition have occurred throughout the Sierra Nevada in the last 100 years (Graber 1996), and the basin is no exception. Losses of large predators, such as the grizzly bear (*Ursus arctos*), change the food chain dynamics within communities significantly. The loss of top predators may affect many other species along the food chain (e.g., "trophic cascades"; Paine 1980; Power et al. 1985; Power 1990). In addition, many exotic species now occur in the basin, and some are aggressive competitors that can outcompete native species. Finally, as discussed above, fire suppression activities have influenced environmental conditions and shifted the competitive advantage among conifer tree species.

Biogeographic Dynamics—The basin is in a transition zone between two zoogeographic provinces, where the flora and fauna change substantially in response to a shift from the Mediterranean climate of California to the more continental climate of the Great Basin (Wallace 1860; Udvardy 1969). In the basin, the east-west distributions of many species, particularly the less mobile terrestrial and aquatic species, overlap but do not extend beyond the basin, suggesting that the basin lies along what is known as a biogeographic line (Wallace 1860; Carlquist 1965; Brown and Gibson 1983). The species composition of the basin represents a combination of taxa from both biogeographic regions, resulting in a higher taxonomic diversity, particularly within genera, than would be expected for an area of this size.

A Historical Context for Biological Integrity

Our ability to rigorously define the "integrity" or "health" of a basin, watershed, or ecosystem or even of a single population of an individual tree species is rudimentary for several reasons. First, it's difficult to measure ecosystem integrity with a single simple number. Human health can sometimes be represented by a single number—body temperature—but some diseases do not affect body temperature. Even if we could summarize present ecosystem status with one number, that number could be interpreted only by comparing it to some standard of "good health." Healthy human temperature is 98.6°F, but what is the standard of good health against which we can judge the biological integrity of the Lake Tahoe basin?

One possible means of answering that question is to reconstruct the landscape or ecosystem as it was prior to the onset of any anthropogenic (human-induced) disturbances thought to affect biological integrity. An understanding of the role of disturbance in ecological communities is critical in any attempt to manage for the sustainability of ecosystems, communities, and populations in the basin. Many biological and physical processes, such as fire, floods, and storms, are considered natural disturbances, and these processes have played an integral part in the evolutionary and ecological history of all communities (White and Harrod 1997). Anthropogenic disturbances, such as recreation, fire suppression, livestock grazing, pollution, tree cutting, and habitat alterations, such as fragmentation, degradation, and loss, are increasingly pervasive. The characteristics and interactions of anthropogenic disturbances influence the structure and composition of ecosystems (White and Harrod 1997) by affecting the probabilities of extinction and colonization and subsequent patterns of biological diversity in a landscape (Meffe and Carroll 1994). In the basin, anthropogenic disturbances have been superimposed on natural disturbance regimes for many centuries, creating complex patterns of influence on biological integrity.

The primary anthropogenic disturbances operating in the basin over the past 150 years varied in their time of onset. For instance, ranching, timber harvesting, and fragmentation began in the 1860s, fire suppression management began in the 1920s, and the release of pollutants in high concentrations began in the 1950s. Dramatic increases in anthropogenic disturbance began after 1844, the year John Fremont became the first Euro-American explorer to glimpse Lake Tahoe. Within a few years of his discovery, the basin became a landmark on an important route east and west for hundreds of travelers each year; the period of anthropogenic influence had begun.

Anthropogenic disturbances have been so pervasive in the basin that a control area unaffected by them does not exist. For the purposes of understanding changes resulting from these disturbances, we are relegated to reconstructing historic conditions to provide a context for interpreting current conditions and potential future trends. How accurately can we reconstruct the basin's ecosystem and landscape conditions? Several types of direct and indirect evidence are available to us. First, existing landscapes with intact natural disturbance regimes and minimal human disturbance can serve as references to demonstrate the ecological potential of landscapes disturbed by humans. Such a landscape with a natural fire regime, no history of logging or pollution, and only modest impacts from domesticated livestock is known to occur in Baja California. We were able to draw on its characteristics to improve our estimate of the nature of the basin's old-growth forest ecosystems before it came into contact with Euro-Americans.

A second source of evidence for the composition and condition of ecosystems in the basin undisturbed by humans is historical records, such as early vegetation maps, land surveys, records of log purchases (log-scaling) from known logging areas, photographs, newspaper accounts, books, and journal entries of early settlers or travelers that describe the landscape. For example, foresters Leiberg (1902) and Sudworth (1900) mapped vegetation and gathered data on forest plots generating quantitative descriptions of precontact vegetation. McKelvey and Johnston (1992) have summarized such data for Sierra Nevada forests in general. In the 1930s the US Geologic Survey initiated a major state-wide effort to quantify vegetation. These data were gathered so early in the period of fire suppression management that they provide our best glimpse of the presuppression landscape. Data from the Sierra gathered in that survey recently have been summarized by Bouldin (1999) and compared to modern data from the same forests. Early ecologists, such as Orr (1949), helped document animal species in the basin. We draw most heavily from historical data sources to describe changes in landscape conditions and species composition and abundance over the past 150 years.

A third source of evidence for the character of landscapes undisturbed by humans is the prehistoric archaeological/anthropological record. There are a number of historic Washoe village sites in the basin, and research has clarified some of the

relationships between Washoe culture and the natural environment, such as the use of fire, availability and use of natural resources, attitude toward nature, and ability to manage vegetation. Records of the occupancy of the Washoe tribe in the basin are impressive. More than 60 prehistoric sites have been documented, indicating a long-term population size of 1,000 to 3,000. The cultural identity of the tribe remains strong today; knowledgeable elders describe traditional land management practices and the structure and composition of biota in the basin (Downs 1966; d'Azevedo 1986; Nevers 1976; Strong 1984; Lindström, Chapter 2, this volume). Other sources of prehistoric information include charcoal deposits in the bottom sediments of small lakes that can be used to date the incidence and frequency of extensive forest fires. Also, submerged stumps in Lake Tahoe can be aged to identify periods of warm dry weather (presumably corresponding to lower lake levels). We draw on some of these sources of data to better understand precontact community structure, fire regimes, and species composition in the basin.

Historical data are inevitably incomplete in some manner, and yet the period used to describe historical conditions can greatly influence the resulting depiction. Many ecologists have correctly warned against selecting a single year, or even a cluster of years, to serve as a snapshot of historic conditions (Norton 1992; SNEP 1996; Millar 1997; Botkin 1990). What is needed is a collection of many years, enough to encompass what has been called the historic range of variation (HRV). For long-lived trees, the HRV should be somewhere between 200 and 300 consecutive years because only this span is long enough to capture the effects of episodic droughts, insect outbreaks, catastrophic crown fires, and fluctuations in the size of indigenous human populations (Millar 1997). Tree ring records and aged stumps growing below Lake Tahoe's current surface level, for example, show that the period from 1750 to 1850 was warm and dry, whereas the periods before and after that were wet and cool. As for references for flora and fauna, under natural disturbance regimes changes in species composition generally happen gradually over multiple decades, if not hundreds of years. However, under the influence of anthropogenic disturbances, dramatic changes can occur in very short periods, suggesting that species composition characteristics of a century or two before contact with Euro-Americans would be an appropriate period for describing species composition. The period from 1600 to 1850, then, is long enough to capture the HRV of major climatic fluctuations and of the biotic response to those fluctuations.

Our Assessment of Biological Integrity in the Basin

The identification of pivotal ecosystems, communities, and species contributing to biological diversity and integrity in the basin serves to highlight areas where conservation efforts can make the greatest contribution to sustaining ecosystems. The first step in building a conservation and restoration plan is identifying the strongest and weakest points in the system, followed by conserving the strong points and restoring the weak points. The components of the system we identify and the issues we address in this chapter highlight these strong and weak points to help focus conservation efforts on protecting and restoring biological integrity in the Lake Tahoe basin.

In this chapter we discuss old-growth forests as a terrestrial community type of interest and concern in the basin and the ability to define desired future conditions for old-growth forests (Issue 1). We then address the need to improve our understanding of the dynamics of fire in the basin—to determine how the likelihood of fire varies geographically, to assess the relative importance of weather, fuels, and ignitions in contributing to the likelihood of fire, and to describe the probable effects of a high severity fire on urban areas, air quality, lake clarity, biological integrity, and human life and property in the basin (Issue 2). We also address the extent to which prescribed burning reduces fire risk, improves wildlife habitat, mimics the process of historic fire, and affects nutrient loading into the lake (Issue 3). We present a conceptual model of forest health with the intent of improving understanding of the primary factors affecting forest health (Issue 4). We describe the status of the aquatic ecosystems that occur in the basin and identify which types are most degraded or

vulnerable and in need of conservation and restoration (Issue 5). Finally, we identify a limited number of unique and diverse ecological communities and ecosystems that contribute significantly to the biological diversity of the basin (Issue 6).

We assess the current and potential future conditions of species and populations of plants, animals, and fungi in the Lake Tahoe basin and identify species of ecological concern and cultural interest (Issue 7). Species of concern include those whose populations are recognized as imperiled or vulnerable to declines and species capable of negatively affecting other species. Species of cultural interest include those that are the target of consumptive and nonconsumptive uses and interests. We identify conservation, monitoring, and research activities regarding these species that would benefit biological diversity in the basin.

Issue 1: Define Desired Future Conditions for Old-Growth Forests in the Lake Tahoe Basin

With contributions from Susan Lindström, Elise Kelley, and Peter E. Maloney

Precontact Status and Trends

Almost all vegetation in the basin is different than it was in precontact time 150 years ago, but the degree and direction of difference are not uniform. From the narrow perspective of human existence, some of the differences have enhanced the quality of life, but from an ecosystem-centered perspective, none of the differences has been beneficial. A measure of how changes in the basin have negatively affected the basin is in the reduction of complexity of the vegetation, biodiversity, resistance to stand-replacing crown fires, the area of meadows and wetlands that serve as a buffer and filter between land and lake, lake clarity, air purity, and soil stability. The extent of this reduction and what it means to ecosystem function and resilience will always be open to question.

The trends—that is, the rate and direction of change—have not been constant over the past 150 years. For example, extensive clear-cutting of the forests ended at the turn of the century. At that time approximately 60 percent of the basin had been clear-cut but not uniformly: much more than 60 percent of low elevation pine forests were harvested, whereas less than that fraction of higher elevation fir forests were cut, and very little of the subalpine forest was entered. Harvesting continued to the present but at much reduced, more local, and selective harvest scales and intensities. The forest biomass trend has been toward recovery, rather than loss, during the past century (although the distribution of the increasing biomass has gone into young trees of small diameter, in contrast to the preexisting forests that had most of the biomass in the largest trees of greatest diameter). Grazing intensities of livestock on meadows and in forests have declined similarly in this century, and the trend is one of vegetation recovery. (However, hydrological recovery of meadows requires correcting past channel erosion, a process that takes so much time that we can conclude there has yet been no measurable recovery.) But, this century has also experienced fire suppression management with consequent trends of increasing fuel buildup and increasing density of stands, trends that have delayed the usual pathway of succession toward old-growth status. In this case, trends toward lower biodiversity and lower resistance to crown fire have continued and intensified to the present. The trend toward fragmentation in the landscape has been increasing in the last 50 years of this century, as the number of roads and homes has increased.

Given the historical record of extensive logging, grazing, and other forms of landscape alteration in the basin and given the length of time it takes degraded vegetation to recover, it comes as no great surprise to know that very little mature vegetation of any kind—forest, meadow, or wetland—exists in the basin. Only five percent of forested land, for example, is in old-growth status.

According to TRPA Resolution 82-11 (which defined threshold carrying capacities for the basin), five percent is not a desired future condition. The management objective is to Provide for promotion and perpetuation of late successional/old growth forests . . . across elevational ranges [and including such associations as Jeffrey pine, red fir, and subalpine forest]." The resolution goes on to propose that the percent of Jeffrey pine and red fir

forests to be in old-growth status shall be 75 to 85 percent.

A definition of future desired conditions is important because that vision will drive management plans and actions for the next several decades. To help frame this particular vision, we will summarize the existing condition of old-growth and recovering forests in the basin, their areal extent and pattern of distribution, how these modern forests differ from precontact forests, and what management approach might best achieve TRPA's proposed standard.

What are the traits of modern relictual stands of old-growth forest in the basin that make them unique from the surrounding matrix of more disturbed (seral) forest vegetation?

The traits of old-growth stands are always relative to the kind of forest that can be supported by the local environment. An old-growth forest at very high elevations with short cool summers and shallow soils will not exhibit the same density of trees or the same number of large trees as an old-growth forest at lower elevations. It was for this reason that Franklin and Fites-Kaufman (1996) relativized their old-growth definitions for the entire Sierra Nevada.

There is a west-to-east gradient of declining precipitation in the basin, such that the average annual precipitation on the northeast shore is about half that on the southwest shore (see Chapter 1 of this document and James 1971, Kittel 1998, Rogers 1974). The basin consists of four climatic subunits: low-elevation west shore (Carnelian Bay through South Lake Tahoe to the state line, <2,250 m), which experiences 75 to 100 cm annual precipitation, high-elevation west shore (>2,250 m), 100 to 150 cm, low-elevation east shore (from the state line just northeast of South Lake Tahoe along the east shore and west to Carnelian Bay), 50 to 65 cm, and high-elevation east shore, 65 to 90 cm. Two-thirds of annual precipitation falls from December through March, and more than 80 percent of it falls as snow. Mean snowpack depth and duration increase with elevation such that April 1 snow depth in subalpine mountain hemlock forests (2,300 to 2,900 m elevation) averages 5.0 m depth, mean seasonal snowpack depth is 3.5 m, and snowpack duration is 200 to 250 days (Nachlinger and Berg 1988). Along the shore of Lake Tahoe, snowpack averages only 0.5 m depth, and snowpack duration is less than 130 days (Rogers 1974). Summer thunderstorms occur when subtropical monsoons occasionally extend north from the Gulf of California, but their contribution to total precipitation is trivial. Potential evapotranspiration, as calculated by the Thornthwaite method, is 48 cm. (Actual evapotranspiration is only 27 cm because soil moisture available for plant uptake is depleted by mid-July (Rogers 1974).) The precipitation to evaporation ratio, then, ranges from 1.3 in the drier parts of the basin to 2.2 in wetter locations or at higher elevations. Such values indicate a favorable environment for forest vegetation (Barbour et al. 1998).

Mean daily minimum winter temperature at lake elevation is about -6° C, mean daily maximum summer temperature exceeds 30° C, and length of the frost-free growing season is about 75 days. At higher forested elevations, length of the growing season drops to 60 days, and maximum summer temperatures are cooler.

The geologic substrate along the eastern, southern, and western shores is typically granite. Bedrock along the north shore is volcanic material about 10 million years old. Most soils are shallow Entisols or Inceptisols. Common forested soil series include Cagwin, Jabu, Jorge, Meeks, and Toem (Rogers 1974). In general, soils become more skeletal and undeveloped with increasing elevation. Much of the western and southern shores has been scoured by glaciers, resulting in a modern mosaic of rock outcrops, shallow soils, and deeper soils on glacial morains. The morains tend to support much different vegetation than the brushfields that dominate thinner soils.

In terms of vegetation, there are lower montane, upper montane, and subalpine zones (Table 5-1 and Figure 5-1). Each zone contains a mix of forest, meadow, and chaparral types of vegetation (Smith 1973). Elevational limits for the three types are approximately lake level to 2,200 m (<7,000 ft), 2,200 to 2,600 m (7,000 to8,500 ft), and greater than 2,600 m (>8,500 ft), respectively.

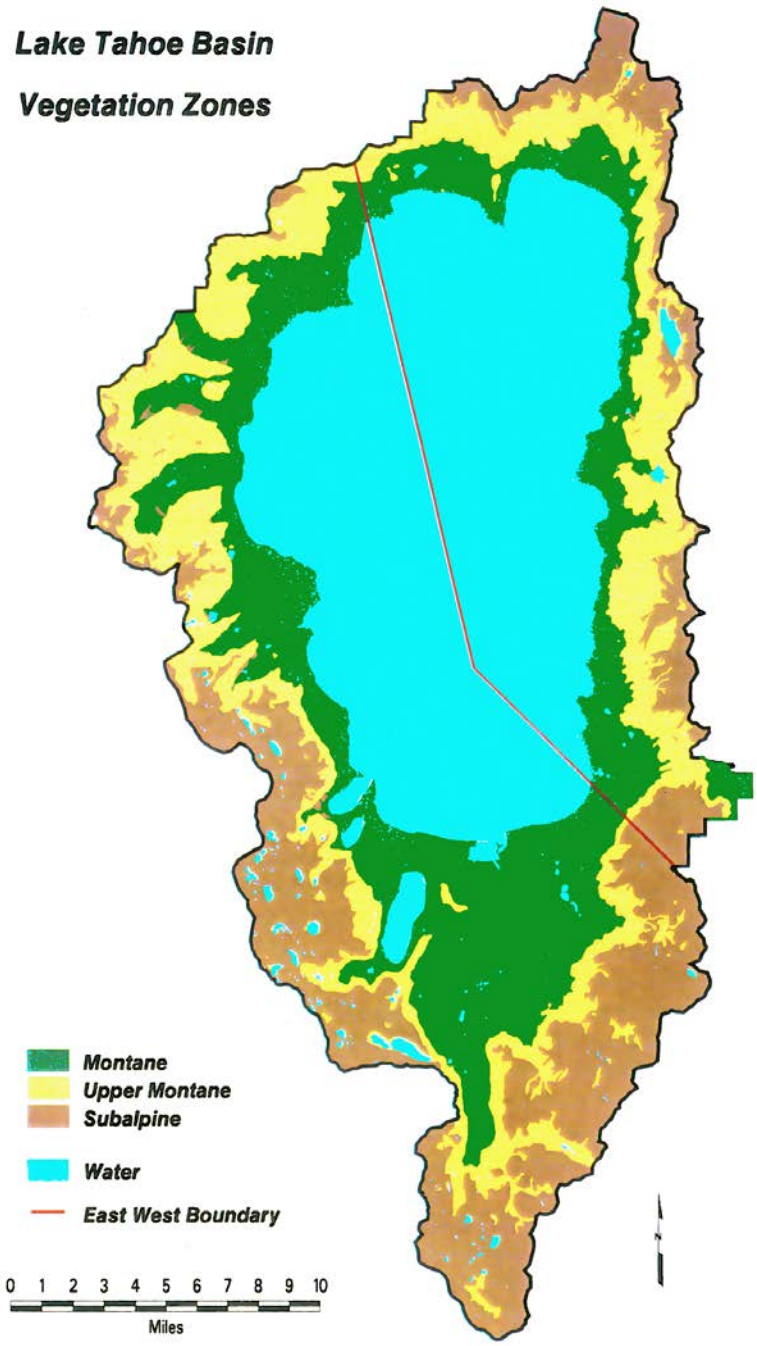


Figure 5-1—Major vegetation zones in the basin.

Table 5-1—Areas (in acres) of major vegetation types within the Tahoe basin.

Elevation Zone and Vegetation Type	West Side	East Side
Lower montane (<7,000 ft elev)		
Jeffrey pine forest	4,300	2,600
Mixed conifer forest	12,300	7,000
White fir forest	9,400	4,900
Lodgepole pine forest	5,100	1,400
Aspen/cottonwood riparian forest	200	600
Montane chaparral	4,800	800
Meadow	4,000	900
Barren	18,700	3,807
Upper montane (7,000-8,500 ft elev)		
Jeffrey pine forest	7,800	6,300
Red fir forest	9,600	900
White fir forest	7,400	5,300
Lodgepole pine forest	4,200	6,200
Aspen woodland	600	500
Montane chaparral	1,600	900
Meadow	7,200	2,600
Barren	24,100	5,700
Subalpine (>8,500 ft elev)		
Mixed subalpine woodland	19,800	5,600
Montane chaparral	300	400
Meadow	1,900	0
Barren	600	800

The most common forest types in the lower montane are Jeffrey pine forest, mixed-conifer forest, and white fir forest. Jeffrey pine forest is thoroughly dominated by *Pinus jeffreyi*, but common associates include *Abies concolor* (white fir) and *Calocedrus decurrens* (incense cedar). Mixed conifer forest is dominated by a complex mix of the same three species—plus *Pinus lambertiana* (sugar pine)—in which no one species consistently contributes more than half of the total number of trees or canopy cover. White fir forest is dominated by *A. concolor*, but a common associate is *A. magnifica* (red fir).

The most common forest type in the upper montane is red fir forest, overwhelmingly dominated by *A. magnifica*. Associated species include *P. monticola* (western white pine), *P. contorta* (lodgepole pine), and *A. concolor*. This forest has less cover by shrubs and herbs than the lower montane forests, possibly because the depth of snowpack and the length of time that snow remains on the ground are far greater than for any other forest in the basin.

A lodgepole forest type occurs in locally wet areas at the edge of meadows in the upper montane zone, and it can extend down into the lower montane where cold air drainage flows at night. Aspen stands also may occupy wet riparian areas or slopes disturbed in the past by wind-throw or avalanche in this elevational zone. Aspen also occurs in similar habitats within the lower montane zone, but to a lesser extent. Lodgepole and aspen

types combined occupy a total of only 8,100 ha (20,000 acres); thus, they are not major forest types.

The most common forest type in the subalpine is mixed subalpine woodland, with *Pinus albicaulis* (white bark pine), *Tsuga mertensiana* (mountain hemlock), and species from the upper montane, such as *A. magnifica*, *P. contorta*, and *P. monticola*.

Thus, we have five major forest types in the basin; these types have been technically called "series" and described by Sawyer and Keeler-Wolf (1996). If we layer distinctly different east and west climates onto these five forest types, we have 10 types. In every case, the eastern variant has a lower density of trees and a lower canopy cover than the western variant. Subalpine forests have been least affected by stressors of the past 150 years because there has been virtually no entry for logging and the fire return interval is so long that a century of fire suppression has not yet missed a single fire cycle (see the discussion of issue two later in this chapter). Even those subalpine forests that have been disturbed show very little indication of cumulative change in the past century because the rate of succession at such an elevation is very slow. We think that a large portion of subalpine forest area is in an old-growth state and condition today not materially different than those of precontact time. Consequently, this section concentrates on three lower montane forest and one upper montane forest that exhibit the effects of disturbance much more extensively than do subalpine forests.

Two major nonforest vegetation types in the basin are meadow and montane chaparral. Their combined area is approximately 8500 ha (21,000 acres), significantly less than the forested landscape (Table 5-2).

Methods of Forest Sampling and Description

We first examined 1978 vegetation maps of the basin that had been prepared by the USDA Forest Service from aerial photographs combined with on-the-ground verification. The maps consisted of polygons of homogeneous vegetation at a scale of 1:24,000. Every forest polygon on the map carried three attributes: the name of the leading one-to-three dominant tree species, the average canopy size of

Table 5-2—Site and vegetation characteristics for 38 old-growth stands in the Tahoe basin.

Trait	Range or Mean
Longitude (degrees W/range)	120°13'/119°51'
Latitude (degrees N/range)	39°17'/38°47'
Elevation (meters/range)	1,794/2,406
Slope (%/range)	8/62
Litter cover (%)	75
Rock + log cover (%)	11
Overstory tree cover (%)	33
Understory tree cover (%)	20
Overstory tree density (per ha)	88
Understory tree density (per ha)	262
Sapling density (per ha)	626
Total tree basal area (m^2 ha^{-1})	45
Shrub cover (%)	20
Shrub species per transect	4.6
Herb cover (%)	<1
Herb species per transect	8.4

categories), and the density of trees (four categories) (Johnson 1995). Minimum polygon size is five ha and the largest polygons are 65 ha.

We highlighted approximately 400 potential old-growth polygons in which the leading dominants were characteristic of lower and upper montane forests on zonal habitats (thus excluding subalpine overstory trees (five woodland and riparian forest), overstory trees had large canopies greater than 7 m (24 ft; categories 4 and 5), and overstory trees were at moderate to high cover (>40 percent; categories N and G). We then visited the polygons by road and trail over two summers and selected 38 of them. We rejected 90 percent of the polygons because they had been entered and thinned since 1978 (stumps and skid trails were present), they had been mistyped as to leading dominants, size, or density, the homogeneous portion of stand area was less than 5 ha, or they had fewer than four trees per 1,000 m^2 of greater than 40 cm diameter at breast height (dbh). We also decided that we would reject any stand so decimated by drought and disease from 1987 to 1992 that it exhibited greater than 30 percent mortality, but none of the sites had such a high mortality, so we never exercised this criterion.

The polygons we accepted, in other words, did not represent a random subsample of available polygons; instead they were a complete census of all acceptable polygons.

Within an acceptable polygon, we chose a random starting point and a random compass bearing for a 300 m long transect. The location of the starting point was defined with GPS coordinates and later was marked on the polygon map. Distances and directions from the nearest road, trailhead, or prominent local feature to the starting point were also recorded.

Trees along the transect were sampled by the point-centered quarter method, generally considered to be one of the most efficient and accurate methods for quantifying trees (Mueller-Dombois and Ellenberg 1974; Engeman et al. 1994). Ten points were visited along the transect, located regularly every 30 m. Eight nearest trees to the point were measured as to distance from the point and their dbh and identity recorded. Four of the trees were overstory trees, defined as having greater than 40 cm dbh; four were understory trees, defined as having one to 40 cm dbh.

Along each transect, cores were taken from a minimum of three overstory trees each of Jeffrey pine and white fir of 40 cm dbh; these cores were later shaved and their rings counted under magnification to determine tree age at breast height (abh). In addition, one sapling of each species present, which was 1 cm dbh, was cut down at the base, and a segment of base wood was taken for later cleaning and ring counting. In this way, we determined the minimum age of understory trees and how many years to add to abh to get actual tree age for 40 cm dbh individuals. The density of trees (saplings) less than 1 cm dbh (including those shorter than breast height) was determined from quadrats (see below).

Each point formed the center of a 25 m^2 circular quadrat. Within that quadrat, all shrubs and herbs were identified to species and their canopy cover separately estimated. Saplings also were counted by species and were defined as being taller than 15 cm but having less than 1 cm dbh (or, of course, including those not even reaching breast height). Tree data were summarized in terms of absolute and relative basal area, density, and frequency. All three relative values then were added and divided by three to obtain an "importance percentage" (Mueller-Dombois and Ellenberg 1974). Shrub and herb data were summarized in terms of absolute and relative cover and frequency. The two relative values then were added and divided by two to obtain importance percentage.

We also estimated ground cover of litter, rocks, and logs (material greater than 25 cm diameter) by taking four samples at the cardinal points along the circumference of the quadrat. When litter was present, its depth was measured.

At the fifth point of the transect we counted and quantified standing snags and coarse woody debris according to USDA Forest Service and Park Service protocols (US Park Service 1992). That is, heights and diameters of standing dead trees and lengths and diameters of downed logs were measured within standard radii of the point (11 and 25 m). Log dimensions were transformed into volume estimates, then volume into biomass using

Smalian's formula, specific density values, and decay factors (Johnson 1995). Snag density was summarized by diameter class for all species combined.

Finally, at three random points along the transect we took three pairs of distance measures for overstory trees and three for understory trees in order to test our presumption of random tree distribution. The point-centered quarter method will generate biased estimates of density if trees are not randomly distributed. We used the T-squared method of detecting nonrandom pattern (Ludwig and Reynolds 1988) and took the required additional distance measures at three of the ten points. After all 38 polygons had been sampled and samples had been grouped by community type (series), we combined the distance measures to generate a single T-squared value for overstory trees and a single value for understory trees of each forest type.

We also assessed the distribution and abundance of old-growth forests by interpreting recent aerial photographs and other remotely sensed data, coupled with periodic ground-truthing. This approach allowed us to be more comprehensive in our survey, but at the expense of not being able to quantify the vegetation in much detail. Our criteria for labeling any polygon as old-growth in this method included total tree cover and the presence of some minimum number of crowns greater than a minimum diameter (which we correlated with trunk diameters of a minimum diameter).

We emphasize that the two procedures we used for locating old-growth stands deliberately eliminated from consideration any slow-growing low-productivity stands on poor soils that had very open canopies and any stands that had suffered very high recent mortality (greater than 30 percent).

Some of the same 38 vegetation sampling transects were used for quantifying disease incidence. Only lower montane stands were included; thus, red fir forest stands were not included. Twenty-two stands were visited in the summer of 1997. In each case, a circular plot 15 m in radius was established around each of the 10 points of the transect. We recorded disease incidence on all trees greater than 20 cm dbh within the plots and separated the data into three size classes of trees: 20 to 50 cm dbh, 51 to 100 cm dbh, and greater than 100 cm dbh. Individual trees, diseased or not, were counted by species. Trees were noted as alive or dead; if dead, year of death was estimated. Live trees also were measured for live-crown ratio (span of height of crown as a fraction of total tree height).

Pest signs and symptoms were searched for in the crown, trunk, and trunk base (e.g., Furniss and Carolin 1977; Hansen and Lewis 1997; Scharpf 1993). Signs included the presence of fungal fruiting bodies, mistletoe plants, and the presence of insects. Symptoms included the formation of witch's brooms (typically caused by mistletoe, some rusts, and *Elytroderma* sp.), chlorosis of foliage, reduced live crown ratio, reduced density of foliage, resinosis, and branch dieback. A synthetic index, which we called "crown vigor," included qualitative assessments of crown position, live crown ratio, color and density of needles, and amount of leader and branch growth. The index ranged from 1.0 (good) to 3.0 (poor).

On living trees, bark beetle attacks were confirmed by the presence of boring dust or pitch tubes. Bark was removed from dead trees to identify characteristic galleries of various bark beetle taxa (Furniss and Carolin 1977). Recently dead trees (1-3 yr old) were dissected to determine possible mortality agents. Fruiting bodies and the architecture of decayed wood can be used to determine pathogenic species. Tree death, of course, is rarely caused by a single agent. A succession of organisms, as well as abiotic stress—such as drought—all contribute to tree death (Ferrell et al. 1994; Filip and Goheen 1982; Worrall and Harrington 1988). However, proximate and ultimate causes of death could sometimes be teased apart. For example, trees killed secondarily by bark beetles would exhibit very little resin around the galleries; saprobic fungal colonization could be distinguished from pathogenic colonization by degrees of callus production and resin excretion; saprobic fungal colonization of trees already dead is usually confined to the outer sapwood, whereas pathogenic infections of living trees extend into the heartwood.

Disease Incidence and Mortality

The 38 stands were located throughout the basin (Figure 5-2). They ranged in size from five to 50 ha and averaged 25 ha. As summarized in Table 5-2, the transects were at elevations of less than 2,400 m (less than 7,500 ft). All aspects were represented, and their slopes ranged from eight to 62 percent. Dominant tree taxa included Jeffrey pine, white fir, and red fir. Tree cover (overstory plus understory) averaged 53 percent, whereas shrub and herb cover were much lower, averaging 20 percent for shrubs and less than one percent for herbs. Density of overstory trees (greater than 40 cm dbh) averaged 88 ha^{-1}, density of understory trees (one to 40 cm dbh) averaged 262 ha^{-1}, and density of saplings averaged 626 ha^{-1}. Mean basal area (45 m^2 ha^{-1}) was low, relative to wetter westside forests (Ansley and Battles 19989).

Species richness was high overall: seven species of trees, 28 species of shrubs, and 78 species of herbs. Within an individual polygon or transect, however, there was an average of only four species of trees, five species of shrubs, and eight species of herbs (Table 5-3). There was considerable species turnover from one transect to another, six shrub taxa and 30 herb taxa occurring only once.

Saplings one cm dbh of four taxa had a weighted average age of 61 years (range = 25 to 110 years; n = 72), and there was no statistically significant difference among the species at the P = 0.05 confidence level. Ring counts of 40 cm dbh individuals of the same taxa had a weighted aver-age of 117 rings (abh; range = 41 to 306; n = 201). Again, there was no significant difference among the taxa. If sapling age is added to ring counts abh, then trees 40 cm dbh had a weighted average age of 178 years. Thus, our three age cohorts were 20 to 60 years, 61 to 178 years, and greater than 178 years.

Table 5-3—Major pathogens, parasites, and insects of conifers on 38 old-growth stands in the Tahoe basin.

Host	Pest
White fir (*Abies concolor*)	Dwarf mistletoe (*Arceuthobium abietinum f.* sp. *concoloris*)
	Broom rust (*Melamsporella caryophyllacearum*)
	Annosus root disease (*Heterobasidion annosum*)
	Trunk rot (*Echinodontium tinctorium*)
	Bark beetle (*Scolytus ventralis*)
Red fir (*A. magnifica*)	Dwarf mistletoe (*Arceuthobium abietinum*)
	Broom rust (*Melamsporella caryophllacearum*)
	Annosus root disease (*Heterobasidion annosum*)
	Bark beetle (*Scolytus ventralis*)
Incense cedar (*Calocedrus*	Broom rust (*Gymnosporangium libocedri*)
decurrens)	Trunk rot (*Oligoporus amarus*)
Jeffrey pine (*Pinus jeffreyi*)	Dwarf mistletoe (*Arceuthobium campylopodium*)
	Root disease (*Phaeolus schweinitzii*)
	Needle cast (*Elytroderma deformans*)
	Bark beetle (*Dendroctonus jeffreyi*)
	Bark beetle (*D. valens*)
	Bark beetle (Ips species)
Sugar pine (*Pinus*	Bark beetle (*Dendroctonus ponderosae*)
lambertiana)	Bark beetle (Ips species)
	Blister rust (*Cronartium ribicola*)

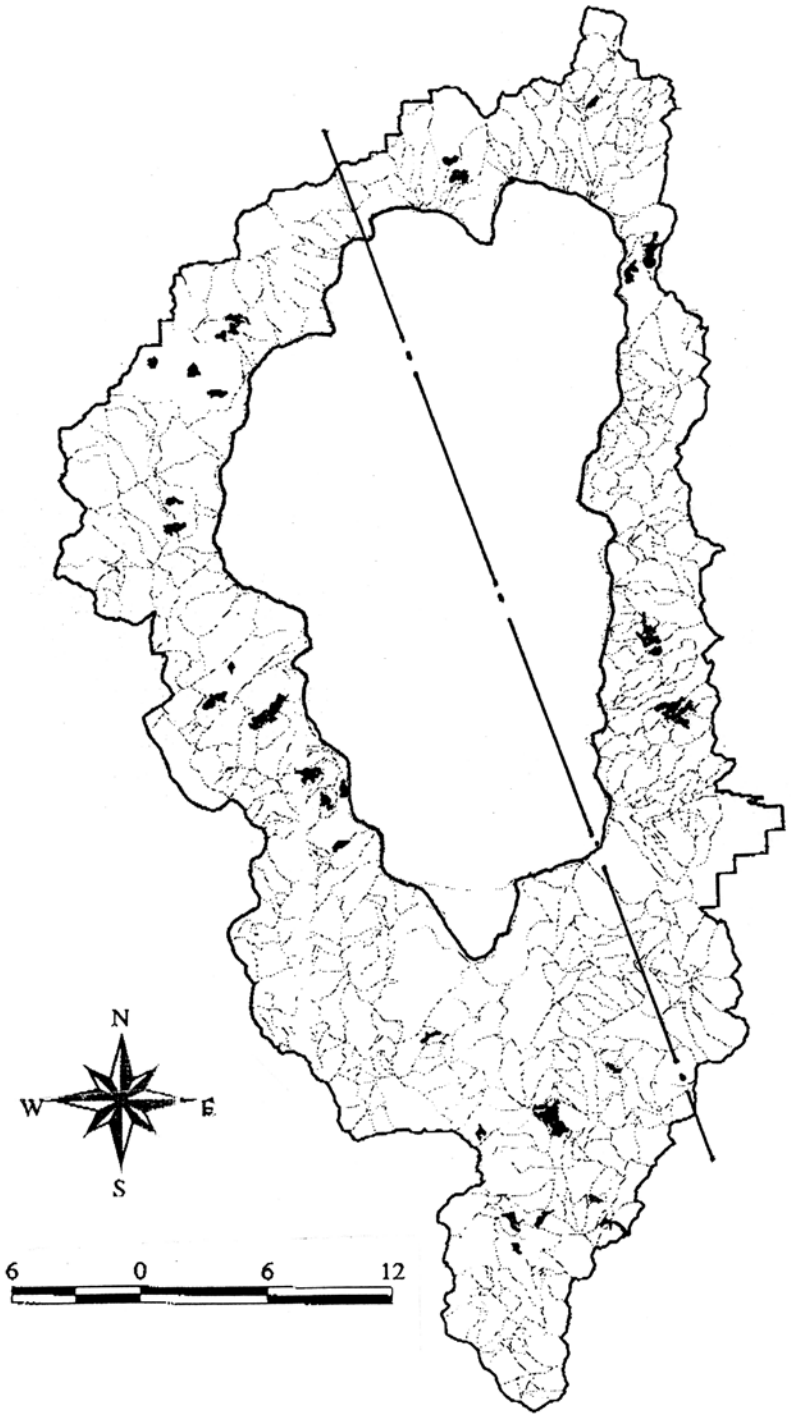


Figure 5-2—Location of 38 old-growth stands.

We did not age the largest and oldest overstory trees, but summaries of life spans in Burns and Honkala (1990) and Sudworth (1967) indicate that individuals in these taxa may commonly attain ages of 300 to 450 years.

Some 24 common pest organisms on our basin transects are summarized by host tree species in Table 5-3. In the most general of categories, the disease organisms fall into the categories of bark beetles, mistletoes, rusts, root rots, and trunk rots.

The most widespread (in terms of presence on the 22 transects) were bark beetles: *Scolytus ventralis* on *Abies concolor* (100 percent presence) and *Dendroctonus jeffreyi* on *Pinus jeffreyi* (68 percent presence). All other pathogens ranged from five to 36 percent presence. With regard to occurrence on individual trees (Table 5-4), bark beetles were associated with nearly 100 percent of dead trees of all species. For example, *Scolytus ventralis* was associated with 96 percent of dead white fir and *Dendroctonus jeffreyi* was associated with 91 percent of all dead Jeffrey pine. Live trees had much lower infection percentages: only 10 percent of white fir and one percent of Jeffrey pine.

The percentage of individuals infected with other pathogens was generally low, with considerable variation from stand to stand. Dwarf mistletoe (*Arceuthobium* species) on Jeffrey pine was found in 41 percent of the stands, but only an average of six percent of the trees was infected, even with the inclusion of one stand that had 56 percent infection. Dwarf mistletoe on white fir was found in 24 percent of the stands but only on two percent of the individuals. There was no significant difference in

Table 5-4—Incidence of major pests in old-growth stands. Incidence is the percent of (living + dead) trees because infection levels did not differ, except for *Dendroctonus jeffreyi* on Jeffrey pine (1 percent of living trees, 91 percent of dead trees) and for *Scolytus ventralis* on white fir (10 percent of living trees, 96 percent of dead trees). Dj = *Dendroctonus jeffreyi*, Dv = *D. valens*, Dp = *D. ponderosae*.

Host	Pest	Incidence
White fir	Dwarf mistletoe	2
	Broom rust	<1
	Annosus root disease	1
	Root disease	<1
	Trunk rot	<1
	Bark beetle	30
Red fir	Dwarf mistletoe	<1
	Broom rust	<1
	Annosus root disease	<1
	Trunk rot	<1
	Bark beetle	54
Incense cedar	Broom rust	10
	Trunk rot	11
Jeffrey pine	Dwarf mistletoe	6
	Root disease	<1
	Needle cast	6
	Dj bark beetle	17
	Dv bark beetle	<1
	Ips bark beetle	1
Sugar pine	Dp bark beetle	3
	Ips bark beetle	2
	Blister rust	<1

infection percentage for mistletoes when live and dead trees were compared. There was a low incidence of root disease, the most common pathogen being annosus root rot (*Heterobasidion annosum*) on white fir, an average of one percent of trees being infected. No incidence of this pathogen was observed in pine or incense cedar. Rusts were similarly low in occurrence: four to ten percent of *Calocedrus decurrens* trees were infected with the rust *Gymnosporangium libocedri* and 11 percent were infected with *Oligoporus amarus*. Less than one percent of sugar pines was infected with *Cronartium ribicola* (white pine blister rust). Crown vigor index for sugar pine, as a consequence, was best among the tree taxa (1.08, where 1.00 is the lowest value possible and indicates excellent health). None of the other tree taxa had indices of greater than 1.44, however, indicating that all tree species were in relatively good health.

Standing dead trees averaged 39 per hectare, which represented 21 percent of all trees, living and dead, that were greater than 20 cm dbh. (If we included all trees greater than one cm dbh, mortality was higher, but it still was lower than the commonly used figure of 30 percent mortality as an average for the basin as a whole, including seral and old-growth stands.) Approximately half the dead trees were queater than 40 cm dbh, and 16 percent were greater than 76 cm dbh. Most of the dead trees were white fir (62 percent) or Jeffrey pine (32 percent); red fir, incense cedar, and sugar pine made up the remaining six percent. All of the dead trees exhibited evidence of insect infestation intense enough to have contributed to or caused death. Most, however, had been infected by multiple pathogens and insects, so we could not identify a sole cause of death.

Stand Structure and Composition

We assigned all 38 samples into the four series: Jeffrey pine series (seven sites), white fir series (14 sites), red fir series (six sites), and mixed conifer series (11 sites).

Statistical analysis (ANOVA) showed that the four series differed in regard to mean elevation, but not with respect to aspect, total tree cover, total shrub cover, estimated depth of snowpack on April first, nor estimated melt date of that snowpack (Royce 1977).

We also showed that the pattern of distribution of overstory trees, understory trees, and saplings, relative to environmental gradients, were not consistent within most species. That is, the three age groups probably were responding to different environments: the overstory was a result of environmental gradients that existed more than 200 years ago, the understory to environmental gradients 100 years ago, and the saplings to environmental gradients of the most recent half a century. Additional evidence for this conclusion is that species importance usually changed from overstory through understory to sapling cohorts within any one stand. The only series that did not show any change in species importance was the red fir series. In all other series, species balance shifted away from pine and toward fir in younger and younger strata.

Tree density was highest in the white fir series (108 overstory plus 431 understory trees per hectare), basal area was highest in the red fir series (59 m^2), and both density and basal area were lowest in the Jeffrey pine series (63 overstory plus 222 understory trees per hectare and 31 m^2 ha^{-1}). Sapling density was lowest in mixed-conifer stands (425 per hectare) and highest in red fir stands (601 per hectare), but these differences were not significantly different.

The density of trees greater than 76 cm dbh was highest in red fir forest (50 ha^{-1}) and lowest in Jeffrey pine forest (24 ha^{-1}). The overall range of density for such trees among all 38 stands was eight to 89 trees ha^{-1}. As a percentage of overstory trees there was no significant difference among the four series in trees greater than 76 cm dbh: white fir was lowest at 13 percent, Jeffrey pine next at 14 percent, mixed conifer was next at 18 percent, and red fir was highest at 19 percent.

Jeffrey pine stands had the simplest overstory in terms of species composition: Jeffrey pine, white fir, and incense cedar in a density ratio of 2.3 to 1 to 0.05, with virtually no other species (Table 5-5). However, the understory and sapling layers were much more diverse. Jeffrey pine declined dramatically in importance percentage from the

Table 5-5—Selected traits of the Jeffrey pine series (n = 7). DEN = density per hectare, BA = basal area in m^2 ha^{-1}, FR = frequency (%), IP = importance percentage, 76 to 100 = density of trees 76-100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	DEN	BA	FR	IP	TOT DEN	TOT BA	76-100	>100
Overstory					63	27	15	9
Pinus jeffreyi	43	20	91	68				
P. lambertiana	0	0	0	0				
Abies concolor	19	6	59	29				
A. magnifica	<1	<1	1	1				
C. decurrens	1	1	4	2				
Others	<1	<1	1	1				
Understory					222	4		
P. jeffreyi 40	1	55	34					
P. lambertiana	3	<1	10	<1				
A. concolor	137	3	89	58				
A. magnifica	<1	<1	3	1				
C. decurrens	39	<1	16	7				
Others	3	<1	3	1				
Saplings					434			
P. jeffreyi 11		3	6					
P. lambertiana	0		0	0				
A. concolor	183		21	54				
A. magnifica	6		1	3				
C. decurrens	234		7	38				
Others	0		0	0				

oldest cohort (overstory, 68) to the understory cohort (34) to the sapling cohort (six)—an order magnitude of 10. At the same time, white fir increased in importance over the same three cohorts from 29 to 54 percent and incense cedar increased from two to 38 percent.

In the mixed-conifer series, Jeffrey pine and white fir shared dominance and three other species were equal associates at considerably lower densities, basal areas, and frequencies (Table 5-6). "Other" conifer taxa encountered lodgepole pine and western white pine. As with stands in the Jeffrey pine series, the importance percentage of Jeffrey pine declined with younger and younger cohorts (29-15-3), while that of white fir increased (33-55-78). Incense cedar also increased but not so much as in the Jeffrey pine series (5-20-11). Red fir showed a strong and unexpected increase in importance (4-17-80).

The white fir series was strongly dominated by white fir and red fir. Jeffrey pine often was present but contributed only about a quarter to a seventh the density of white fir (Table 5-7). The contribution of other conifer taxa was lower than in the mixed-conifer series. The importance percentage of Jeffrey pine declined with increasingly younger cohorts (14-7-1), but the importance of other conifers—including white fir—did not show any consistent pattern of change.

Finally, the red fir series was more completely dominated by a single species than

Table 5-6—Selected traits of the mixed-conifer series (n = 11). DEN = absolute density per hectare, BA = absolute basal area in m^2 ha^{-1}, FR = frequency (%), IP = importance percentage, 76-100 = density of trees 76 to 100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	DEN	BA	FR	IP	TOT DEN	TOT BA	76-100	>100
Overstory					67	40	13	17
Pinus jeffreyi	19	12	67	29				
P. lambertiana	6	8	31	14				
Abies concolor	27	11	76	33				
A. magnifica	4	2	15	6				
C. decurrens	5	5	24	10				
Others	6	2	24	8				
Understory					211	5		
P. jeffreyi 20	1	35	15					
P. lambertiana	4	<1	9	3				
A. concolor	135	4	90	55				
A. magnifica	17	<1	23	9				
C. decurrens	20	<1	19	8				
Others	15	<1	21	11				
Saplings					425			
P. jeffreyi 7		2	3					
P. lambertiana	0		0	0				
A. concolor	327		26	78				
A. magnifica	80		5	16				
C. decurrens	11		3	5				
Others	0		0	0				

Table 5-7—Selected traits of the white fir series (n = 14). DEN = absolute density per hectare, BA = absolute basal area in m^2 ha^{-1}, FR = frequency (percent), IP = importance percentage, 76-100 = density of trees 76 to 100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	DEN	BA	FR	IP	TOT DEN	TOT BA	76-100	>100
Overstory					108	41	22	12
Pinus jeffreyi	10	6	25	14				
P. lambertiana	<1	<1	1	1				
Abies concolor	74	28	88	63				
A. magnifica	21	5	36	16				
C. decurrens	1	1	4	1				
Others	2	1	7	5				
Understory					431	8		
P. jeffreyi 10	<1	16	7					
P. lambertiana	<1	<1	1	<1				
A. concolor	315	7	91	64				
A. magnifica	75	1	41	21				
C. decurrens	10	<1	7	3				
Others	21	<1	9	5				
Saplings					543			
P. jeffreyi 3		1	1					
P. lambertiana	0		0	0				
A. concolor	489		32	83				
A. magnifica	46		7	13				
C. decurrens	0		0	0				
Others	11		2	4				

any other series (importance percentage of red fir = 76 in the overstory). Lodgepole pine and western white pine had relatively high importance percentages in this series. Red fir showed a modest decline in importance in younger and younger cohorts, while white fir increased four-fold (7-15-28). No other taxa exhibited any consistent pattern of change (Table 5-8).

Pattern analysis, via the T-squared test, showed that overstory trees in each of the four series were distributed randomly. However, understory trees were clumped in all but the mixed-conifer series. Simulation testing by Engeman et al. (1994) have shown that moderate clumping underestimates tree density by 15 percent. Consequently, we can be sure that understory tree densities are at least as high as we show in tables 5-5 through 5-8, and they could be up to 15 percent higher.

Coarse Woody Debris

Forest floor surfaces of the four series were not statistically different in terms of percent cover by shrubs, herbs, rock, litter, or coarse woody debris (Table 5-9). Litter depth averaged five cm and litter covered 80 percent of the ground; rocks and coarse debris covered 11 percent of the ground.

Table 5-8—Selected traits of the red fir series (n = 14). DEN = absolute density per hectare, BA = absolute basal area in m^2 ha^{-1}, FR = frequency (%), IP = importance percentage, 76 to 100 = density of trees 76-100 cm dbh, >100 = density of trees >100 cm dbh.

Cohort and Species	DEN	BA	FR	IP	TOT DEN	TOT BA	76-100	>100
Overstory					107	53	25	25
Pinus jeffreyi	3	2	15	6				
P. lambertiana	1	<1	3	2				
Abies concolor	6	1	20	7				
A. magnifica	86	47	100	76				
C. decurrens	0	0	0	0				
Others	11	3	28	10				
Understory					217	6		
P. jeffreyi 1	<1	5	2					
P. lambertiana	0	0	0	0				
A. concolor	34	1	33	15				
A. magnifica	155	4	100	67				
C. decurrens	0	0	0	0				
Others	27	1	38	16				
Saplings					601			
P. jeffreyi 7		2	2					
P. lambertiana	0		0	0				
A. concolor	167		13	28				
A. magnifica	380		27	59				
C. decurrens	0		0	0				
Others	47		7	11				

Table 5-9—Forest floor attributes of the four series. Litter depth (LD) is in centimeters, coarse woody debris (CWD) is in tons per acre for all material >25 cm diameter. Snag density per hectare is by diameter breast height class (in centimeters).

	Cover (%)				Snag density				
Series	Shrub	Herb	Litter	Rock+log	LD	CWD	<76	76-100	>100
Jeffrey pine	27	2	75	15	3.8	15	97	8	4
Mixed conifer	21	2	77	12	4.2	11	28	3	6
White fir	17	4	84	9	6.1	46	80	5	3
Red fir	16	1	86	0	3.4	24	31	6	9

Fuel loads of coarse woody debris (greater than 25 cm diameter) were high, averaging 26 tons per acre (58 metric tons per hectare; Table 5-9). This amount is well within values for mixed-conifer, white fir, and red fir stands from throughout the northern Sierra Nevada, which range from one to 46 tons per acre of coarse woody debris (Blonski and Schramel 1981). We did not measure fine debris smaller than 25 cm diameter, but according to tables in Blonski and Schramel (1981), such debris would contribute another 60 percent biomass. For our stands, that would be an additional 15 to 16 tons per acre. A few stands had exceptional fuel loads; one white fir stand had 73 tons per acre of coarse woody debris, and another white fir stand had 70. There was no statistically significant difference in the amount of coarse woody debris among the four series, but there was a definite trend: Jeffrey pine and mixed-conifer stands had about half the biomass of white and red fir stands.

Snags of all diameters averaged 70 per hectare, equivalent to 16 percent of total (live plus dead) tree density (Table 5-9). Snag density was lowest for the red fir series (46 per ha, 12 percent of all trees) and highest for the Jeffrey pine series (109, 28 percent of all trees). Perhaps this cline of mortality reflects the relative severity of the 1987-1992 drought at lower elevations. Most of the snags were less than 76 cm dbh in all series, but mixed-conifer and red fir series showed the highest percentages of snags greater than 76 cm (25 and 33 percent, respectively) whereas Jeffrey pine and white fir series had only 10 percent of their snags with greater than 75 cm dbh. These data could be taken to indicate that young and small trees were more at risk than old and large trees during the drought period.

How does the present condition of old-growth forest differ from precontact time and what are the reasons for that difference?

Historic Reconstructions

We have no quantitative summary of precontact forest in the basin, nor, for that matter, for anywhere in the Californias. Two kinds of indirect evidence, however, can be used to reconstruct the precontact vegetation.

One type of indirect evidence is the density, size distribution, and species identity of stumps still remaining from clear-cuts of old-growth forest accomplished in the late 1800s. Alan Taylor (1998) examined 17 such sites on the east side of the basin, harvested between 1875 and 1902. Relatively cool and dry conditions preserved stumps down to a diameter of 10 cm. It is possible that fir stumps disintegrated faster; if so, this method could have biased Taylor's reconstructions in favor of pine. Half-hectare samples were taken of 11 Jeffrey pine and six red fir stands, the data consisting of stump diameter, location, and species identification.

An abstraction of Taylor's results give us precontact Jeffrey pine stands with 68 trees per hectare and a basal area of 26 m^2 ha^{-1} and an importance percentage for Jeffrey pine of 79, for white fir of 19, and for red fir of two. These values are remarkably similar to those from the overstory of modern old-growth Jeffrey pine stands in the basin (Table 5-5). Today's overstory density is 63 trees per hectare, and it has a basal area of 27 m^2 ha^{-1}. Total tree density today is higher (285; four times Taylor's reconstruction of precontact density), but surely part of the difference is because our modern data include trees as small as one cm dbh, whereas Taylor counted stumps greater than only 10 cm dbh.

Taylor's precontact red fir stands had 160 trees per hectare and a basal area of 57 m^2 ha^{-1}; red fir had an importance value of 66, western white pine 29, and lodgepole pine five. Modern red fir stands (Table 5-8) have much less of an overstory tree density of 103 trees per hectare but only a slightly lower overstory basal area of 53 m^2 ha^{-1}. Total tree density today is much higher (324; twice the precontact density), but that could be due to the fact that our modern data include trees less than 10 cm dbh.

Lindström and Waechter (1995, 1996) sampled five north shore Jeffrey pine clear-cuts and obtained much smaller stump counts, averaging only 13 per hectare. They also sampled one east shore white fir clear-cut and counted 43 per hectare. We think these values are either underestimates or anomalies, given the much higher density of trees in modern Baja California forests that have never experienced fire suppression management (see below). Possibly stump decay was much faster in these wetter sites than where Taylor did his work.

Lindström, who has made a thorough search of 19th century scaling records in the basin, concluded that average maximum trunk diameters then were 130 cm and that clear-cuts yielded predominantly Jeffrey pine, lodgepole pine, white fir, and incense cedar in declining order (see Chapter 2).

Another view of the basin soon after contact time comes from surveys conducted by the General Land Office (GLO) in the last quarter of the 19th century. Surveyors annotated their routes through uncut forests by identifying overstory trees as to species and dbh at particular intervals along section lines or in four directions from section corners. J. A. Fites has summarized hundreds of trees recorded in GLO notes from lower and upper montane and subalpine zones for our report (figures 5-3, 5-4, and 5-5). The relative abundance of "fir" (a combination of white and red fir) to "yellow pine" (a combination of Jeffrey pine and ponderosa pine) in the lower montane is surprisingly close to 1:1 from these GLO notes, in contrast to Alan Taylor's stump counts (1:4) and in contrast to the common assumption that the ratio of fir to pine the previous century was low—certainly lower than it is today.

Anecdotal accounts by the two early foresters Lieberg (1902) and Sterling (1904) ratify the GLO's picture rather than Taylor's. They wrote that white fir accounted for 25 to 40 percent of lower montane stands in precontact time but 60 to 75 percent of secondary forests. Sugar pine and Jeffrey pine in contrast, they wrote, were not regenerating in sufficient abundance (only two to three percent of second growth stands) to recapture their past abundance (20 to 25 percent for each in precontact stands). To summarize their precontact estimates: white fir = 25 to 40 (mean = 32), sugar pine = 20 to 25 (mean = 22), Jeffrey pine = 20 to 25 (mean = 22), others (incense cedar, Douglas fir, lodgepole pine) = 24; that is, the fir to pine ratio must have been about 32 to 22, or 1.5 to 1. Second-growth stands at that time were heavily dominated by fir, at a ratio of 30 to 1.

The GLO records indicate that the upper montane zone was fir-dominated then, just as it remains today, the ratio of fir to pine being approximately two to one (Figure 5-4).

The subalpine zone was very high in fir (no doubt almost all red fir) and low in mountain hemlock, western white pine, and whitebark pine. One possible explanation for such a high ratio of fir is that few locations in the basin are high enough to exhibit dominance by whitebark and hence were rarely encountered in the surveys. Another explanation could be improper species identification, in which surveyors recorded many mountain hemlocks as firs by mistake.

The size distribution of trees in the three zones is relatively flat in the montane and subalpine zones (Figure 5-5). Such a size and age pattern is not the classic inverse-J shape expected of self-maintaining, multiple-age old-growth forest. However, the patterns do summarize a complex age structure and architecture, and they are similar to size and age distributions for modern old-growth subalpine tree populations (Major and Taylor 1988; Nachlinger and Berg 1988) and even for some lower montane old-growth mixed conifer stands (Ansley and Battles 1998). Distributions today for the basin's montane zones are very different; they show highest densities in the smallest and youngest cohorts, less than 16 inches dbh (less than 40 cm dbh; refer to tables 5-5 through 5-8). These small-trunked cohorts are the ones that exhibited a doubling to quadrupling of densities over the past 150 years.

Comparison to Modern Baja California Forests

A second type of evidence for reconstructing precontact basin forests comes from modern mixed-conifer forests in the Sierra San Pedro Martir (SPM) of Baja California, an ecological analog to the basin (Minnich 1986; Minnich et al. 1995, 1999). The SPM is the southernmost portion of the Peninsular Ranges, which extend from southern California across the international border for 250 km. Forests of Jeffrey pine, lodgepole pine, sugar pine, white fir, and incense cedar dominate a rolling plateau at 1,900 to 2,500 m elevation. Mean annual precipitation is 65 cm, more than half of which is snow. Fire suppression management has never been practiced in SPM. Fire scar studies

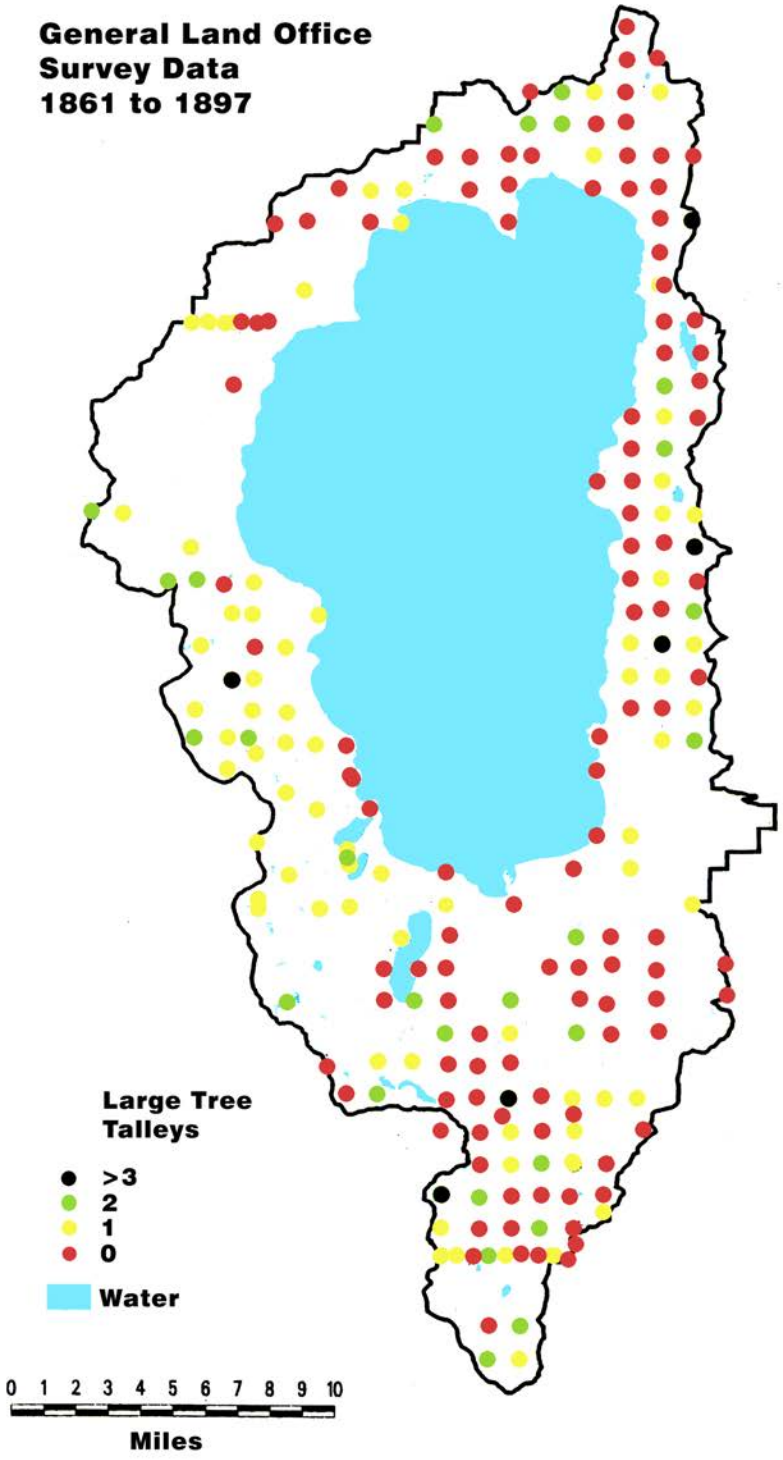


Figure 5-3—Location of areas surveyed by the General Land Office from 1861 to 1897. Dots show section corners at which the nearest trees in four quadrants around the corner totaled 0-4 with dbh >36 inches.

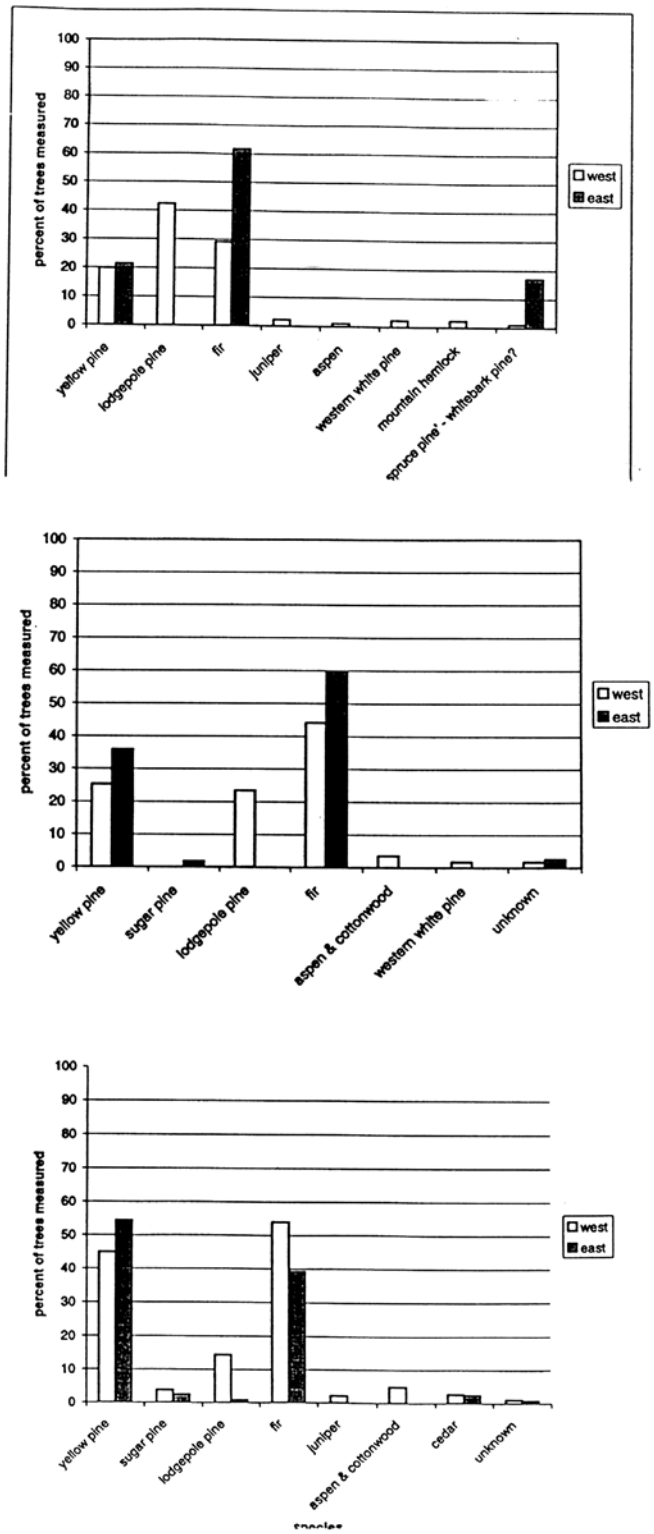


Figure 5-4—Species composition in the basin ca 1880, as recorded by the General Land Office survey. Top is subalpine zone woodland species, middle is upper montane, bottom is lower montane. From J. A. Fites, unpublished data.

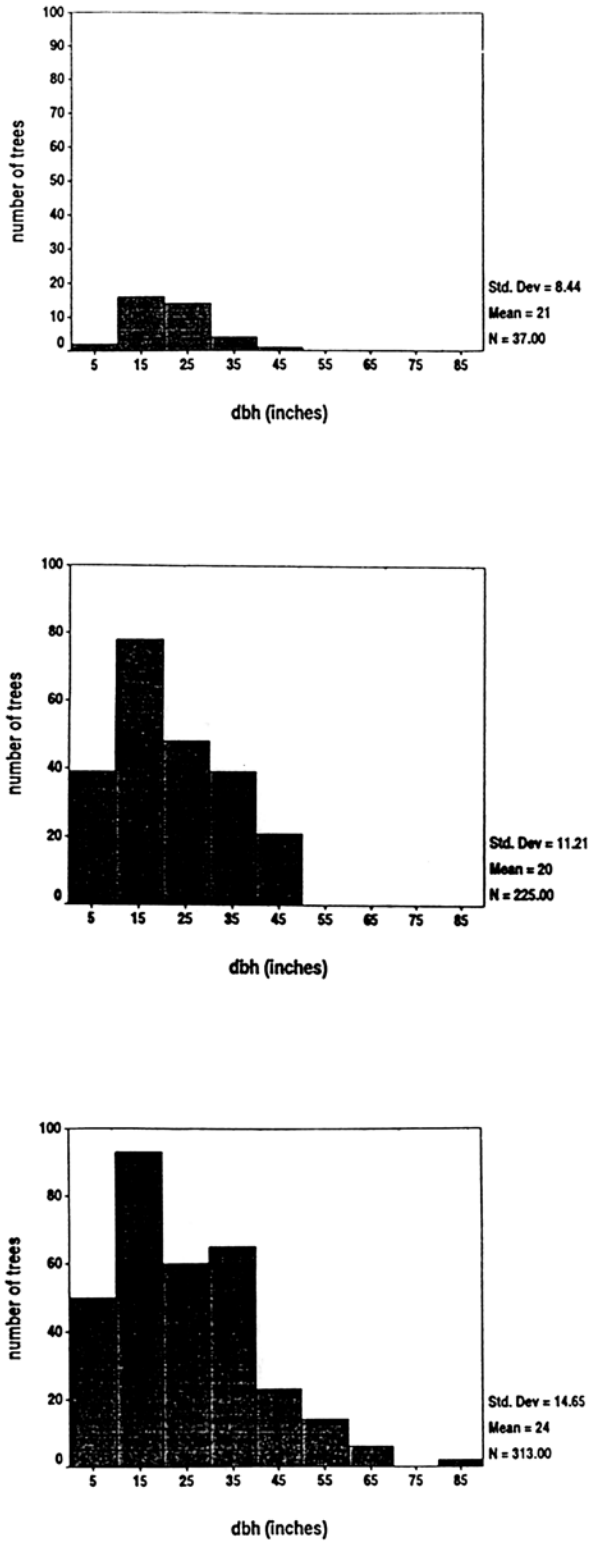


Figure 5-5—Diameter at breast height distribution of all trees encountered in the basin ca 1880 by the General Land Office survey. Top is subalpine zone, middle is upper montane, bottom is lower montane. From J. A. Fites, unpublished data.

indicate a mean fire return interval of 26 years over the past 400 years, with no evidence of any increase (that is, no evidence of fire suppression) during that time.

Minnich and his colleagues quantified twenty-one forest stands comparable to those of the Tahoe basin, using the same point-centered quarter technique tha we used. Tree density (trees greater than three cm dbh) ranged from 78 ha^{-1} in Jeffrey pine forest to 156 ha^{-1} for white fir forest. (A single Jeffrey pine-white fir stand sampled independently by Savage [1997] had a density of 162 ha^{-1}.)

The size-class distribution was flat and complex, similar to the GLO records for basin forests. Mixed conifer, white fir, and Jeffrey pine stands showed either equal densities in 10 to 30, 31 to 60, 61 to 90, and greater than 91 cm dbh classes or somewhat higher densities in the 31 to 91 cm dbh classes. The stands, in other words, exhibited the same size and age complex structure as uncut stands of the basin in the late 1800s (Figure 5-5). If we estimate that half the 61 to 91 cm dbh class represents trees greater than 76 cm dbh, then these forests had 20 to 25 trees ha^{-1} of size greater than 76 cm dbh (17 to 28 percent of all trees). Basal area ranged from a low of 21 m^2 ha^{-1} in Jeffrey pine stands to 34 m^2 ha^{-1} in white fir stands.

These SPM data are remarkably similar to overstory data for modern Tahoe forests. Overstory tree density in Jeffrey pine forests in the basin is 63 ha^{-1} and in white fir 108 ha^{-1}; overstory basal area in basin Jeffrey pine forests is 27 m^2 ha^{-1} and in white fir 41 m^2 ha^{-1}; and some 24 to 34 trees ha^{-1} are greater than 76 cm dbh in the same two series, accounting for just over 30 percent of all trees. The quantitative values of the two forests are within 25 percent of each other. On the other hand, if we include trees down to one cm dbh, then Tahoe old-growth forests have four times the density of SPM forests.

Unlike the Tahoe area, SPM understory and sapling species composition showed no trends toward increasing importance of white fir and incense cedar nor decreasing importance of Jeffrey pine.

We can conclude that the overstories of modern Tahoe Jeffrey pine and white fir old-growth forests closely resemble (within 25 percent) precontact old-growth forests in terms of species composition, density, and basal area. The modern forests differ from precontact forests in understory tree species composition and density: they have four times the density, the importance of white fir and incense cedar are two to three times higher, and the importance of Jeffrey pine is 50 percent less. We have less information on precontact red fir forests; the modern overstory appears to closely resemble precontact red fir forests, while the modern understory is about twice as dense as it once was, with a modestly larger importance of *A. concolor*.

How does the disease incidence of modern old-growth Tahoe forests compare with seral Tahoe forests and those in SPM?

We quantified disease incidence within 14 seral conifer stands in the basin and within 16 old-growth stands in SPM for the purpose of assessing modern forest health.

Tree mortality was approximately equal, in terms of percent of all trees dead (21 to 22 percent) for old-growth and seral Tahoe forests (Table 5-10). There was considerable variation from stand to stand, ranging from a low of six percent to a high of 41 percent. Most of the standing dead trees had died during the drought of 1987-1992. The age pattern of mortality was somewhat different, a larger percentage of dead trees coming from understory trees (70 percent) in seral forests than in old-growth forests (50 percent). White fir made up more than half of all mortality in all stands, but mortality was somewhat higher in seral stands (78 percent) than in old-growth stands (62 percent). Seral forests also had four to five times more infestation of dwarf mistletoe on both white fir and Jeffrey pine and of rust on incense cedar (Table 5-10). Bark beetle infestation was similar for seral and old-growth stands.

While much of the 1990s tree mortality in the basin can be indirectly attributed to the short-term effects of drought and the long-term effects of a century of fire suppression (which increased tree density and competition), the final cause of death has been due to a suite of insects and pathogens. For each of the major conifer species, overall pest incidence is lower in old-growth stands than in seral

Table 5-10—Mortality and the incidence of the most important pests in 17 old-growth and 14 seral stands of the Tahoe basin and in 16 old-growth stands of the Sierra San Pedro Martir (SPM). Incidence is expressed as a percentage of all trees, living + dead. Mortality (Mt) is expressed as a percentage of all trees, living + dead. Host species: Pj = *Pinus jeffreyi*, Ac = *Abies concolor*, Pl = *Pinus lambertiana*, Cd = *Calocedrus decurrens*. Technical names of diseases are in Table 4. T = trace, <1%.

Forest type/Mt	Host	Dwarf mistletoe	True mistletoe	Bark beetle	Annosus root rot	White pine blister rust	Cedar rust	Heartrot	Total
Old-growth/21	Pj	6		17					23
Seral 29		21		18					39
SPM 12		0*		12					12
Old-growth Ac	3	0	30	1				T 34	
Seral		11	0	35	3			T	49
SPM		0	60	28	2			T	90
Old-growth Pl			3		0			3	
Seral				5		3			8
SPM				1		0**			1
Old-growth Cd						9	11	20	
Seral							34	1	35
SPM (this host not surveyed)									

stands (for example, 23 percent versus 39 percent total pest incidence for Jeffrey pine in old-growth and seral stands; 34 percent and 49 percent for white fir), but these differences were not large enough to be statistically significant.

Epidemic levels of several bark beetle species are the most important pests causing tree death in the past 10 years. The high level of mortality in the basin was not out of the norm for forests statewide; similar levels have been reported for the Modoc Plateau, the southern Cascades, the entire eastside of the Sierra Nevada, and mountains in southern California (Smith et al. 1994; Ferrell et al. 1994; Dale 1996).

There are few records of mortality prior to Euroamerican contact, but we can use the SPM forests as a surrogate for precontact basin forests. SPM forests had experienced the same 1987-1992 drought as Tahoe forests, yet mortality was much about halved. Tree mortality in SPM accounted for only 12 percent of all trees (range of variation from stand to stand = four to 15 percent). The overwhelming majority of snags (90 percent) were overstory trees greater than 50 cm dbh, whereas 60 percent of basin snags were less than 50 cm dbh.

A more localized sample of SPM mortality by Savage (1997) had only four percent mortality, in contrast to 14 percent mortality in similar Jeffrey pine forests in the Transverse Range north of the international border in southern California. Her analysis of SPM snags indicated that most had died prior to the 1987-1992 drought, whereas the great majority of snags in the Transverse Range had died between 1984 and 1991. Apparently, recurring surface fires in SPM keep tree density so low that episodic droughts do not increase competition for soil moisture. The different patterns suggest that fire is responsible for most stand thinning in SPM and that insects have replaced fire as thinning agents in the basin (Minnich et al. 1999).

Our analysis of 16 SPM stands showed that some of the same pathogens, parasites, and insects of Tahoe forests were present (tables 5-3, 5-4, and 5-10). Major exceptions were that dwarf mistletoe was absent in SPM, but true mistletoe (*Phoradendron pauciflorum*) was present and very abundant on white

fir; also, white pine blister rust was absent in SPM. Jeffrey pine trees showed much lower combined incidence of bark beetles, mistletoe, and root and trunk rots in SPM than Tahoe (12 percent versus 23 percent). However, white fir had a much higher combined incidence in SPM, largely because of parasitism by true mistletoe (91 percent at SPM versus 33 percent dwarf mistletoe infection in the Tahoe basin). The combined disease incidence on sugar pine was virtually the same in both locations. Thus there is no consistent pattern of pest differences between SPM and Tahoe forests. However, we can conclude that SPM forests are healthier because mortality there has been almost half that of Tahoe during the past decade.

What is the present condition of seral (non-old-growth) forests in the basin?

The condition of Tahoe basin seral stands is significantly different than that of old-growth stands (Table 5-10). In comparison to more open old-growth forests of SPM, seral stands appear even more different; disease incidence is 325 percent higher, mortality is 167 percent higher, and tree density is 400 percent higher.

Old-growth forests can readily be compared to modern seral forests in the basin by reference to 774 plots quantified by the USDA Forest Service in the 1980s and 1990s as part of the Forest Inventory Analysis system (FIA Johnson 1995). By "seral," we mean any forest that has been previously entered, whether harvested individually, selectively, or entirely. Some FIA plots, therefore, do have old and large trees, and a few could be classified as old-growth, but we would not have selected most FIA plots for our old-growth group because of the presence of scattered stumps.

A summary of tree density and basal area for all five forest series, including east and west variants (tables 5-11 and 5-12) shows that for every series, except the subalpine mixed-conifer woodland, the west variant had at least a 30 percent greater tree density and greater basal area for all trees greater than 10 cm dbh (and at least 50 percent greater for trees greater than 91 cm dbh). Average total tree density for all FIA sites was 994 per hectare (no difference whether subalpine stands were or were not included), compared to average tree density for our 38 old-growth sites of 350 per hectare. Density of seral basin forests, therefore, was [(994-350)/350 = 184percent] greater than old-growth basin forests. Density of trees greater than 91 cm dbh in seral forests was seven per hectare, compared with old-growth density of 16 per hectare for trees greater than 100 cm dbh (Table 5-11).

In theory, restoring Tahoe forests to their precontact densities should mitigate most serious pest outbreaks in the future. However, thinning and prescribed burning can increase pest incidence and mortality. For example, thinning may damage residual trees and can increase the incidence of annosus root rot by exposing freshly cut stumps to airborne spores.

Table 5-11—Mean, minimum, and absolute minimum values for density of living trees >76, 91, and 100 cm dbh ha^{-1} in four series. Data come from this document, FIA Tahoe plots, and recommendations by Fites and Potter and their colleagues (F&P). Absolute minimum is defined in text.

			Trees >76		Trees > 100		Trees >91
Series	**Our mean**	**Our min**	**F&P min**	**F&P ab.min**	**Our mean**	**Our min**	**FIA seral mean**
Jeffrey pine	24	12	13	5	9	1	4
Mixed conifer	30	22	27	12	17	8	14
White fir	34	11	35	15	12	1	3
Red fir	50	44	42	18	25	11	6

Table 5-12—Area (hectares) of old-growth forests in the Tahoe basin estimated from the interpretation of remotely sensed images. Criteria for the inclusion of any polygon as old-growth include the >2 trees per acre with dbh >30 inches and four different percentages of canopy cover. Areas (hectares) are summarized separately for three forest zones (lower montane, upper montane, subalpine) and into western and eastern portions of the basin.

	West			East			
Old-growth criteria	**Lower**	**Upper**	**Subalpine**	**Lower**	**Upper**	**Subalpine**	**Total**
Tree canopy >60% cover	569	76	23	6	119	21	814
40-60%	439	377	58	141	280	14	1,309
25-40%	230	166	15	169	19	0	599
10-25%	87	170	87	19	15	7	385
Total	1,325	789	183	335	433	42	3,107

What is the distributional pattern of relictual old-growth forest now and what should it be in the near future? What sustainable mix of seral and old-growth forests is possible?

Old-growth stands in the basin occupy a very small percent of the landscape. Our field check of 400 potential old-growth polygons revealed only 38 to actually be unentered old-growth stands. On the one hand, if we presume that this field survey was exhaustive, then the total old-growth area of lower and upper montane forest is 38 x 25 ha = 1,030 ha. If, on the other hand, we interpret remotely sensed images more generally for overstories that meet some less quantitative criteria of old-growth status (let's choose greater than 40 percent cover), the potential total old-growth area in the lower and upper montane zones combined is 2,007 ha. Subalpine old-growth (choosing greater than 25 percent canopy cover) would add another 131 ha.

The area of lower montane plus upper montane forests, including all seral phases is 38,340 ha; subalpine forest area would add another 10,280 ha (Table 5-1). Taking the largest estimate for today's old-growth area, (2,007 plus 131), it totals four percent of all conifer forest area in the basin.

What percentage of basin forest land was in old-growth status prior to Euroamerican contact? The best estimate might come from an examination of old-growth landscapes in Sierran national parks. Franklin and Fites-Kaufman (1996) analyzed Lassen Volcanic, Yosemite, Sequoia, and Kings Canyon National Parks and concluded that 55 percent of the modern forested landscape was in old-growth status; the rest was seral. As logging had never occurred in those parks, they deduced that 55 percent of the landscape had been old-growth in precontact time. (In contrast to national forests, adjacent Forest Service lands had been open to logging, and these exhibited 13 percent cover by old-growth forests.) Applying the 55 percent "rule" to the Tahoe basin gives 26,740 ha. So, today's 2,138 ha of old-growth represents eight percent of the preexisting old-growth area.

The distributional pattern of remaining old-growth stands is scattered. There are no clumps of contiguous or nearly contiguous stands that form nuclei about which managers might build out from over time. Several areas do stand out as having loose clusters of stands (Figure 5-2): six stands on the east side between Logan House Creek (north) to Highway 207 (south), four stands in the northeast just north of Marlette Lake, four stands on the west side just north of Emerald Bay, and five stands in the extreme south in the Upper Truckee watershed.

An image of the location of old-growth stands from the interpretation of remotely sensed data (Figure 5-6) shows additional loose clusters. Looking only at the darkest colored areas (stands with greater than 60 percent canopy cover), there are more than 20 clusters, each greater than 200 ha,

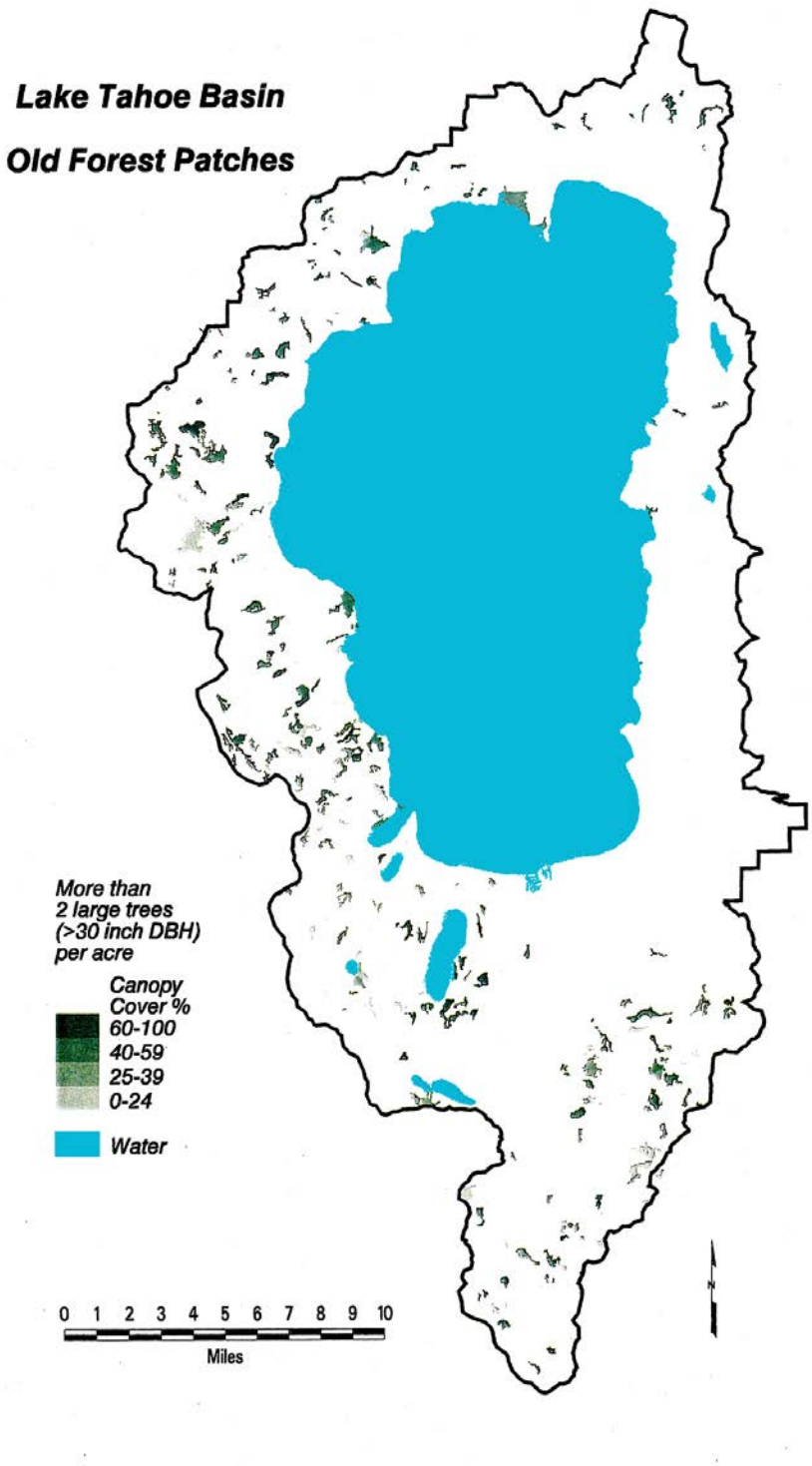


Figure 5-6—Clusters of old-growth stands identified from remotely sensed images and using the criterion of polygons having >2 trees per acre, >30 inches dbh, and various amounts of total canopy cover. About 20 clusters with cover >40 percent (darker green) are scattered in the north, west, and south parts of the basin.

located to the north, west, and south of the lake.

We suggest that these clusters be visited and their "neighborhood" forest vegetation be evaluated as to its potential to be moved toward old-growth status. Such traits as size of the old-growth core, slope stability, distance from structures and roads, and homogeneity of the neighborhood could be used to rate the suitability of each cluster for active management. A few of the highest rating clusters then would be identified for management and monitoring. Then, as funds, consensus, and abilities improve, the management area could be expanded, either by enlarging the area of the original clusters or by extending management to other clusters.

What should the ultimate distribution and extent of old-growth forest be? Should it be managed all the way to TRPA's Resolution 82-11 of 75 percent of forested land? Should it be returned to the precontact extent of 55 percent? Forest ecologist Jared Verner (1980) proposed that 40 percent of the Sierran landscape be old-growth, based on considerations of optimal habitat requirements for birds and other wildlife. Or should old-growth in the basin simply be increased a modest amount, to mirror the 13 percent typical of Forest Service lands (Franklin and Fites-Kaufman 1996)? We certainly can conclude that there are strong ecological reasons to make it larger than the present four percent, but there is not much consensus on how much larger.

Issue 2: The Current Likelihood of Fire; the Relative Importance of Weather, Fuels, and Ignitions in Contributing to the Likelihood of Fire; and Effects of a High Severity Fire on Urban Areas, Air Quality, Lake Clarity, and Biotic Health

With contributions from Sue Husari, Don Carlton, and Steve Beckwitt

In the Sierra Nevada, most fires prior to European settlement were thought to be of low to moderate intensity, with extensive areas (>100 acres) of high tree mortality uncommon (Skinner and Chang 1996). Fires typically spread along the surface, torching or consuming taller vegetation or tree crowns in small to medium patches. Litter, herbs, shrubs, and tree saplings were consumed, but most mature trees had a thick enough insulating bark to withstand the heat. Sometimes the upslope-facing side of a tree would be scarred because debris had accumulated there and temperatures were hotter. Once scarred, such trees often were scarred again in the same area by subsequent fires because of the lack of thick bark and accumulations of pitch. The wood of these trees thus bears a fire history record for several hundred years or longer. It is through the examination of such wood records (the science of dendrochronology) that we can determine the fire return intervals (number of years between fires for the same place) that occurred historically. Some fire scar records for the Sierra Nevada stretch back nearly 2000 years because of the long length of life of the scarred trees (Swetnam 1992).

The frequency of these surface fires appears to be determined mainly by the availability of fuel. Both the presence of fuel and the dryness of the fuel determine availability of fuel. At higher elevations of the Sierra Nevada, such as the red fir zone of the basin, fuels are often present, but, because of the short fire season, fuels are not always flammable for long periods. At lower elevations the weather is always suitably arid by late summer. Lightning strikes saturate the landscape at both lower and higher elevations, although patterns can vary locally due to topography. But if too few years have passed between the last surface fire and the lightning strike, then too little fuel is available to carry the flame. As growing conditions improve—because of increasing annual precipitation or locally wetter sites, a longer growing season, and productive soils—the speed with which fuel accumulates increases, and thus the minimum time between fires becomes shorter (Minnich et al. 1995).

By the 1920s, fire protection was a primary concern. Tahoe has now completed 75 years of fire suppression management, during which there normally would have been three to five fire cycles in the mixed-confer and pine zones. One consequence has been an increase in the amount of fuel on the forest floor and increased density of understory vegetation. Fire played an important role in thinning historic forests, and reducing surface fuels. Today

fires are likely to be more intense because of the accumulation of surface fuels and understory. The amount of fuels available to burn at any given time in a given area is referred to as fire hazard. Our very successful program of fire suppression of low to moderate intensity fires has made the occurrence of high intensity fires more likely than ever. In upper montane and subalpine zones, fewer fire cycles have been missed; consequently, the effects of fire suppression are less evident in these zones.

In the Lake Tahoe basin, there have been many additional changes in vegetation from the time of settlement, which are the result of activities other than fire suppression. Extensive harvest in the late 1800s and early 1900s (Elliott-Fisk et al. 1997; Lindström, Chapter 2, this volume; Raymond 1992) resulted in an overall young forest. There is concern that these changes have contributed to an increased likelihood of severe fire. Younger forests are more susceptible to mortality from fires. This is due to the lower height and size of small trees. Their bark is thinner, and their crowns are lower to the ground, making them more susceptible to lethal heating by flames of a low height. With much of the basin in a younger state, a large proportion of it would burn severely, with high rates of mortality.

In addition to instituting fire suppression measures that may have increased fire hazard through fuel accumulation, humans have increased the number and changed the distribution of ignitions. Fire risk typically is defined as the probability that an ignition will occur and ignite fuel. Human caused fires are the source of most of the acres burned by wildland fire in the Lake Tahoe basin. People tend to ignite fires that escape and get larger than do lightning fires. Some of the fires that people ignite are on severe fire days, which are dry, windy, and hot; lightning fires often are ignited under conditions of higher humidities and cooler temperatures and during events that are usually forecasted, allowing fire managers to gear up for the subsequent fires.

These two human activities—creating younger forests by harvesting older trees and suppressing fires that otherwise would have burned off accumulated fuel—have increased the likelihood of severe fire in the basin. The Lake Tahoe basin is high elevation, with a relatively short fire season compared to other parts of the Sierra Nevada, two factors that greatly decrease the likelihood of fire. In addition, fire suppression is excellent in the basin, as demonstrated by the lack of large fires since the early 1900s. However, the likely consequences of fire in the basin are particularly great because of the importance and status of lake clarity and the high density and value of human development. There is a need to quantify the likelihood of fire in the basin, to assess the potential tools that would be most effective in reducing risk and hazard, and to set priorities about how best to reduce the likelihood of fire.

The potential effects of unplanned fire on vegetation in the basin are also important to consider. Vegetation in the basin provides important ecosystem and social values that would be at risk if a large, high severity fire occurred. Vegetation provides cover for the soil, filtering nutrients and sediment that might flow into the lake, reducing water quality. Vegetation also provides wildlife habitat and is an important component of the scenic beauty of the basin. For this assessment, we modeled the likelihood of unplanned fire occurrence in the basin and likely effects of fires on ecosystem and social/economic resources.

Definition of Terms

For clarity it is important to define some terms that are used throughout this section that people often use in varied ways. These terms include risk, fire risk, high severity fire, large fire, fire or fuel hazard, and likelihood of fire. The term "fire risk" has a very specific meaning in fire literature and is described as the likelihood that an ignition will occur. We use the term in this sense. "Fuel hazard" refers to the amount of fuel available to burn at any given time in a given area. Both the total quantity of fuel and the dryness of the fuel determine the amount of available fuel. High quantities of fuels may be present at a location, but if the fuel is wet or moist, then it is not available for combustion. Fire hazard and fire risk combine to determine the likelihood of fire. "High severity fire" refers to fires

where a large proportion of the overstory vegetation is killed (i. e., >70 percent mortality of overstory trees). In the basin, any fire greater than 10 acres may have detrimental consequences. Fires of this size can cause extensive damage because of the high density and value of human development and importance of lake clarity. The term "risk" is used often by many people in a very general sense to refer to the likelihood of a high severity or large fire. To ensure clarity, we emphasize use of the more specific terms "fire risk," "fuel hazard," and "likelihood of fire" and use "risk" only in the general sense when considering the likelihood of a high severity fire or large fire that may jeopardize valued resources.

The following questions are addressed under this issue:

- What is the likelihood of large or severe fires in the Lake Tahoe basin under different weather conditions?
- What are the likely weather conditions associated with a high severity fire or a large fire?
- What is the relative importance of fuels, weather, and ignitions in contributing to the likelihood of large or high severity fires?
- What are the likely effects of a high severity or large unplanned fire on soil erosion, air quality, lake clarity, biotic health, old growth, and urban areas?
- How will susceptibility to fire change in the future when snags fall to the ground?
- Where are the key areas to restore or manage to reduce the likelihood of unplanned large or severe fires?

What is the likelihood of large fires in the Lake Tahoe basin under different weather conditions?

The likelihood of large fires is often quantified by analyzing historical patterns of large fires, such as was done for the Sierra Nevada Ecosystem Study Project (McKelvey and Busse 1996). In the Lake Tahoe basin, this approach is not directly applicable because fires have been few in the last 90 years. Therefore, an indirect approach was applied, using a combination of information sources, individually and together, to develop a fire susceptibility index (see Appendix A for computations). The sources of information included history of fires, recent ignition patterns, fuel conditions, weather patterns, suppression resources and effectiveness, and the spatial overlap of ignitions, fuels, weather, and topography.

The fire occurrence analysis determines the probability of an area igniting. It is based on historic data obtained from USFS files and from its Personal Computer Historical Analysis (PCHA) program. The PCHA databases contain daily weather records and individual fire report data. Data were obtained from the Tahoe and Eldorado national forests (NF) for the area within 10 miles of the Lake Tahoe basin and the Lake Tahoe Basin Management Unit (LTBMU). Forest lands on the Toiyabe National Forest, east of the LTBMU, were not included in the assessment because we were unable to obtain data in time for the assessment.

Various data sources were evaluated to provide a historical perspective on fire occurrence in the study area. These data were used only to provide a framework to evaluate the frequency and sizes of wildland fires in the study area. The Eldorado NF PCHA database had data for 1911 to 1939 and for 1960 to 1996; the Tahoe NF database had incomplete data for 1947 to 1959 and a complete data set for 1960 to 1996. Other sources from the Tahoe NF provided fire occurrence data from 1908 to 1996. Data from the LTBMU database was used to describe fire occurrence from 1973 to 1996. The USFS provided digital fire occurrence data for the LTBMU from 1973 to 1997. Very few fires greater than 100 acres have occurred in the basin, since fires have been recorded (approximately 1908).

No wildland fire greater than 2,000 acres has occurred in the basin since 1908 (Table 5-13). The largest fire since 1908 was 1,013 acres in 1918. Between 1974 and 1996, only nine fires larger than 10 acres have occurred in the basin, with the largest consuming 160 acres (Table 5-14). Humans caused all but one of these fires.

There are several reasons why very few large fires have occurred in the basin. First, fire detection and suppression is excellent. Reporting is very good, and average response time is among the shortest in the Sierra Nevada (Husari 1999). Although the basin has one of the highest

Table 5-13—Fire occurrence for wildland fires greater than 100 acres in the Lake Tahoe and adjacent forest lands (within 10 miles of the Tahoe and Eldorado national forests) from 1908 to 1939.

Current Admin Unit	Date of Year	Size	Location
LTBMU	1908	160 acres	Twn 16N Range 17E Section 14
Tahoe NF	1910	185 acres	Twn 15N Range 17E Section 32
LTBMU	1911	100 acres	Twn 16N Range 18E Section 19
LTBMU	1918	1,013 acres	Twn 14N Range 17E Section 18
LTBMU	September 15, 1917	480 acres	Twn 14N Range 16E Section 36
LTBMU	April 6, 1919	600 acres	Twn 12N Range 18E Section 2
LTBMU	1924	320 acres	Twn 16N Range 18E Section 35
LTBMU	August 13, 1924	180 acres	Twn 12N Range 17E Section 19
Tahoe NF	1926	612 acres	Twn 17N Range 16E Section 32
Tahoe NF	1926	526 acres	Twn 17N Range 16E Section 29
LTBMU	1928	335 acres	Twn 16N Range 16E Section 35
Tahoe NF	1928	1,355 acres	Twn 17N Range 17E Section 13
Tahoe NF	1928	259 acres	Twn 17N Range 18E Section 19
Eldorado NF	October 28, 1929	325 acres	Twn 12N Range 16E Section 22
LTBMU	October 28, 1935	120 acres	Twn 12N Range 18E Section 17

Table 5-14—Fire occurrence in the Lake Tahoe and adjacent (within 10 miles on the Tahoe and Eldorado national forests) forest lands from 1973 to 1996.

Study Fire ID	Current Admin Unit	Ignition Date	Size	Cause	Location
1	LTBMU	September 13, 1974	12 acres	Burning Bldg.	Twn 16N Rge 18E Sec 19
2	Eldorado NF	June 12, 1975	20 acres	Lightning	Twn 10N Rge 16E Sec 25
3	Tahoe NF	August 9, 1977	1,305 acres	Lightning	Twn 18N Rge 17E Sec 28
4	Tahoe NF	August 24, 1978	500 acres	Arson	Twn 17N Rge 17E Sec 6
5	LTBMU	June 26, 1979	23 acres	Smoking	Twn 13N Rge 17E Sec 28
6	Eldorado NF	September 16, 1979	7,024 acres	Campfire	Twn 11N Rge 11E Sec 31
7	Tahoe NF	September 24, 1979	35 acres	Arson	Twn 17N Rge 16E Sec 7
8	Eldorado NF	August 8, 1981	3,600 acres	Burning Vehicle	Twn 11N Rge 16E Sec 21
9	LTBMU	November 1, 1984	19 acres	Debris Burning	Twn 12N Rge 18E Sec 21
10	LTBMU	November 2, 1984	107 acres	Debris Burning	Twn 14N Rge 18E Sec 3
11	Eldorado NF	August 7, 1985	19 acres	Campfire	Twn 11N Rge 17E Sec 13
12	Eldorado NF	October 29, 1986	420 acres	Debris Burning	Twn 13N Rge 13E Sec 13
13	LTBMU	May 25, 1987	25 acres	Lightning	Twn 9N Rge 17E Sec 10
14	Eldorado NF	August 28, 1988	12 acres	Lightning	Twn 11N Rge 17E Sec 15
15	Tahoe NF	June 3, 1989	10 acres	Misc	Twn 14N Rge 15E Sec 5
16	Tahoe NF	August 11, 1994	1,300 acres	Equipment Use	Twn 18N Rge 17E Sec 29
17	LTBMU	September 9, 1994	34 acres	Misc	Twn 12N Rge 17E Sec 27
18	Eldorado NF	November 3, 1995	104 acres	Debris Burning	Twn 10N Rge 15E Sec 17
19	LTBMU	November 5, 1995	105 acres	Debris Burning	Twn 14N Rge 17E Sec 29
20	LTBMU	November 8, 1995	40 acres	Debris Burning	Twn 14N Rge 17E Sec 27
21	LTBMU	June 23, 1996	160 acres	Child. /Matches	Twn 12N Rge 18E Sec 9
22	Eldorado NF	August 12, 1996	40 acres	Lightning	Twn 8N Rge 16E Sec 1

ignition rates in the Sierra Nevada, the highest levels are concentrated around urban areas (Figure 5-7), where response time is most rapid. Data from 1973 to the present indicate that wildland fire control keeps fire to less than 10 acres 99. 5 percent of the time (Table 5-15).

Fires ignited by lightning are common in the basin in late summer, but these fires often remain limited in area because of associated rainfall and limited fuels at high elevations where lightning strikes are most common, or because suppression is highly effective. Twenty-three percent (figures 5-8, 5-9) of the terrestrial area in the basin has very limited (sparse vegetation) or no fuels (rock). A large proportion of the upland areas has sparse vegetation. Most of the heavier fuels that are likely to burn occur in a narrow band that coincides with the lower elevations and areas of heavy human access. The large expanse of Lake Tahoe breaks up continuity of fuels at low elevations. Because the basin is high elevation, the fire season is relatively short, reducing the likelihood of fire in most years.

The conditions that would most likely result in a fire greater than 10 acres are a human-caused ignition at lower elevations, along the lakeshore during a drought year. Fires move more rapidly and are more intense when they are moving upslope. During drought years, fuels are more flammable and likely to ignite and support rapid fire spread due to low moisture levels. Fires are more common outside of the basin, but topography and wind patterns indicate that there is a very limited likelihood that they would enter into the basin. Analysis of weather data, shows that only two percent of the time are east winds present (Table 5-16), that would carry a fire downslope into the basin that started outside the

Table 5-15—Occurrence of all wildland fires in the Lake Tahoe basin from 1973 to 1996.

	0-. 24 ac.	. 25-9. 9 ac	10 - 99 ac.	100-299 ac.	300+ ac.	Totals
Fires	1721 92. 28%	135 7. 24%	6 0. 32%	3 0. 16%	0 0%	1865
Acres	176	150	153	372	0	851

Table 5-16—Wind data from the Meyer Weather Station during fire season (July through September) from 1961 to 1996.

	No.	% of Time	90th %ile SC	20' Wind Speed (mph)		
				Moderate	High	Extreme
N	895	27%	10	8	12	14
NE	173	5%	10	8	11	14
E	59	2%	10	7	13	15
SE	149	4%	14	9	14	26
S	668	20%	15	11	16	17
SW	680	20%	15	10	16	20
W	291	9%	11	8	12	15
NW	411	12%	10	8	11	14

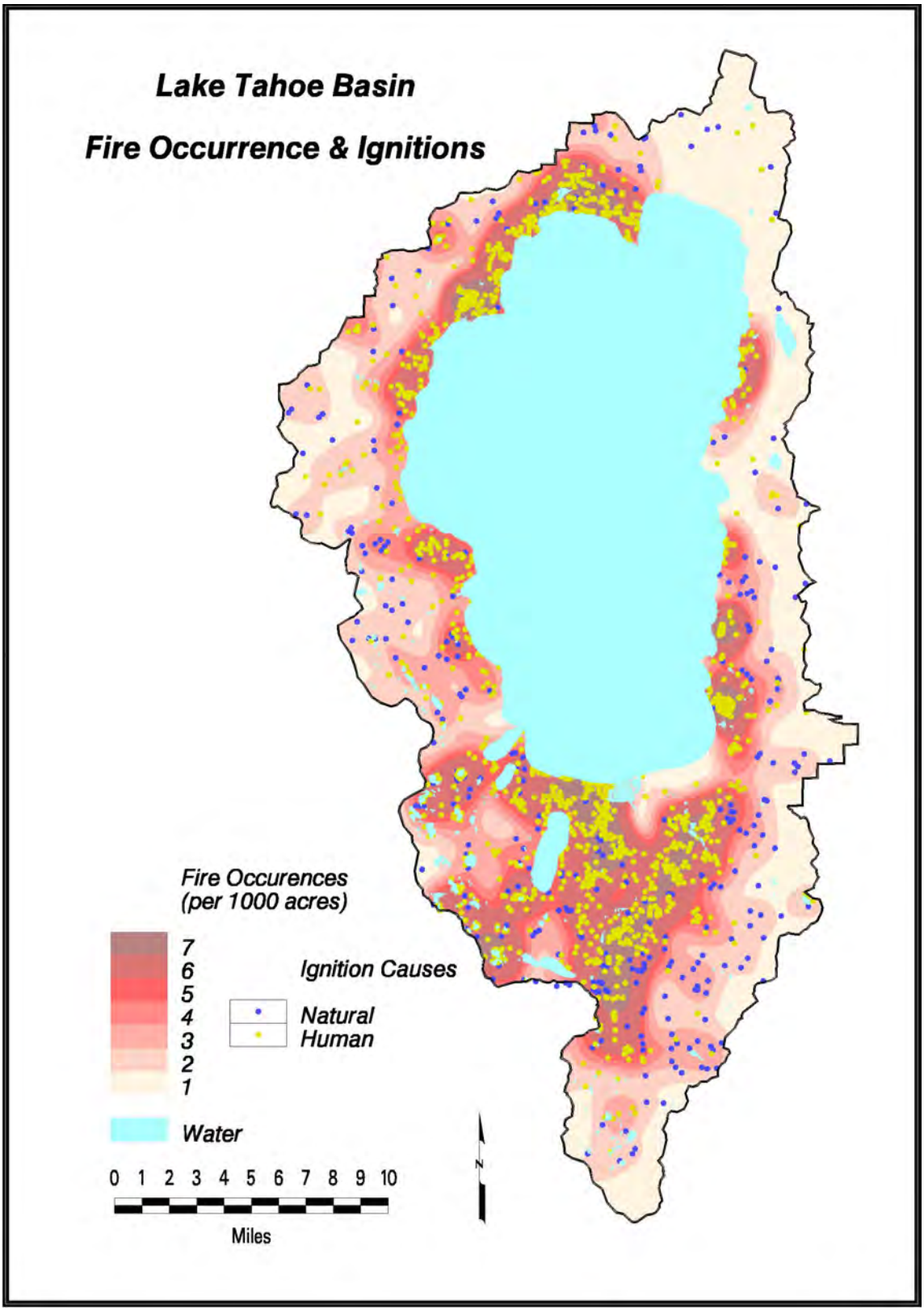


Figure 5-7—Spatial patterns of fire occurrences in the Lake Tahoe basin with human ignitions overlaid on top.

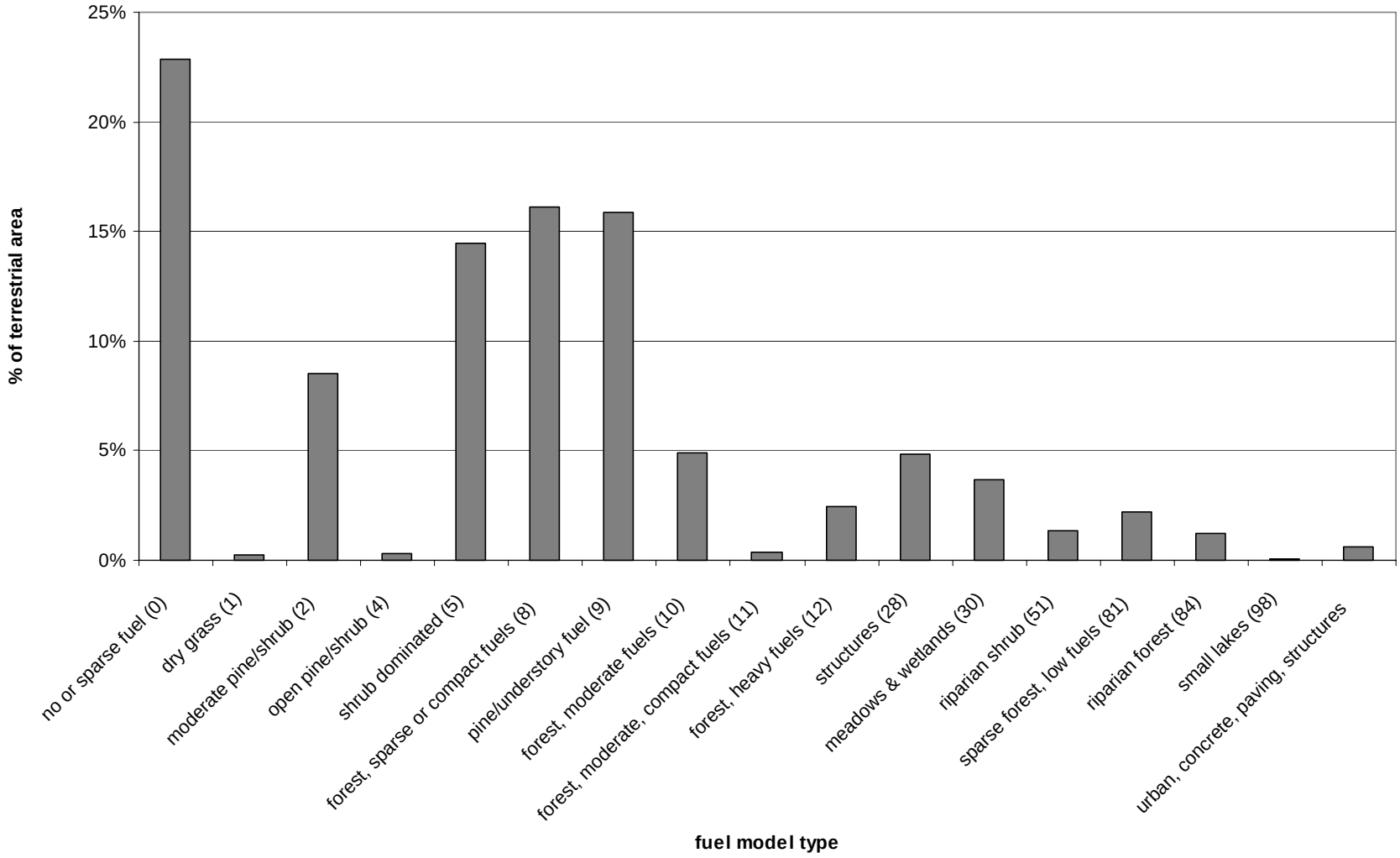


Figure 5-8—Proportion of area in different fuel types in the Lake Tahoe basin.

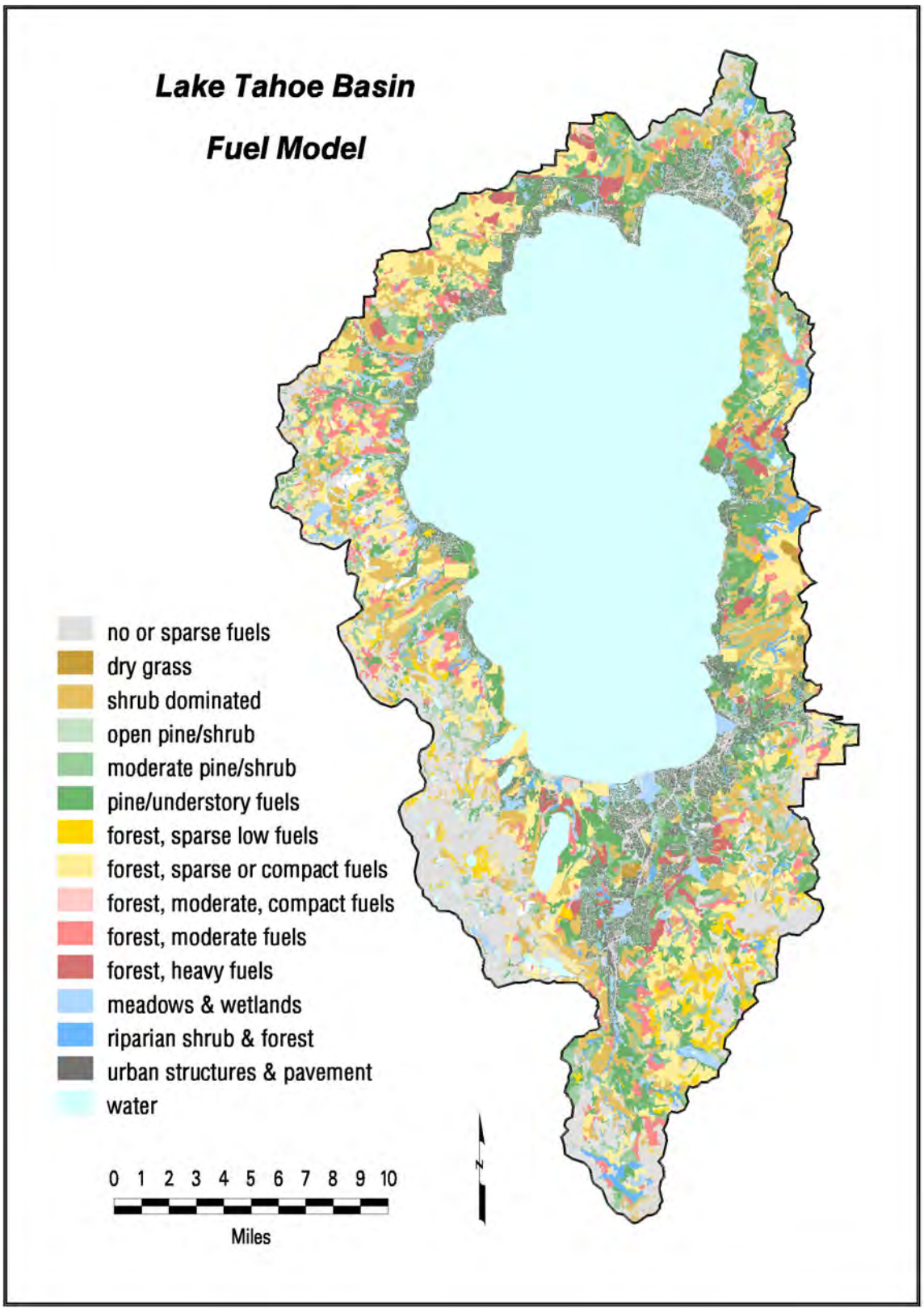


Figure 5-9—Spatial patterns of fuel model types in the Lake Tahoe basin.

basin to the east. On much of the south and west shores, there is a high proportion of rocky, low fuel areas at the top of the basin that would slow or stop fires from entering from the south or west. Diurnal wind patterns (upslope and downslope) are generally depressed in the basin because of the cold temperature of Lake Tahoe. This large body of water reduces temperature differentials between low and high elevations that produce diurnal wind patterns.

What are the likely weather conditions associated with a high severity fire or a large fire?

Two aspects of weather are important to the likelihood of high severity or large fires. One is weather that occurs during fire season, which influences fuel moistures in fine fuels (litter and small diameter branches). Fine fuels with low moistures are more easily ignited and have higher fire spread rates. The second important aspect of weather is climate, such as drought patterns. Climate, especially the annual precipitation level, influences fuel moistures in live vegetation and large fuels in addition to fine fuels. The climate in the Lake Tahoe basin is Mediterranean, which means that there are consistently dry periods every summer, with the period of dryness as the primary climate variation. We address both of these aspects of weather and their contribution to the likelihood of high severity or large fires.

Weather

Weather data from the Meyer Weather Station on the south shore was the primary source of information for analyzing fire weather. Temperature, relative humidity, and wind are the primary weather components important to fire behavior. For fire behavior analysis, weather data during the fire season is typically summarized by percentiles. For this assessment, we summarized data into the following percentiles and classes: moderate, 75th percentile; high, 93rd percentile (90 to 96 percent); and extreme, 98th percentile (97 to 100). We summarized the average, maximum, and minimum values for temperature, relative humidity, and wind for each of these different percentile classes (Table 5-17). These three classes represent different likely spread rates of fire. It is the combination of weather conditions that produce a given level of expected fire behavior, not any single component.

We analyzed weather associated with fires 10 acres or larger in the basin, occurring between 1973 and 1996. Five of these fires had no weather data for the day of the fire discovery at the Meyer Weather Station. The Meyer Station is operated during the typical fire season (June through September). One of the fires occurred in May, and four others occurred in November. For the remaining fires, the wind speed, spread component, and energy release component for the day the fire was discovered were compared to the 90th percentile values for these three variables.

The 90th percentile values are as follows: 20-foot wind speed at 13 mph, spread component at 13, and energy release component of 53 (see Appendix A for more detail on analysis). Of the sixteen fires examined, nine of the fires (60 percent) occurred on days when one or more of these three variables were at or above the 90th percentile values. When conditions are equal to or greater than the 90th percentile values, the weather conditions become aligned so that if an ignition were to occur where fuels are available for fire spread, then the likelihood for significant fire is high. A fire occurring in these weather conditions, with sufficient available fuels, results in rates of spread (greater than 25 chains/hour) that is an escape threshold in fire behavior and suppression analysis.

On average, there are 10 days each year when 90th percentile weather conditions occur. The actual number of days each year varies widely though. During wet years, there may be only one day with dry enough conditions. Most days occur during hot dry years.

All of this weather analysis is based on the Meyer Weather Station. We do not know how well this single weather station represents the weather in other parts of the basin. At least one other weather station on the north shore of Lake Tahoe would increase our ability to model likely fire weather and behavior. One other consideration of the Meyer Weather Station is that it is somewhat protected from wind. Therefore, windspeed data from the Meyer Weather Station used here to characterize different fire weather may be lower than what actually occurs throughout the basin.

Table 5-17—Weather at the Meyer Weather Station for three major fire weather classes: moderate (75th percentile), high (93rd percentile), and extreme (98th percentile). The average, maximum, and minimum values for environmental conditions are shown on the days when the spread component was at its median value for each weather class. The median spread component for the moderate weather class was 7 and for the high weather class was 15. For the extreme weather class, the median spread component was 30. Abbreviations are defined as follows: HERB—herbaceous, PPT AMT—precipitation (hundredths of an inch), DB—dry bulb temperature (degrees Fahrenheit), RH—relative humidity, FM—fuel moisture (percent), IC—NFDRS (National Fire Danger Rating System) ignition component, ERC—NFDRS energy release component, BI—NFDRS burn index.

Weather Class and Values	2pm	2pm	WIND	MAX	MIN	MAX	MIN	PPT	1HR	10 HR	100 HR	1000 HR	HERB	WOODY				
	DB	RH	SPD	DB	DB	RH	RH	AMT	FM	FM	FM	FM	FM	FM	IC	SC	ERC	BI
Moderate																		
Maximum	92	70	14	95	78	100	68	0. 37	13. 1	29. 0	27. 1	28. 2	200	178	46	7	72	54
Average	76	43	8	79	39	91	27		6. 5	7. 0	12. 9	13. 7	107	95	23	7	45	42
Minimum	49	5	5	54	21	10	4		2. 2	3. 0	5. 8	8. 4	64	35	5	7	5	16
High																		
Maximum	86	54	20	88	62	100	46	0. 01	9. 8	17	17. 5	16. 6	131	119	67	15	78	77
Average	75	29	14	80	42	78	22		5. 2	7. 1	11. 3	12. 8	100	85	41	15	50	63
Minimum	53	10	11	58	30	45	10		2. 2	4. 0	6. 1	7. 4	56	50	14	15	33	52
Extreme																		
Maximum	84	55	40	89	58	100	42	0. 01	7. 5	11. 0	15. 7	26. 2	200	150	85	46	67	108
Average	76	26	21	78	43	69	19		4. 7	6. 9	11. 4	13. 3	103	83	56	25	49	79
Minimum	58	9	15	0	0	0	0		2. 4	3. 0	6. 9	9. 3	71	37	30	20	16	42

Climate

Longer-term weather patterns, namely drought, influence the likelihood of fire. McKelvey and Busse (1996) analyzed the relationships between drought and large fires for the Sierra Nevada, using the Keetch-Byram drought intensity index (KBDI) (Keetch and Byram 1968). Days with KBDI values greater than 500 (out of a maximum of 800) were considered drought days. McKelvey and Busse (1996) concluded that nearly all extreme fire years occurred during hot dry periods, although not all hot dry years were extreme fire years. They found that the number of average drought days per decade was negatively correlated with elevation. Based on regressions of drought days as a function of elevation, 30 drought days occurred at 6,200 feet elevation between 1979 and 1989, at lake level. At 7,500 feet in elevation, approximately 18 drought days occurred. Although drought days are less common at higher elevations in the Sierra Nevada, they still occur regularly.

The highest likelihood of drought days is during drought years, when snowpacks are lightest. McKelvey and Busse (1996) found that fire acreage in the Sierra Nevada was negatively correlated with seasonal rainfall (March through October). The largest number of acres burned in the Sierra Nevada coincide with critical or dry years in the Sacramento and San Joaquin River Valleys, as defined by the California Department of Water Resources (Husari 1999). Their data from the cooperative snow surveys show that since 1906, 31 years out of 92 (34 percent) have been considered dry (Figure 5-10).

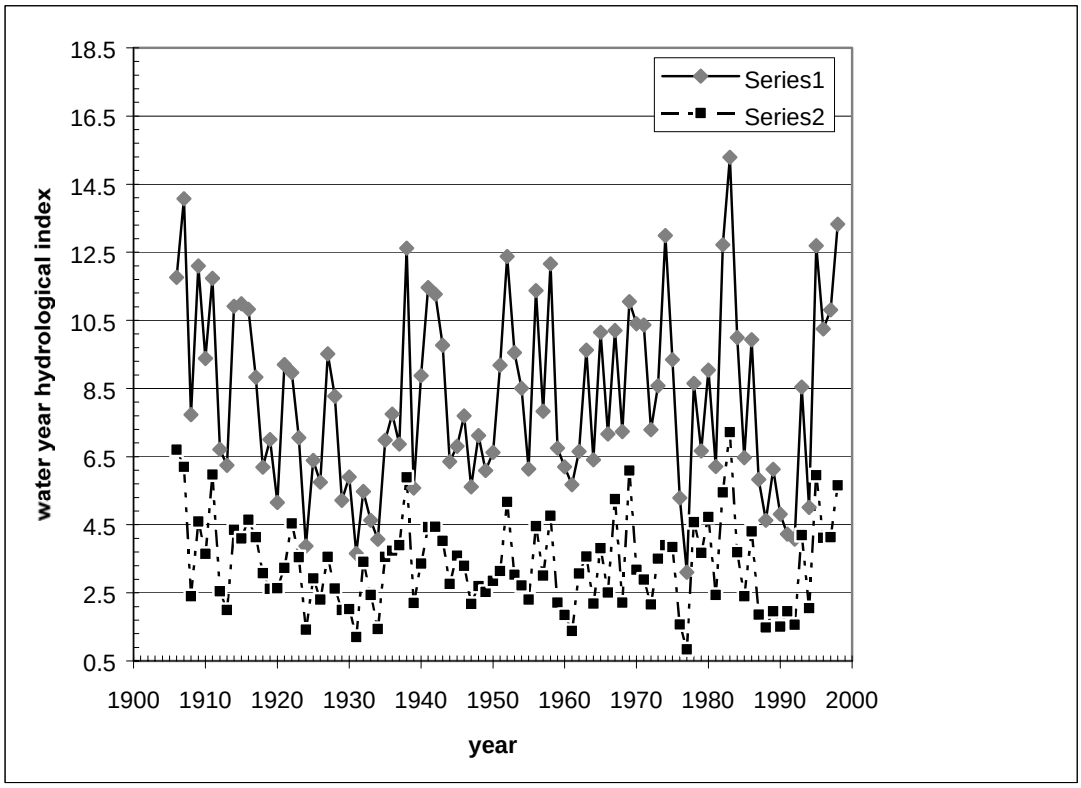


Figure 5-10—Water year (October 1 to September 30) hydrological indices, based on measured unimpaired runoff from the Department of Water Resources California Cooperative Snow Surveys. Series 1 is for the Sacramento Valley basins, with dry years classified as below 6.5. Series 2 represents the San Joaquin basin, with dry years classified as below 2.5.

Over longer periods, droughts have been far more common in the recent past. The period of 1937 through 1986 was the third wettest half-century in the past 1,000 years and the fourth wettest in the last 4,000 years (Graumlich 1993; Stine 1996). The occurrence of submerged stumps in Lake Tahoe indicates that these drier conditions have influenced the basin significantly (Elliott-Fisk et al. 1997; Lindström, Chapter 2, this volume). Swetnam (1992) found that fire activity in giant sequoia groves over a 2,000-year period was influenced by both temperature and moisture. Fires were more frequent during warmer periods, which is a situation that Swetnam attributes to the increased length of the fire season. Moisture was more related to synchrony of fires across the giant sequoia distribution. During moist periods, occasional dry years burned larger areas, presumably because of higher fuel accumulation rates from the moister conditions, whereas during dry periods fires were smaller, likely due to lower fuel accumulation rates. In New Mexico and Arizona, Swetnam and Betancourt (1992) found that variation in regional fire activity was associated with El Niño/Southern Oscillation patterns.

These longer-term weather patterns that can influence the amount of wildland fire depend on future climate trends. While we did not attempt to model future climate trends and their effect on the likelihood of fire, it is clear that climate is not constant and that changes in climate influence the likelihood of fire. Furthermore, it is likely that droughts will occur in the future to an unknown degree and frequency and that the greatest likelihood of large or severe fires will be associated with these droughts. It appears that the climate generally is warming and that past warm periods have been associated with dryness (Stine 1996). Therefore the trend appears to be one toward climate conditions with an increasing likelihood of large or severe fires. In simulations of forest pattern, fire, and climate change in the southern Sierra Nevada, Miller and Urban (1999) found that a warmer drier climate tended to produce more frequent fires. In higher elevation zones, comparable to much of the Lake Tahoe basin, the trends are more complicated because of the possible changes in biomass or fuels and the effects of snowpack changes on fuel-bed depth and bulk density. A longer growing season may increase biomass accumulation and thus fuel loading in the upper montane (i.e., red fir) and subalpine forests of the basin. Lighter snowpacks may compact these fuels less; thus increase the fire hazard overall. In the drier parts of the basin, such as the east shore, the changes may be the opposite. Biomass and thus fuel accumulations in the drier pine forests may decrease with warmer and drier conditions, resulting in reduced fuel hazard. There are uncertainties of the interaction of other disturbances, such as insect and disease outbreaks, with fire and climate. There may be increases in frequency and severity of insect and disease outbreaks (Ferrell 1996) that would increase fuel loading.

What is the relative importance of fuels, weather, and ignitions in contributing to the likelihood of large or high severity fires?

Fuels, ignitions, and weather conducive to fire simultaneously contribute to the likelihood of large or high severity fires. As mentioned previously, ignition rates are high in the basin, particularly in the urban interface areas. These ignitions occur in the portion of the basin with the greatest amount of fuel: the low elevation rim around the lake in the pine and mixed-conifer zone. The weather is rarely a factor in fire suppression because of the high elevation environment and relatively short fire season.

Fire behavior simulations were conducted using FARSITE for several randomly selected watersheds around the basin to evaluate the relative importance of fuels and weather and the likely fire effects. The parameters and conditions used in the modeling are described in more detail in Appendix B. The random selections were conducted with the constraint that at least one watershed occurred in each of the major portions of the basin, representing the major variation in fuel conditions and topographic orientations (i.e. north shore, east shore, and south shore). These behavior runs indicate that under all but the most extreme conditions (less than

two percent of the fire season) fire suppression is effective in limiting the size of fires to less than 1,000 acres.

Although fire behavior was not modeled for extreme weather conditions, the topography and fuels in the basin make it highly unlikely that fires would exceed one or two subwatersheds in size. The basin has a complex topography, composed of many smaller subwatersheds that break up the continuity of slopes. Based on weather data from the Meyer Weather Station, 88 percent of the time wind direction is from the N, NW, W, SW or S (Table 5-16). Such wind orientations would tend to funnel fires within drainages, limiting their spread to just one or several subwatersheds. On the west shore, the upper ends of drainages are bounded by large rocky areas and the lower end of drainages by Lake Tahoe. On the east shore, the upper ends of drainages are bounded with sparse vegetation. Fires burning under the strongest winds (from the SW, W, or SE) have the greatest opportunity to become larger in the area south and especially north of Lake Tahoe. In these areas, topography lines up better (drainage orientation) with wind direction, and these areas contain more area with continuous fuel.

Fuels are composed of four basic components: ground fuels, surface fuels, ladder fuels, and crown fuels. Ground fuels are composed of litter and duff. Surface fuels are defined as the downed wood (twigs, branches, and logs) found on the ground. (In the remaining discussion, ground fuels are referred to as a component of surface fuels.) Ladder fuels are composed of the live vegetation that is low growing and in the forest understory, such as shrubs or smaller trees. Crown fuels are composed of tree foliage in the crowns of trees.

Fuel characteristics include the types of fuel (downed wood, shrub grass or tree or combinations of these), the amount of fuels (tons per acre), the sizes of fuels; and the arrangement (i.e., depth and compactness) (Anderson 1982). We modeled fuel types based on vegetation cover, dominant vegetation type (i.e., shrub, tree, grass, meadow, and riparian forest), dominant tree species, recent tree mortality survey locations, tree size (i.e., mature, seedling, and pole), treatment (thin and burn), and land use (TRPA land use layer) (figures 5-11 and 5-12). The sources of information included an updated existing vegetation layer based on the USFS 1978 photo-interpreted layer, a potential natural vegetation layer from the USFS, and the TRPA land use layer. Data from these layers were converted to 30-meter cell grid layers. The decision tree was programmed into Arc-Info Macro Language (ESRI 1998) to generate the fuel layer for uplands. Ground-truthing of the fuel loadings and configuration were conducted in a randomly selected subset of the photo-interpreted polygons (Fites-Kaufman and Weixelman, in preparation).

Urban areas and urban/wildland intermix areas were more difficult to model because of the fine-scale variation in vegetation, buildings and unvegetated areas (i. e. , pavement) and lack of spatial data at that scale. Further, the fuels inventory of randomly selected, undeveloped lots within urban areas conducted during 1998 indicated that fuels were highly variable. At present, there are no fire behavior models that can show how fire spreads from wildland to buildings, or that can test if some buildings can survive fire better than others.

Satellite imagery (landsat thematic mapper) was used to map two different fuel patterns in urban and urban/intermix areas. The urban and intermix zones were first identified on the existing vegetation map. In these areas, we examined the NDVI composition, which is an index of greenness. Based on visual examination of the NDVI patterns, we modeled three different categories of urban and urban/intermix areas separately (Figure 5-12). The first was of sparse vegetation, making up approximately 30 percent of the area. The second was of moderate vegetation, making up more than 30 percent of the area. The third was in the heavily developed areas, most of it in paved or bare ground around structures. For each of these three categories varied proportions of three different fuel models were randomly applied to 30-meter pixels (Table 5-18). The fuel types were assigned randomly because the resolution of the source data and precision of identifying individual fuel types precluded exact mapping. The fuel mapping provides a first approximation of general patterns. Detailed ground-based mapping would be required for more detailed

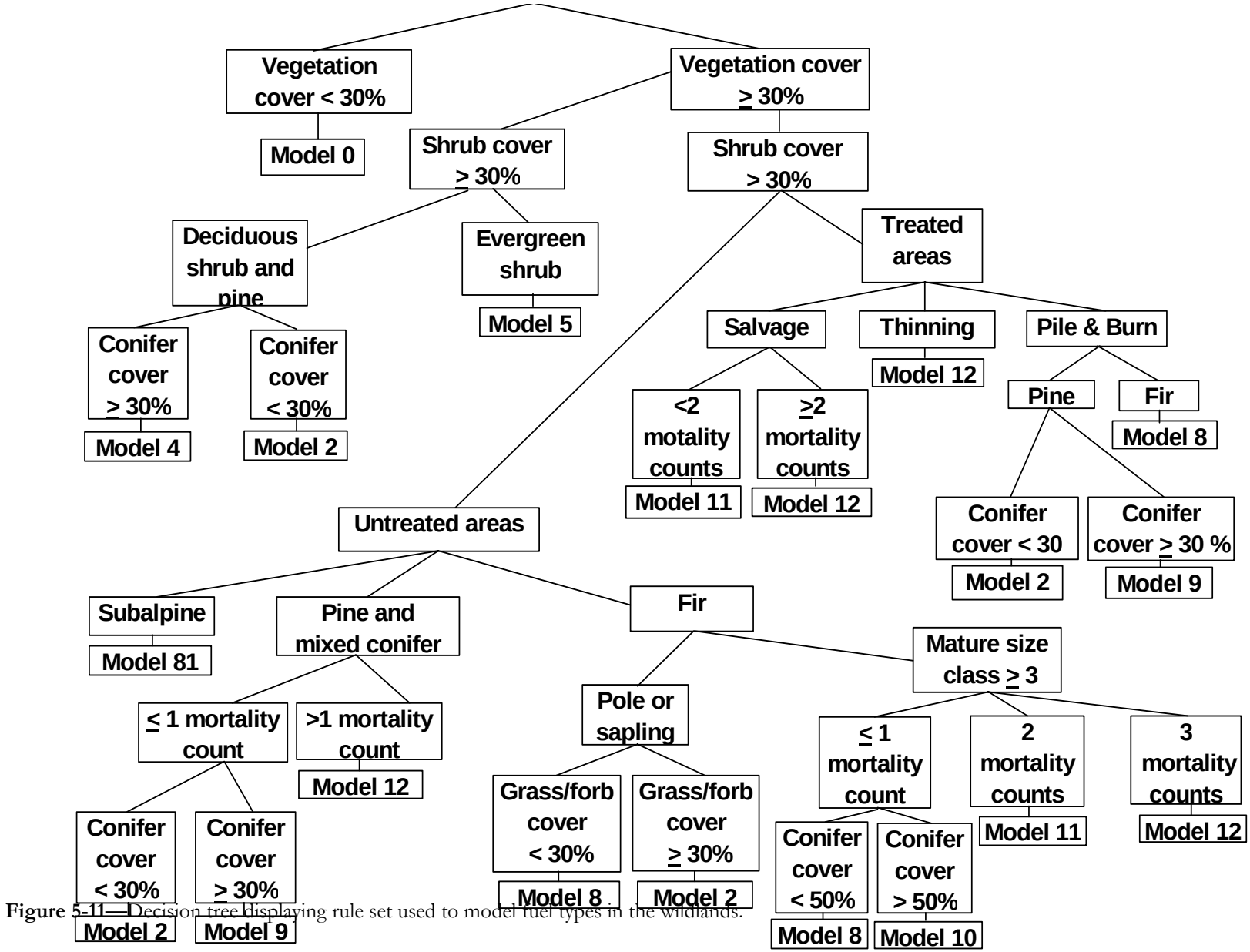


Figure 5-11—Decision tree displaying rule set used to model fuel types in the wildlands.

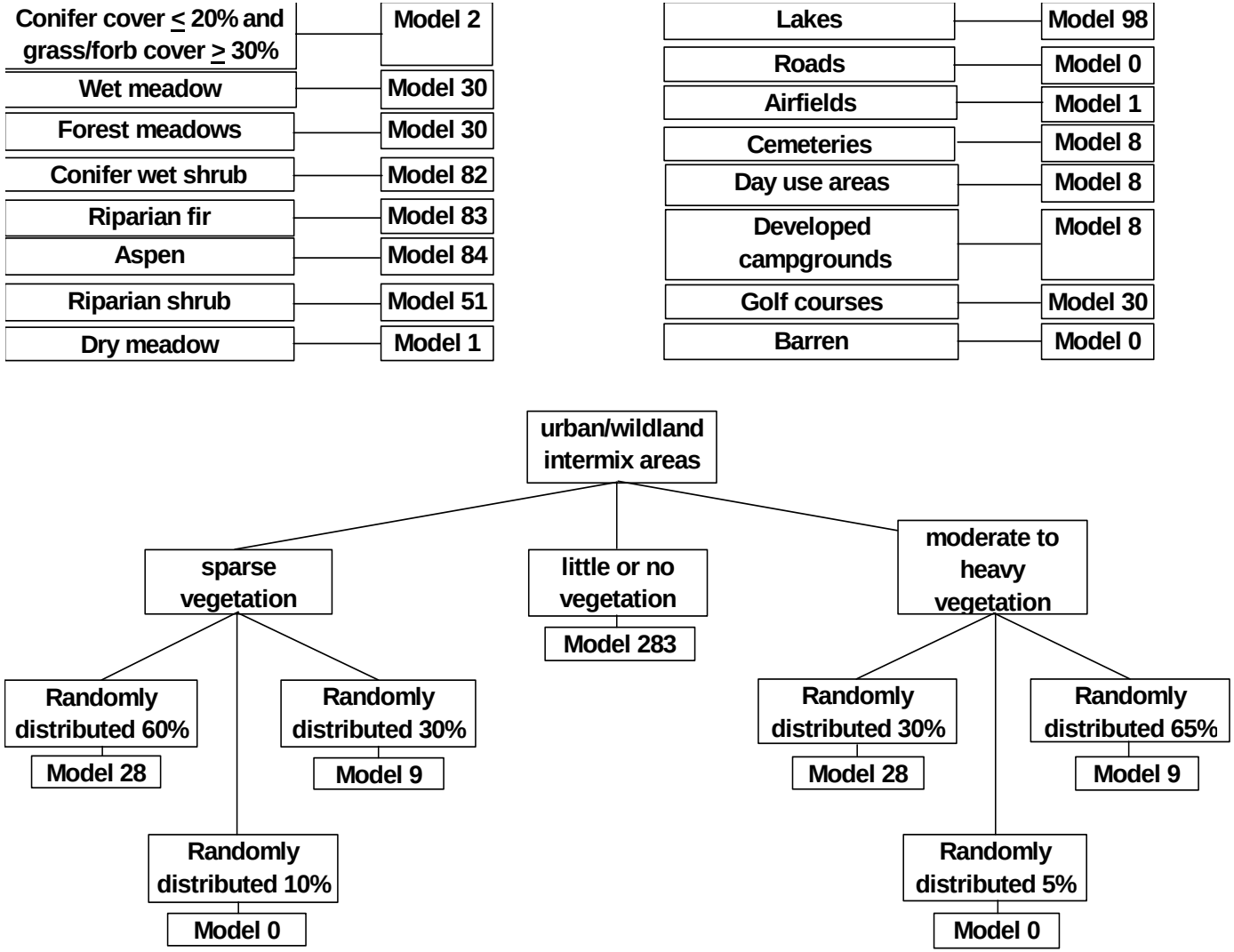


Figure 5-12—Decision tree displaying rule set used to model fuel types in the urban/wildland intermix zones and riparian or nonforested wildland areas. Randomly distributed cells were assigned to the different fuel types within a given urban/wildland intermix zone type using the random function in ArcInfo.

Table 5-18—Rules for assigning fuel model types to three different classes of urban and urban/wildland intermix zones.

Fuel Model Types	Percentage of Area Randomly Assigned to Fuel Model Type (by urban/wildland class)		
	Moderate to high vegetation amounts	Low vegetation amounts	Little or no vegetation
Structure model (model 28)	30	60	100
Vegetation model (model 9)	65	30	
Bare ground, pavement or concrete (model 0)	5	10	

and locationally specific urban/wildland intermix fuel model assignments. Major roads, golf courses, and airfields were modeled separately.

Fuels in the basin are characterized by variations in elevation, soil depth, precipitation, and vegetation. Glaciation in the west and south portions of the basin contributed to large expanses of scoured rocky expanses and rocky soils. These areas often are sparsely vegetated, and 23 percent of the upland areas have little or no fuel (Figure 5-9). An additional 16 percent has compact and relatively low fuel levels (model 8), which typically results in low to moderate intensities of fire and rates of fire spread. In the high elevation environment of the basin, heavy snowpacks are prevalent in much of the basin every year. This snowpack compacts fuels, reducing the likelihood of active burning even when fuel loading is high because a low surface area to fuel ratio. This results in a low oxygen to fuel ratio. Fires burn only when both oxygen and fuels are present in the right proportion. Compact fuels tend to burn more as slow smoldering fires, which are more easily suppressed.

Another 15 percent of the basin is composed of montane chaparral, with an evergreen shrub-dominated fuel type (model 5). Huckleberry oak and manzanita are the most common shrubs in this fuel type. These shrubs are often resistant to fire, except when foliar moisture is very low, such as during droughts and hot weather (Husari 1999). Concentrations of heavier fuels in the basin are often discontinuous due to small patches of rock and meadows and changes in vegetation.

Although fires have been and are likely to continue to be small in the basin, the severity of any fire can be high. Vegetation patterns and fuels are most important in contributing to likely high severity of unplanned wildland fires in the basin. In modeling fire behavior in all but extreme weather conditions, there is usually more variation in fire behavior among different fuel types than there is among different weather conditions for the same fuel type. Urban areas tend to have a lot of nearby vegetation, and many buildings are constructed of wood, leading to ready consumption by fire. In the wildland, trees are often young and small. Smaller trees are less resistant to fire because their bark is thinner and their crowns are lower to the ground (nearer flames). These smaller trees are more likely to die as a result, even when fire intensities are modest. However, in the most extreme weather conditions differences in fire behavior among different fuel types lessen.

In summary, weather, fuels, and ignitions all contribute to the likelihood of large or severe fires. Although weather conditions usually limit large or severe fires in the basin, some weather conditions can result in large or severe fires, particularly in hot and dry years. Fuel hazard is not particularly great in the Tahoe basin, but the small stature of vegetation and the high proportion of urban/wildland interface increase the likelihood that fires will be severe. Importantly, ignition densities are high in the urban/wildland interface. Although high levels of suppression forces and relatively cool, wet weather conditions limit the number and sizes of fires from

these ignitions, reducing the number of ignitions would substantially reduce the likelihood of fire.

What are the likely effects of a high severity or large unplanned fire on soil erosion, air quality, lake clarity, biotic health, old growth, and urban areas?

Randomly selected watersheds around the basin were modeled for fire behavior using FARSITE (Finney 1998) to evaluate some of the likely effects of unplanned fires on wildlands and urban areas (see Appendix B for detail). In addition, the model FLAMMAP (Finney 1999) was run for four different sets of weather conditions for the entire basin. FARSITE simulates the spread of a fire burning on a landscape, with weather and wind varying diurnally and based on historic weather station data. Fire suppression also can be modeled. Outputs of the model can be used to determine likely fire size, intensity (heat per unit area, flamelength), and rate of spread. FARSITE also can be used to predict likely effects on vegetation during the fire when the flamelengths are combined with vegetation data using a mortality model. FLAMMAP provides similar fire behavior outputs as FARSITE but treats every point on the landscape separately. It does not predict the behavior of a fire, but displays the likely fire behavior characteristics and potential effects on vegetation for the entire landscape for any given weather conditions.

The effects of a large or high severity unplanned fire on soil erosion and lake clarity were not modeled. The modeling and integration chapter provides more detail on the integration of models that would be required to make such an assessment. The effect of a large or high-severity unplanned fire on urban areas also was not modeled directly. Urban fire modeling requires separate models and a higher level of detail on fuel patterns than were available. An in-depth inventory of urban fuels would be required at a high resolution, but some indirect inferences can be drawn from the FARSITE and FLAMMAP runs.

The FARSITE model was used on several randomly selected watersheds that represent the east, south, west, and north shores of the basin (Figure 5-13). Ward Creek watershed was selected purposely because of the erosion and nutrient models that have been and are being conducted in the watershed. The FARSITE model was run for high (93 percentile) weather conditions (see Question 2) with and without suppression. Although there are many effective suppression resources in the basin, the runs without suppression provide insight into some of the worst-case scenarios. The model was run for two burning periods (48 hours). Fires were started in locations in each selected watershed where the density of ignitions have been the greatest; usually at the interface between the urban and wildland areas.

Every run showed spotting and crowning of fire, but, with simulated direct attack, fire suppression tactics were controlled to a small size (42 to 546 acres). The largest simulated fire was on the north shore, where it reached 546 acres, due to the orientation of wind with the slope in that area. Without simulated suppression, flamelengths were high enough to reach the crowns and surface fuels were heavy enough to carry fire in the crowns in part of the fire perimeter (Table 5-19). However, only a portion of each area burned as a crown fire (Figure 5-13). Surface fires dominated (55 to 87 percent) the simulated fires. This corresponds well with observed behavior of actual fires in the basin (Bahro 1999). The maps of crown versus surface fire likely underestimate the area that would exhibit high tree mortality, which also would have occurred in some of the area modeled as a surface fire. If mortality had been included, total mortality would be greater.

Tree mortality is a function of bark thickness, the insulating ability of the bark of a given species, and the proximity of tree crowns to the flames (Agee 1993). Younger trees have thinner bark and crowns that are closer to the ground, making them more susceptible to mortality from fire than larger and taller trees. Jeffrey pine, ponderosa pine, and incense cedar are more resistant to fire than white fir and red fir. Lodgepole pine has thin bark and is readily killed by fire. In the previous section on vegetation, we discussed the finding that mixed-conifer and pine old-growth stands have many small, young, understory trees, and these are likely to be

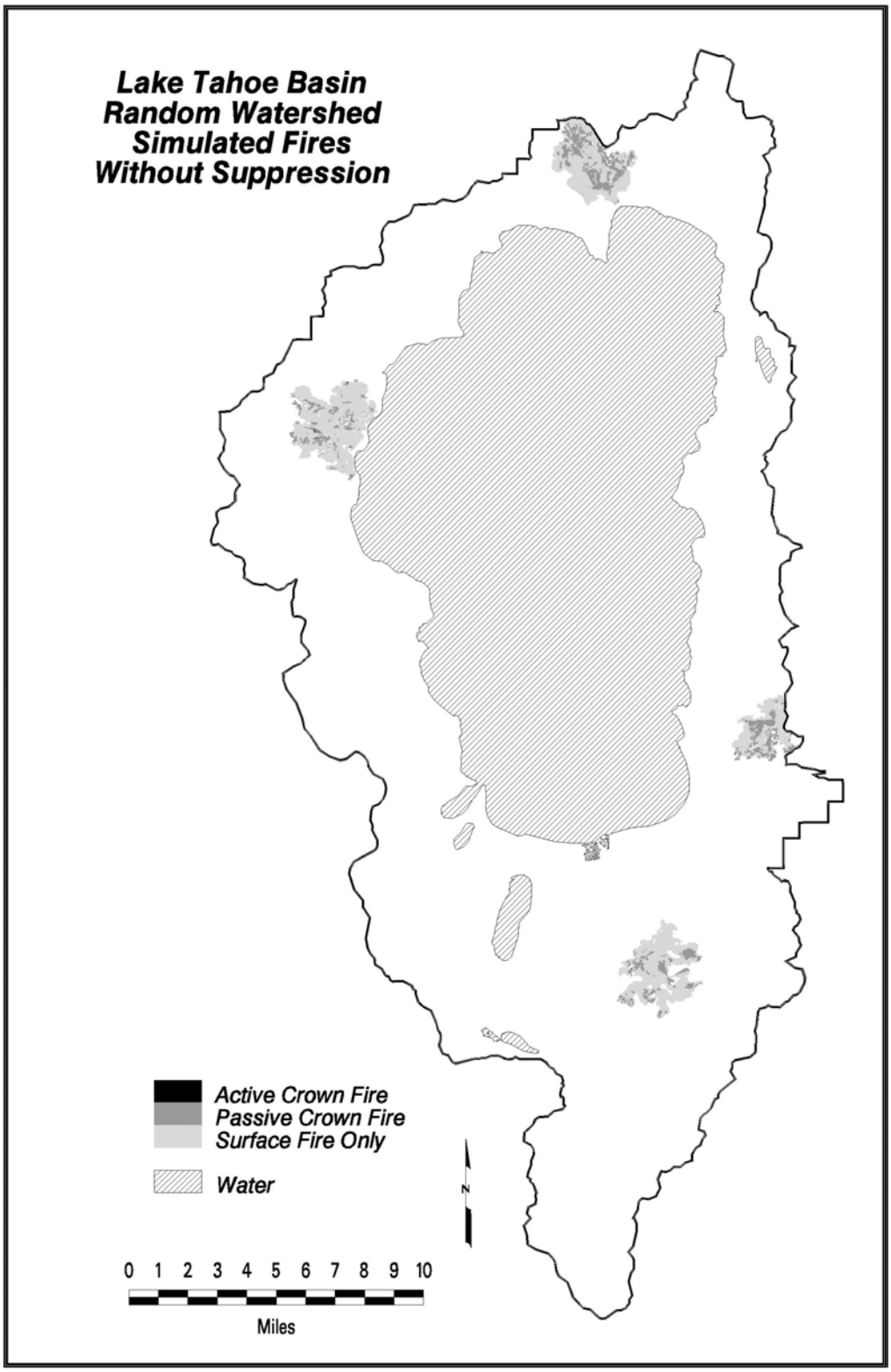


Figure 5-13a—Spatial patterns of simulated fire behavior (from FARSITE), for selected watersheds in the basin, without fire suppression. Models were run with the 93rd percentile weather, with ignitions located at the highest point of fire occurrence in the watershed.

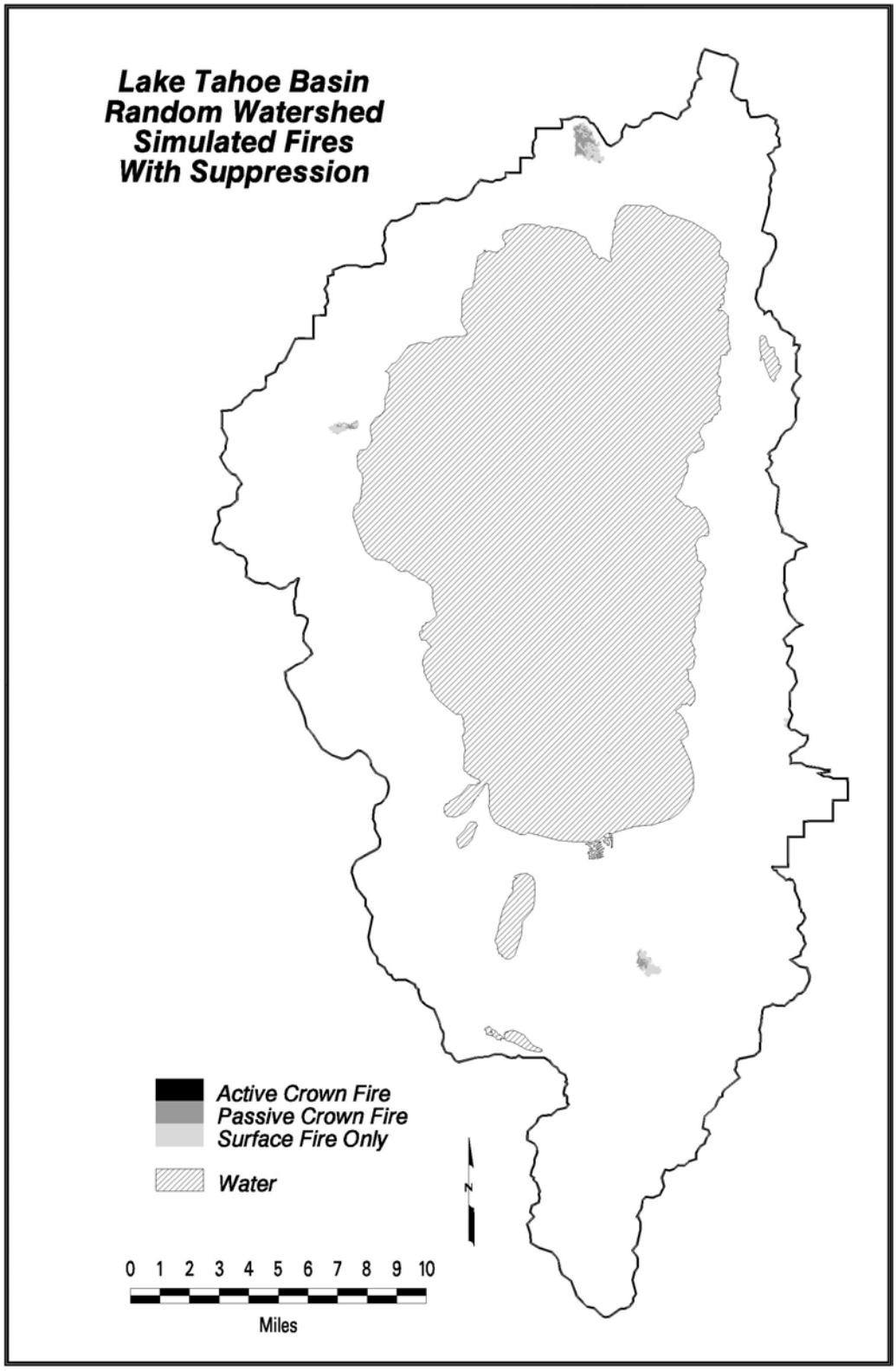


Figure 5-13b—Spatial patterns of simulated fire behavior (from FARSITE), for selected watersheds in the basin, with fire suppression. Models were run with the 93rd percentile weather, with ignitions located at the highest point of fire occurrence in the watershed.

Table 5-19—Potential fire behavior from simulated fires under high weather conditions (93rd percentile), with and without fire suppression for selected watersheds in the Lake Tahoe basin. Fires were modeled for two burning periods (48 hours).

Watershed and Fire Behavior Class	With fire suppression		Without fire suppression	
	Acres	% burn area	acres	% burn area
Ward				
Surface fire	123	76	3162	87
Passive crown fire	38	24	482	13
Active crown fire	0	0	6	0
Total	161		3650	
Trout				
Surface fire	195	77	2485	83
Passive crown fire	59	23	504	17
Active crown fire	0	0	0	0
Total	254		2989	
Edge				
Surface fire	36	86	1220	69
Passive crown fire	6	14	544	31
Active crown fire	0	0	0	0
Total	42		1764	
Griff				
Surface fire	300	55	2137	70
Passive crown fire	246	45	928	30
Active crown fire	0	2	0	0
Total	546		3065	

killed in an unplanned surface fire and carry flames into larger old trees.

The FLAMMAP runs for the high (93rd percentile), and extreme (98th percentile) weather sets (see Question 2) show that potential flamelengths vary considerably around the basin (Figures 5-14a-d). Higher elevation areas and much of the upper montane areas on the west and south shores do not have high flamelengths because of the sparse, discontinuous, or compact fuels (Figure 5-15). Flamelengths and consequent fire effects are likely to be most severe in the mixed conifer and pine zones at lower elevations and on the east shore where pine forest mortality has been prevalent.

As mentioned previously, fire behavior in urban areas was not modeled directly because insufficient detail about available fuels and lack of fire behavior models for these situations. However, some inferences can be made on likely fire effects. As described in the previous subsection, the urban areas were classified into three different categories: little or no vegetation and high proportion of paved and bare area, low amounts of vegetation and moderate proportion of paved and bare areas, and moderate to high amounts of forest intermixed with structures. The latter category is the one most likely to experience severe effects of an unplanned wildfire. The mix of forests and structures can result in increased rates of spread. This outcome is highly variable, however, depending on the amount of surface and ladder fuels, debris surrounding houses, and house building materials. In our inventory of fuels in undeveloped urban lots, we found that many had low surface and ladder fuel levels, while others had high levels. Fuels from structures and

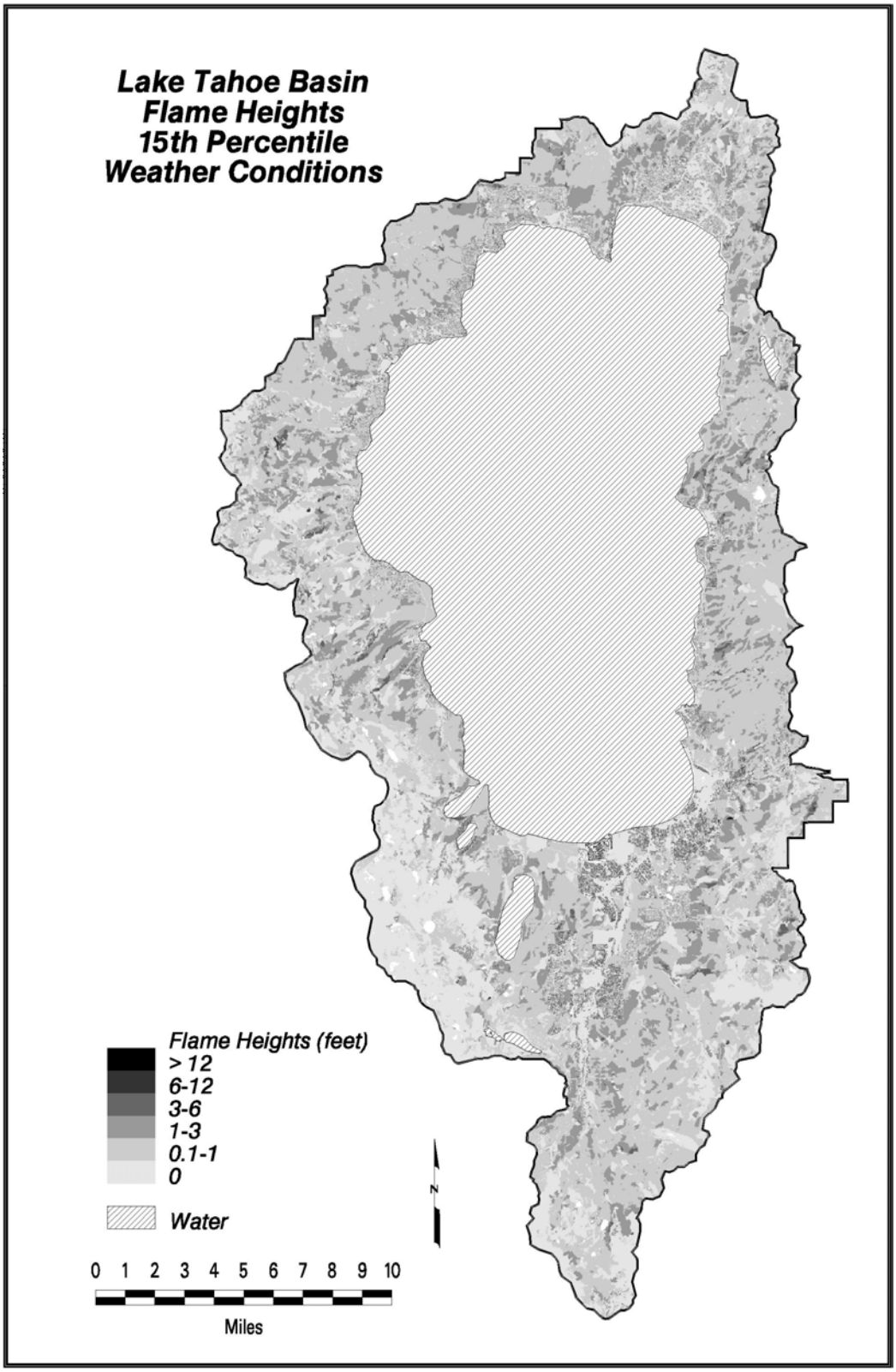


Figure 5-14a—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 15th percentile weather set in the Lake Tahoe basin.

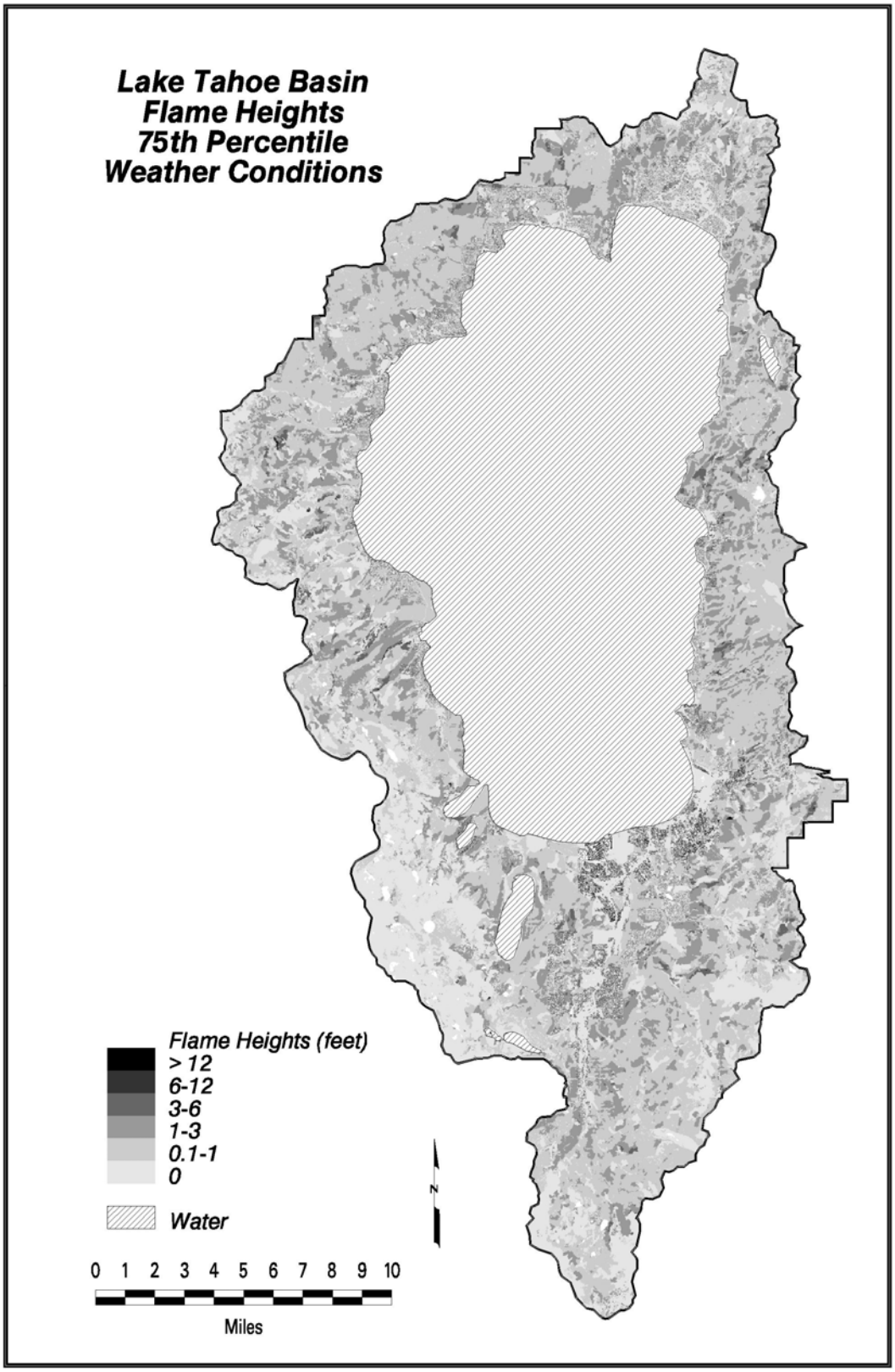


Figure 5-14b—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 75th percentile weather set in the Lake Tahoe basin.

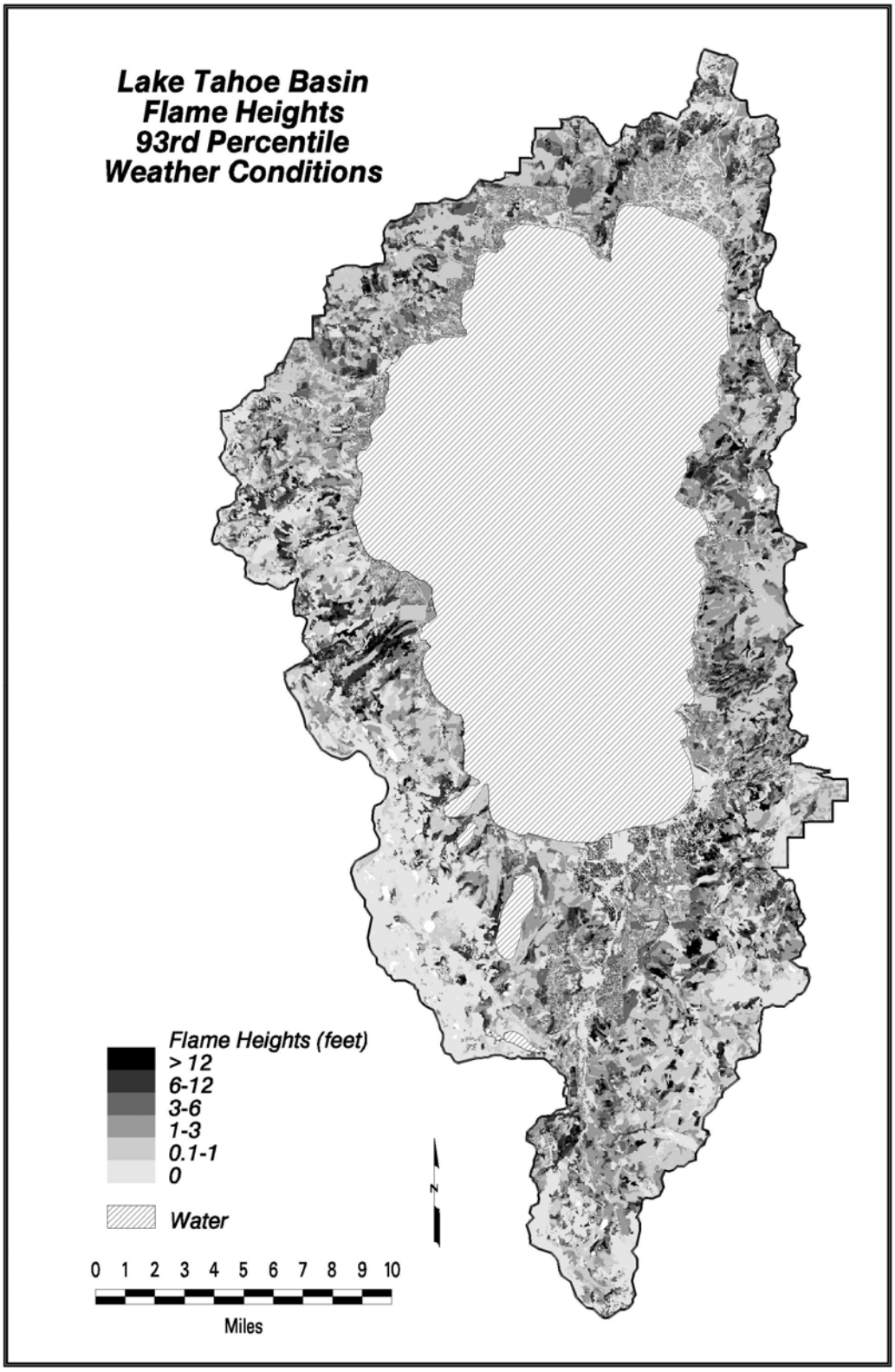


Figure 5-14c—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 93rd percentile weather set in the Lake Tahoe basin.

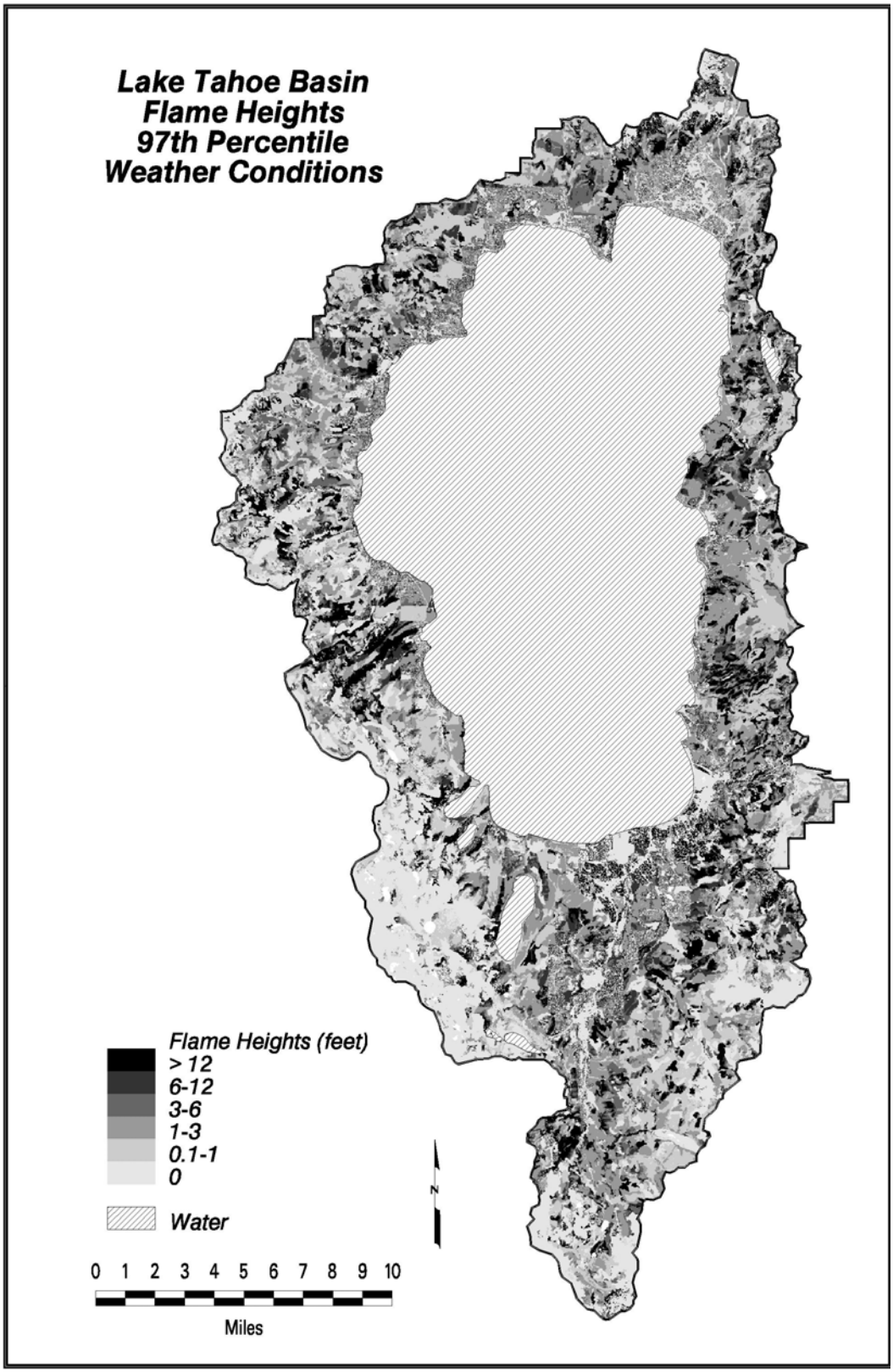


Figure 5-14d—Spatial display of potential flamelengths from fire behavior analysis (FLAMMAP) for 97th percentile weather set in the Lake Tahoe basin.

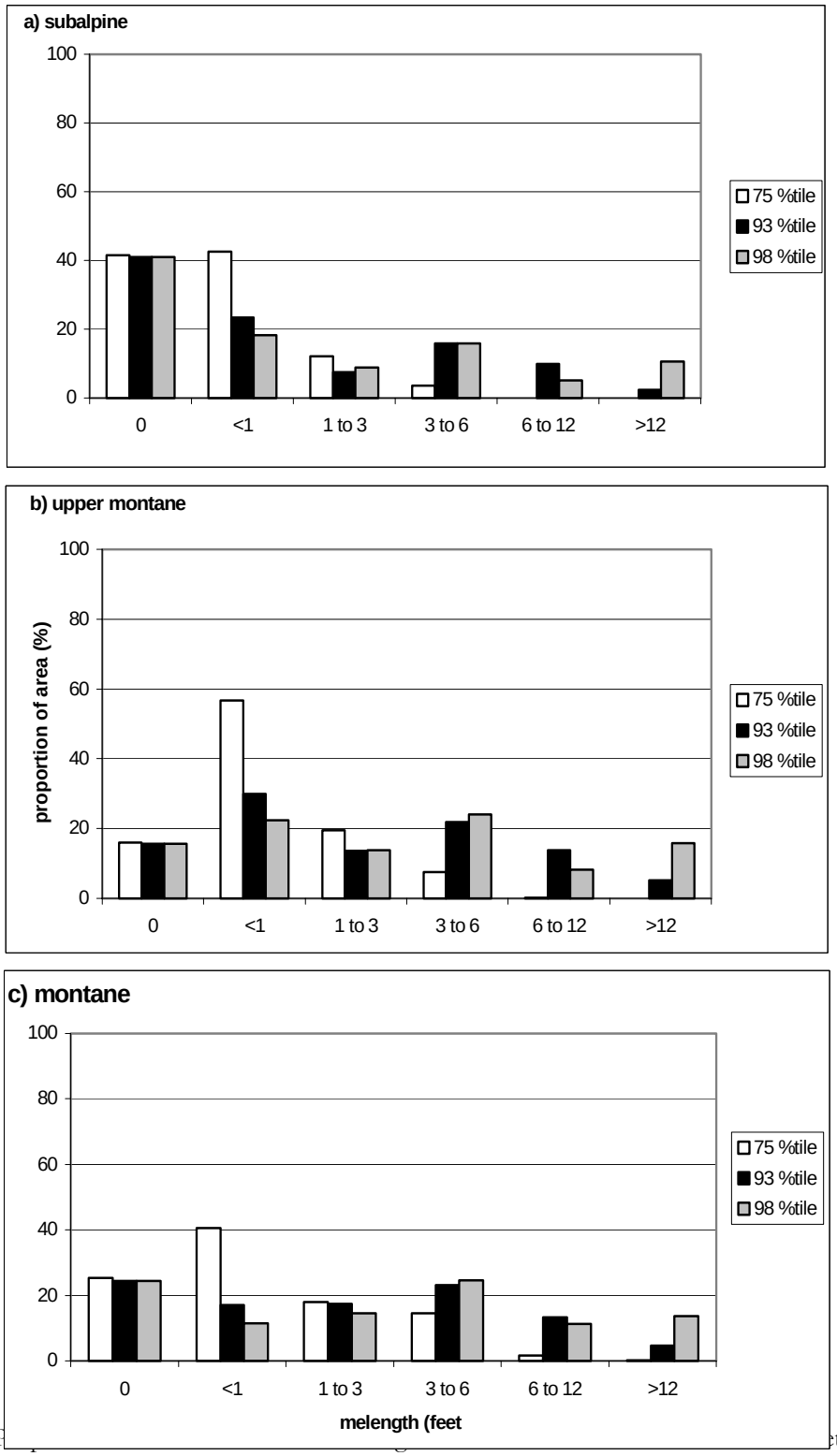


Figure 5-15—I ets: 75th percentile (moderate); 93rd percentile (high); and 98th percentile (extreme).

material stored next to houses are also important. Roof composition is critical to potential fire effects in urban areas; wood roofs provide a readily available combustible material, whereas metal, cement, or slate roofs are not combustible. Litter accumulations on any roof provide locations where embers can ignite. Flammable materials, such as firewood, stored in the yard and especially next to the house also provide fuel for fire. Exposed decks also provide a potential fire hazard. Even fiberglass boats, when they have flammable material stored in them, can increase the fuel load and likelihood of structure fires. Determining the continuity of fuel between lots across an entire subdivision and the flammability of structures in that subdivision is most critical to predicting the likely effects of fire on urban areas in the basin.

How will susceptibility to fire change in the future when snags fall to the ground?

This question is difficult to answer in detail because of the complexity in modeling the effects of snags and logs on fire behavior, effects, and suppression. Fire behavior models use only material smaller than three inches in diameter because these are the fuels that most influence intensity and rate of spread. Logs can influence fire effects and suppression, but available models are limited in their ability to portray the effects. For these reasons we provide a general qualitative discussion.

Snags provide ready receptors for embers in the air to land on and ignite (spotting). Also, pockets or concentrations of snags affect fire line tactics during suppression. They pose a danger of falling on fire fighters during combustion. Logs on the ground can slow fire line construction (reduced production rates) during suppression because it takes additional time to saw through and then dig a fire line. The effect on fire line production depends on the distribution of the logs. If logs are uniformly spread at high levels, then it will reduce production rates everywhere. If logs are patchy, then production rates may not be affected.

Logs can result in more severe fire effects, depending on how they are distributed within a patch of vegetation. Large logs next to individual trees result in higher intensities of fire and especially longer duration of heat. Both of these effects can increase the likelihood of mortality of adjacent trees.

The effect of recent and future mortality on fire in the basin depends on where in the basin the mortality occurs. At higher elevations and the red fir zone, effects can be less dramatic than at lower elevations in the mixed-conifer and pine zones. At higher elevations, shorter dry seasons reduce the window when logs are dry and contributes to the fire spread and its effects. The higher intensities of fire and the heat associated with them during a fire are important in producing a complex spatial pattern of varying fire patterns and effects that influence horizontal and vertical vegetation complexity. What is difficult to ascertain are the historic levels of snags and logs compared to current levels.

Where are the key areas to restore or manage to reduce the likelihood of unplanned, large, or severe fires?

Two different approaches were used to assess the key areas to restore or reduce the likelihood of unplanned fire. First, the spatial patterns of the fire susceptibility index were examined. Secondly, an analysis of values at risk was conducted by watershed.

The combined information from the fire occurrence layer and fire behavior outputs from FLAMMAP, reflected in the relative fire susceptibility index, show that the most critical areas to reduce fire hazard and risk are low elevation areas (Figure 5-16 and Table 5-20), especially in proximity to urban/wildland interfaces (Figure 5-17). Mixed conifer and pine forests are the most important. There are two approaches that would be effective in reducing fire risk for the entire Tahoe basin by management in this zone. First is increased fire prevention patrols and education to reduce human-caused ignitions. Humans have caused all but one fire since 1973. Second, reduction of fuels in the urban areas and urban/wildland interface would reduce fire risk for the entire basin. Most of the fires are ignited in these areas, most of the heaviest fuels

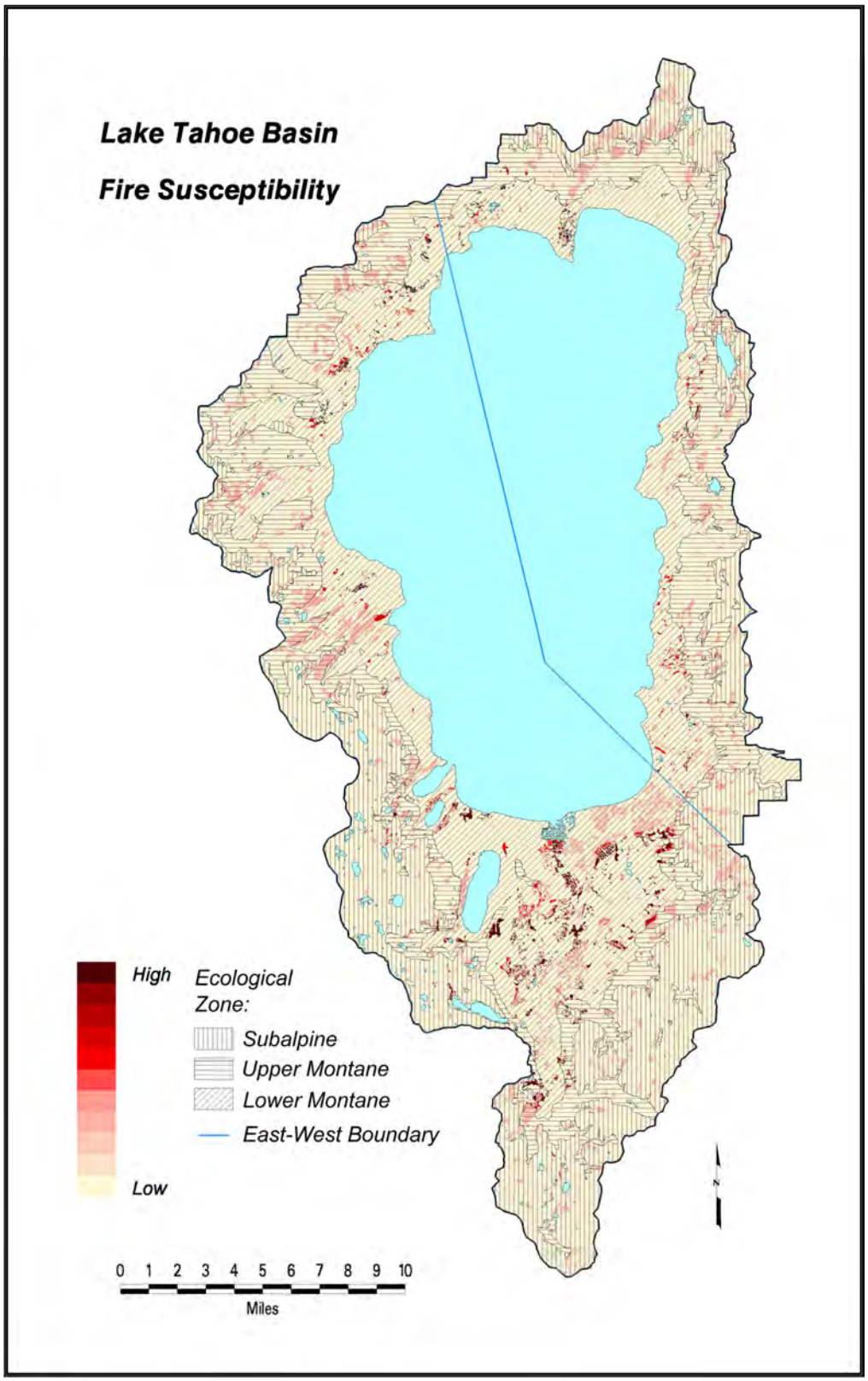
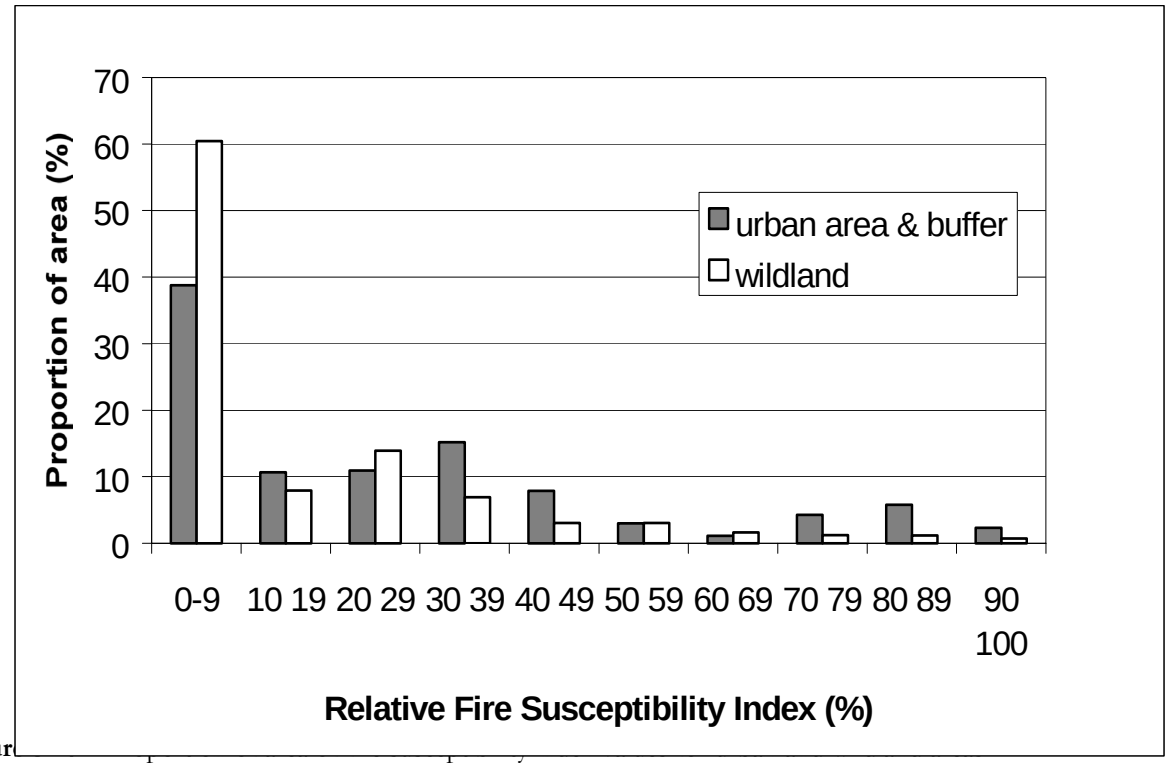


Figure 5-16—Spatial patterns of relative fire susceptibility index by major ecological and elevation zones (montane, upper montane and subalpine).



Figur

Table 5-20—Relative fire susceptibility index by major elevation zones and east and west portions of the basin. Only nonwater area is included in area calculations. The fire susceptibility index is based on the ratio among expected acres to be burned within a fire occurrence zone and burnable acres and fire spread potential (from FLAMMAP). Because the acres expected to be burned are not precise, the index is relative. Precise estimates of acres burned would be required to produce an actual probability of an acre burning.

Relative Fire Susceptibility Index	West zone (% area)			East zone (% area)		
	Montane	Upper Montane	Subalpine	Montane	Upper Montane	Subalpine
0-24%	60	71	81	61	73	71
25-49%	23	20	14	28	21	25
50-74%	7	5	3	9	5	3
75-100%	11	4	2	2	1	1

occur there, and the longest fire season is in this zone. Contributing to the fuel hazard are the flammable building materials (i.e., shingle roofs) frequently used in the basin.

The primary emphasis should be on surface fuels, which create intensity and affect rate of fire spread. Lastly, there may be some need to reduce tree crowns, but reducing crown density is not effective in changing fire behavior if surface fuels are not treated first and effectively. Independent crown fires, where tree crowns carry fire independently of surface fuel, are rare in the Sierra Nevada. Opening the canopy allows more drying sunlight to reach surface fuels and increases wind speeds at low heights (Countryman 1955; Weatherspoon 1996). Reducing crown density may be more important for restoring historic forest densities than decreasing fire hazard and the likelihood of severe fire in the basin. In the immediate interface with urban areas, crown closures of 40 to 50 percent will keep sites sheltered from the wind and will reduce crown fire hazard if surface fuels are treated thoroughly. Reducing crown closures in other areas in the urban interface zone, and especially in such sensitive areas as riparian zones, should be weighed against ecosystem functions of maintaining the crown cover.

Values at risk were analyzed at the watershed scale because ecosystem values at risk, such as lake clarity, are impacted at these broader scales. Lake clarity is most likely to be affected by larger fires occurring in a particular watershed, with erosion and sediment and nutrients funneled through stream channels and roads. Such a watershed focus also will protect old-growth stands.

The area-weighted average of the fire susceptibility index rating (Figure 5-18) was used to determine the relative ratings of the likelihood of an unplanned large or severe fire for each watershed. The three values at risk assessed were soil erosion (primary potential influence on reduced lake clarity), human structures and developments, and old growth. For the human developments, the proportion of the area in each watershed in land with structures or developments was computed based on the TRPA land use layer. The area-weighted average of the erosion hazard rating from the soil survey layer was used to determine the relative risk of fire to reduce lake clarity. Finally, the proportion of area with old growth was computed from the updated existing vegetation maps completed for this assessment (patches with at least two trees per acre were used to calculate the old-growth area).

The greatest coincidence of watersheds with a high proportion of erodible soils and the likelihood of fire occurs on the east shore (Figure 5-19). Steep granitic soils and flammable fuels occur here. The south and north shores also contain some watersheds with high ratings. Urban and urban interface areas on the south and north shores have the greatest fire occurrence, whereas the west shore and the Incline area have relatively low ratings (Figure 5-20). However, fire occurrence data from the Incline area may be underestimated due to lack of fire ignition records in the USFS PCHA database used. The greatest concentrations of old growth occur on the west and south portions of the basin. Although old growth is more scattered on the northwest portion of the basin, fire occurrence is high, therefore the relative risk rating is moderate to high. There are few low priority areas in the basin due to low likelihood of fire or low value. Watersheds with little or no urban development, low soil erosion hazard (due to rocky soils), and low fire risk and hazard (high elevations) are the only areas not moderate or high on a combined rating. The overall low likelihood of a large, high severity fire provides an opportunity to reduce fire hazard and risk at a rate that will minimize affect on lake clarity.

The means for reducing fire hazard and risk are as important to consider as the key areas to restore. In the immediate urban interface areas, emphasis on mechanical treatment is probably the most appropriate. Smoke generated from fires is more likely to create health and nuisance problems for humans in this zone. Secondly, an extensive network of roads provides access for mechanical treatment. In upland areas, with erodible soils and

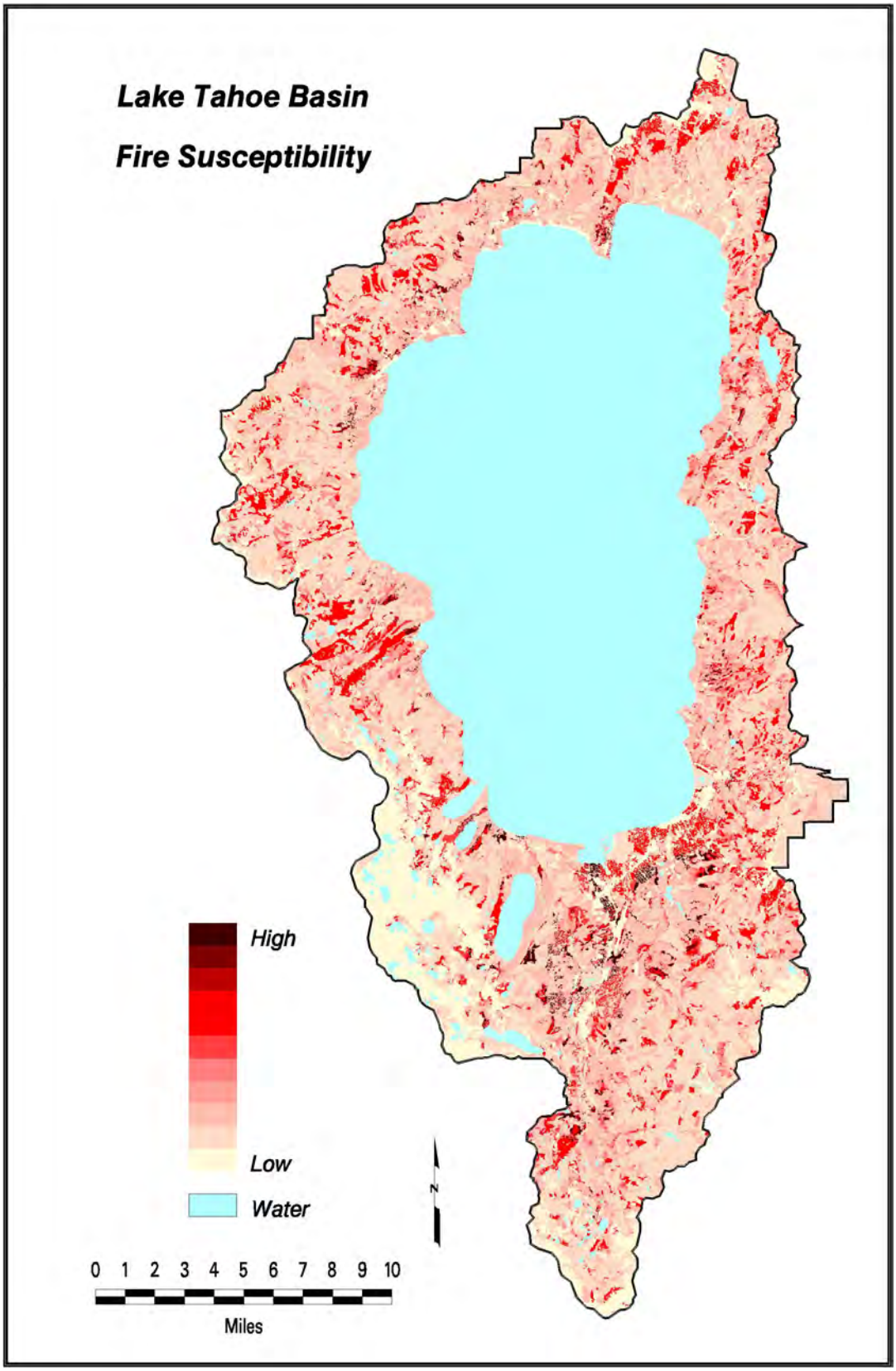


Figure 5-18—Mean fire susceptibility index values by watersheds.

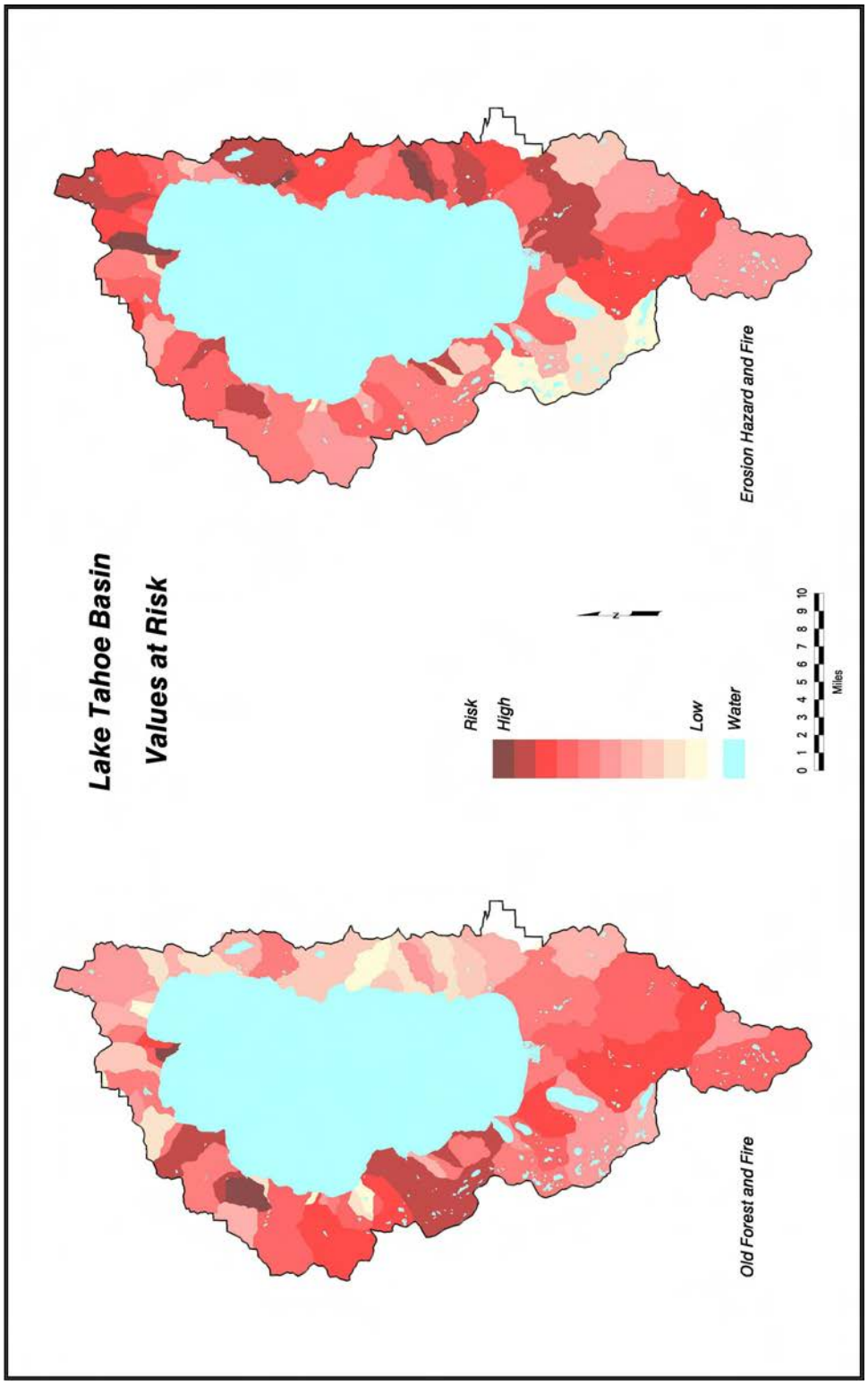


Figure 5-19—Combined watershed rating of fire susceptibility index (relative risk rating) and values at risk. Soil erosion hazard represents the value of lake clarity. Old-growth values are based on the proportion of the area in patches with greater than two trees (>30-inch diameter) per acre.

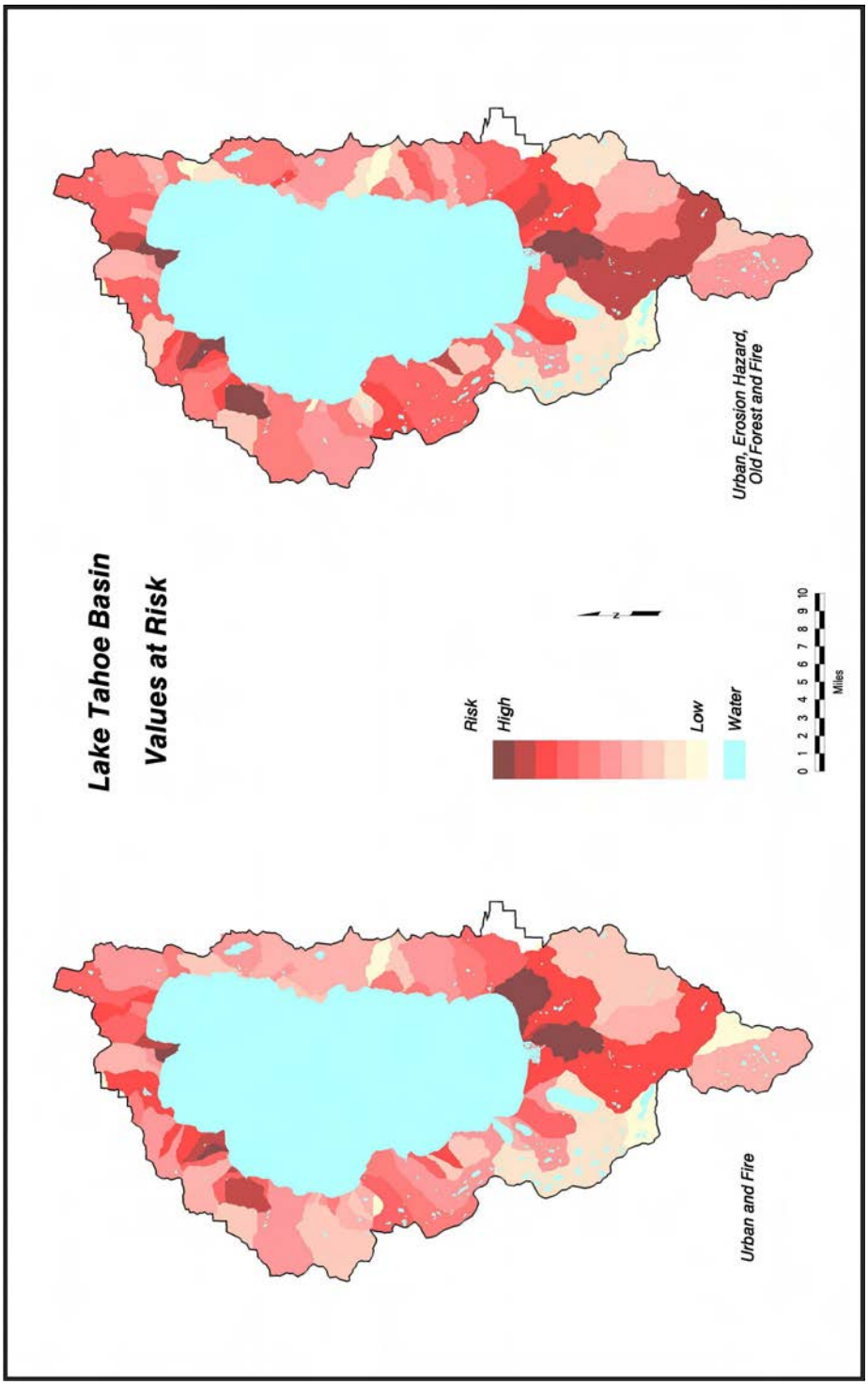


Figure 5-20—Combined watershed rating of fire susceptibility index (relative risk rating) and values at risk. Urban values are based on the proportion of the area in developed lots with structures from the TRPA land use map. The combined values at risk are the sum of urban values, lake clarity values at risk, and old-growth values, with the relative fire susceptibility rating by watershed.

concentrations of old growth, prescribed fire should be the major treatment. Mitigation for minimizing soil erosion from fuel reduction on erodible soils with mechanical treatment can be effective. Prescribed fire reduces surface fuels with minimal effects on soil erosion but may affect streamwater nutrient concentrations (see Chapter 4, Water Quality, for more detail). In old growth, prescribed fire is the best tool for reducing fuel hazard. We know little about the effects of mechanical treatment on the ecological function of old growth. Fire has played a role in shaping old-growth stands over time, and these forests have evolved with fire; therefore, prescribed fire in old growth not only can reduce fuel hazard but also can restore a key ecosystem process. With the limited ability to reintroduce fire in the basin due to air quality standards and concerns over the effects on lake clarity, it is important to use prescribed fire where it is most critical to ecosystem function.

Issue 3: The Need to Determine the Extent to which Prescribed Burning Reduces Fire Risk, Affects Wildlife Habitat, and Mimics the Process of Historic Fire

With contributions from Sue Husari and Steve Beckwitt

Prescribed burning is one of the tools that is important in reducing fire hazard and the likelihood of large or severe fire. In many situations, it is the most effective means of reducing surface fuels, the primary component of fire hazard. Prescribed burning is also critical in restoring fire as an important ecosystem process. Fire plays many important roles in shaping vegetation structure, composition, and landscape mosaics. Nevertheless, there are potential associated impacts on other resources with prescribed fire, including air quality (see Chapter 3) and lake clarity (see Chapter 4). Information on the historic role of fire, likely effects of prescribed fire, and effectiveness of the current prescribed burning program are summarized to address the trade-offs between reintroducing fire to reduce fire hazard and restoring fire as an integral ecosystem component with possible deleterious effects.

Three basic questions regarding the effects of prescribed fire are addressed under this issue and are as follows:

- What were the historic fire regimes in the Lake Tahoe basin?
- What is the state of knowledge of fire in the ecosystem in the Lake Tahoe basin?
- What is the effectiveness of current prescribed burning and other treatments in reducing fire hazard and risk, and mimicking the process of historic fire?

What were the historic fire regimes in the Lake Tahoe basin?

It is not enough to know that fire occurred historically in the basin; we also must consider the different fire regimes in order to understand the role of fire in shaping vegetation and the role of vegetation in the spread of fire. The fire regime includes fire return period (years between fire), predictability, extent, magnitude (severity), and timing or seasonality (Agee 1993).

Ignitions and Fire Return Intervals

Two sources of fire ignitions occurred historically (prior to European settlement) in the Lake Tahoe basin. Lightning is prevalent during the summer, especially late summer, and has a high enough density to ignite fires. Humans are the other source of ignitions. While the exact extent and frequency of Native American burning is not known, it is evident that the Washoe tribe used fire in the basin, particularly in or near meadows (Lindström, Chapter 2, this volume; Elliott-Fisk et al. 1997).

Most often, information on historic fire regimes is restricted to what can be derived from fire scars on trees. Very few fire history studies have been completed in the Lake Tahoe basin (Skinner and Chang 1996). We supplement the fire history data of Taylor (1998) with fire history data from similar areas outside of the basin to develop descriptions of historic fire regimes (Table 5-21).

Fire history data were summarized by forest type, based on dominant tree species. Only fire history studies that had dendrochronological cross-dating and a known area were included. (Fire return

Table 5-21—Summary of historic fire return intervals from fire history studies in the Tahoe basin or in areas in the Sierra Nevada or southern Cascades with similar vegetation and climate.

Location	Forest Type	Average Annual Precipitation (cm)	Mean Fire Return Interval (years)	Range of Fire Return Intervals (years)	Area Sampled (ha)	Reference
Caribou Wilderness, Lassen National Forest	White fir-red fir	91	53		several ha	Solem 1995
Lake Tahoe basin, eastshore	Red fir	56	16	9-36	several ha	Taylor 1998
Swain Mountain, Lassen National Forest	Red fir-white fir	110	42	5-65	.48	Taylor and Halpern 1991
Swain Mountain, Lassen National Forest	Red fir-white fir	110	40	17-65	1	Taylor and Halpern 1991
Swain Mountain, Lassen National Forest	Red fir-white fir	110	13*		3	Taylor 1993
Swain Mountain, Lassen National Forest	Red fir	110	26*		3	Taylor 1993
Mammoth to June Lake Region, Inyo National Forest	Red fir-lodgepole pine	68	28	11-41		Millar and Woolfenden (1999)
Lake Tahoe basin, eastshore	Red fir-lodgepole pine	74	13	8-23	several ha	Taylor 1998
Lassen National Park & Caribou Wilderness, Lassen National Forest	Lodgepole pine-red fir	109	35		several ha	Solem 1995
Lake Tahoe basin, eastshore	Jeffrey pine-white fir	76	12	5-28	several ha	Taylor 1998
Lake Tahoe basin, eastshore	Jeffrey pine-red fir	79	22	9-47	several ha	Taylor 1998
Caribou Wilderness, Lassen National Forest	Jeffrey pine-white fir	97	23		several ha	Solem 1995
Caribou Wilderness, Lassen National Forest	Jeffrey pine-white fir	97	32		several ha	Solem 1995
Prospect Peak, Lassen National Park	Jeffrey pine-white fir	89	29		several ha	Solem 1995

* Only intervals prior to 1850 were included.

intervals are sensitive to the area sampled [Agee 1993], therefore, to make relative comparisons, the spatial scale of sampling has to be taken into account.) The fire return intervals summarized here (Table 5-21) are point or plot composites, which means they are the sum of fire intervals for several to many trees in an area of several hectares or less. This scale is useful for comparing fire patterns and effects on different vegetation. The data summarized represent a period that generally encompasses several hundred years prior to European settlement.

Fires were most frequent in the vegetation types found on drier sites, such as lower elevation Jeffrey pine and Jeffrey pine-white fir forests (mean fire return intervals of 12 to 32 years) (Taylor 1998). Higher elevation red fir forests on the east shore of the Tahoe basin, where precipitation is considerably lower than in the red fir forests on the west shore, also had short intervals between fires (13 to 16 years) (Taylor 1998). Data from the Lassen National Forest and Lassen National Park (Solem 1995; Taylor 1993; Taylor and Halpern 1991) were used to represent red fir and mixed red fir and white fir forests on the west shore, which receives greater precipitation than the east shore. Average fire return intervals ranged from 26 to 53 years. One site (Taylor 1993) had a mean fire return interval of only 13 years. There is some uncertainty of the similarity in weather and therefore fire regimes between the Lassen and Lake Tahoe basin areas, but these data provide a first approximation. Parts of the west shore are wetter than these areas in the Lassen area. A study of red fir and lodgepole pine forests on the Inyo National Forest showed slightly lower fire return intervals (28 years) (Millar and Woolfenden, 1999). However, there were periods of 100 years or more when no fires were recorded, including the most recent period, presumably due to lack of ignitions.

Keifer found that evidence of fire in the subalpine zone varied with the bark characteristics of the species affected. Thin-barked lodgepole pine, which is common in subalpine forests in the Lake Tahoe basin, showed evidence of fire, whereas the more thick-barked foxtail pine did not. Lightning ignitions are common in subalpine forests, but because of the discontinuous pattern of vegetation and fuels, fires are small and often are limited to a single tree or patch of trees. Based on analysis of lightning-ignited fires in Yosemite National Park, van Wagtendonk (1998) estimated that the fire return interval in white bark pine forests would be over 26,000 years.

Variation in intervals between fires at any one site is more critical than average intervals to understanding the effects of fire over time on vegetation. For example, one 70-year interval between fires on a site is sufficient to allow white fir or red fir to establish and grow to a size where they are fire resistant (Agee 1993; Taylor 1993). A short interval between fires tends to favor pines because of their thicker bark and more protected buds. Fire return intervals are generally more variable on moister sites or in higher elevation red fir or subalpine zones. Moister sites, such as riparian or north-facing slopes, are less likely to have fuels sufficiently dry to burn as frequently as fuels on drier or south/west-facing slopes. Variation in snowpack and the length of the snow-free period can greatly alter the likelihood of fire in the higher elevation red fir and subalpine zones. Furthermore, red fir also has small needles that compact under the heavier snowpack in that zone, making surface fuels more resistant to combustion.

Fire return intervals interpreted from fire scars are generally considered conservative because data is limited to those fires that leave trees scarred (Skinner and Chang 1996). When fuels are more resistant to fire or are less continuous, a lack of fire scars may be due to a patchy burn pattern (some trees previously scarred are missed) or very low intensity burning (insufficient heat to scar trees). The range of intervals for all of the studies examined was relatively great (Table 5-21) compared to lower elevation mixed-conifer forests on the western slopes of the Sierra Nevada (Fites-Kaufman 1997). In particular, areas with higher precipitation in the red fir forests tended to have the greatest variability. This is consistent with observations of current fire patterns in Yosemite National Park (van Wagtendonk 1998), where fire patterns in red fir are highly variable in space and time. Information on historic vegetation composition from dendrochronological reconstruction (Taylor 1998) and General Land Office Survey Data provide

additional insight into variability in fire return intervals.

Taylor's reconstruction (1998) revealed that five out of six stands reconstructed in the pine-white fir zone were codominated by Jeffrey pine and white fir. The remaining one had only one cohort of white fir. Because young white firs are not especially resistant to fire and Jeffrey pines are resistant, this indicates either that fires were discontinuous or that there was sufficient variability in intervals between fires to occasionally allow white firs to establish and survive. The General Land Office survey data further corroborates this pattern, with white fir comprising a substantial proportion of the trees measured in the late 1800s.

We developed two statistical models of historic fire return intervals based on regressions of mean fire return interval and average annual precipitation (Figure 5-21, Table 5-22). Current precipitation was used as an indicator of historic precipitation. Both models were statistically significant, and the shapes of the modeled curves are similar. They provide two similar but slightly different estimates of fire return patterns and burned acres. They should be considered working hypotheses of historic patterns (Figure 5-22) because much of the data is from areas outside of the basin, and there has been no validation of the models.

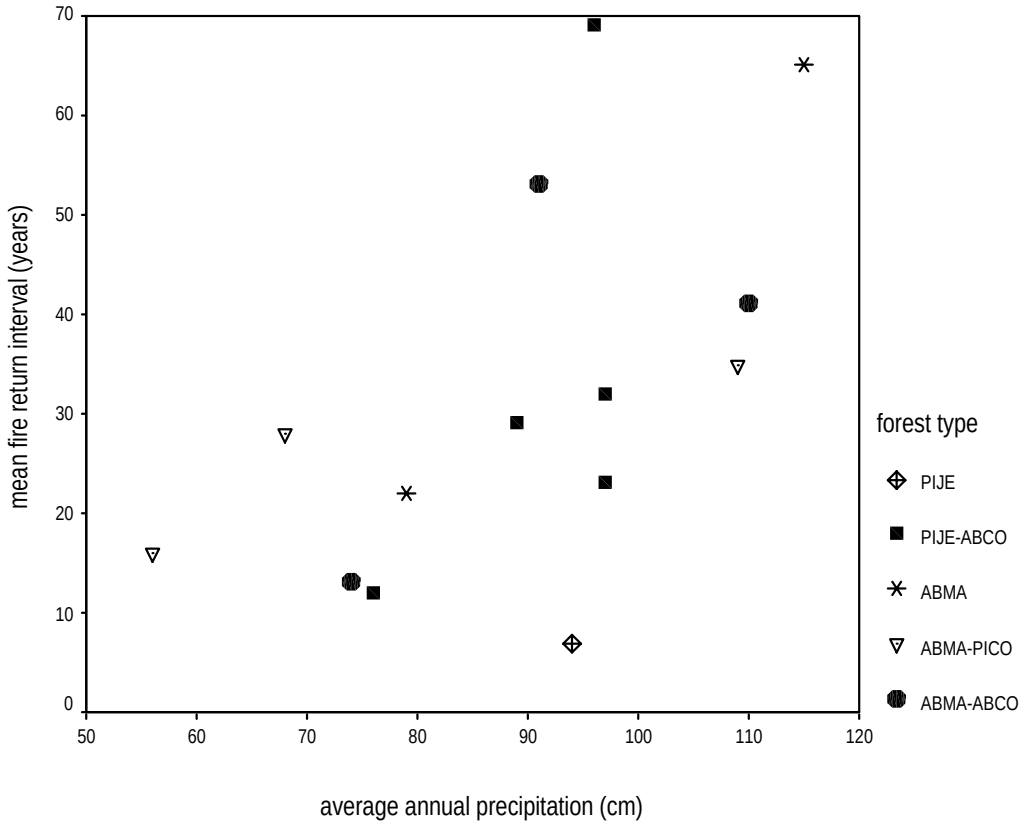


Figure 5-21—Mean fire return intervals (years) plotted against average annual precipitation (cm) by major forest type for fire history studies in or applicable to the Lake Tahoe basin. Forest types are abbreviated as follows: PIJE—Jeffrey pine, PIJE-ABCO—Jeffrey pine-white fir, ABMA—red fir, ABMA-PICO—red fir—lodgepole pine, ABMA-ABCO—red fir-white fir.

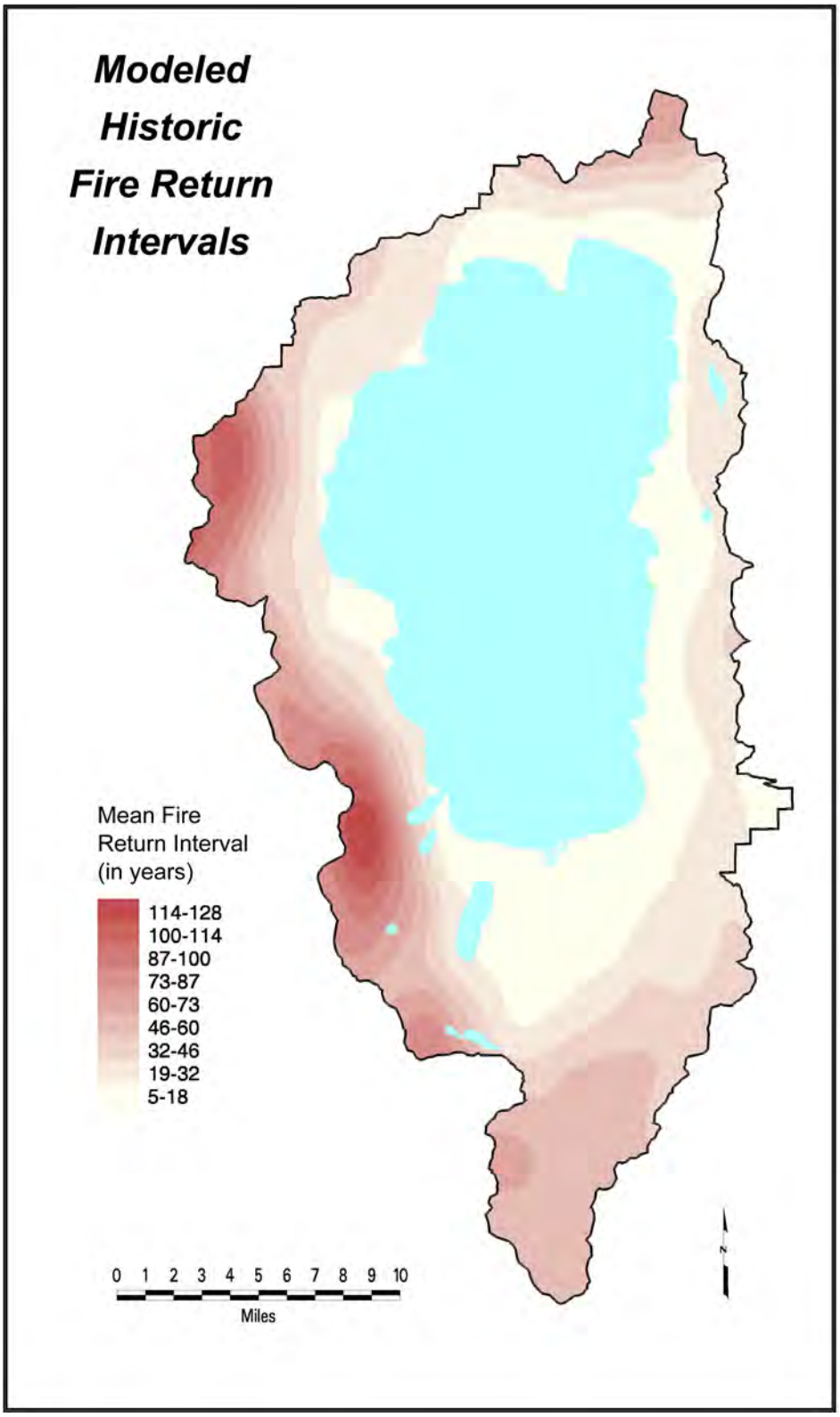


Figure 5-22—Modeled spatial patterns of historic fire return intervals based on nonlinear regressions of fire return intervals as a function of average annual precipitation.

The models enabled us to estimate the historic average of acres burned annually. The estimates were summarized for major vegetation zones and east versus west portions of the basin (Table 5-23). The differences in the models provide one measure of the variability in acres that may have burned—between 2,000 and 8,000 acres on average each year. Nearly half or more of the acres burned were at the lower elevations in the montane zone. Consequently, the montane zone had the greatest proportion of area burned annually, averaging 1.3 to 6 percent of the total area on average. Similar acres of the upper montane and subalpine zones burned, but the relative proportion of the area burned was slightly higher in the upper montane (0.9-3.3 percent) than in the subalpine zone (0.8-2.3 percent).

Fire Severity

High severity refers to high mortality of overstory trees, while low severity refers to little or low mortality of overstory trees. It is not possible to measure historic fire severity directly. Inferences generally are drawn based on patterns of fire return intervals and sometimes age-structure or species composition.

In the montane forests of the Lake Tahoe basin, fires were relatively frequent, therefore it is likely that most of them were low in severity. However, on moister sites, where fir was likely more dominant, fire severity may have been more of a mixture of intensities, leading to highly localized mortality. Little work has been done on patterns of fire in white fir. Taylor and Halpern (1991) studied

Table 5-22—Results of regressions of historic fire return interval as a function of average annual precipitation (ppt).

Model & Variables	Coefficient	adjusted R^2	F statistic significance
Cubic model		.33	.06
Ppt	-0.126		
ppt^2	0.005		
Constant	6.063		
Compound model		.46	.01
Ppt	1.02		
Constant	3.84		

Table 5-23—Estimates of acres burned annually (average) in the Lake Tahoe basin in the several hundred years prior to European settlement. Data are based on regressions of mean fire return intervals, from point composites, as a function of average annual precipitation (current). Low acre estimates are from the composite regression model, and high acre estimates are from the cubic regression model.

	Estimated Area Burned (acres)		
Vegetation Zone	**West**	**East**	**Total**
Montane	689-2964	326-1592	1015-4556
upper montane	291-838	261-1045	552-1883
Subalpine	389-1011	153-525	542-1536
Total	1369-4813	740-3162	2109-7975

mixed white fir and red fir stands on the Lassen National Forest and suggested that highly variable fire severity occurred. Russell et al. (1999) studied post-fire succession for several more recent fires (the early and mid 1900s) and found that these fires in the basin were high severity. However, it is not clear whether these high severity fires were influenced at least in part by human activities. Lindström (see Chapter 2) summarizes early accounts that reveal high severity fires ignited by sheepherders across broad areas or ignited inadvertently by settlers in logging slash. It is uncertain whether the oldest fire that Russell et al. describe in 1890 was a lighnting caused fire in natural vegetation or if it was ignited by European settlers and their activities.

In upper montane forests, fire intensity and severity were likely more variable than in the montane zone. Fires on sites with rocky or very shallow soils with scattered vegetation, such as Jeffrey pine, would result in little mortality due to lack of fuels. On more productive red fir sites, fire severity likely varied considerably. Recent wildland fires in red fir in Yosemite National Park exhibit diverse levels of mortality even within the same fire event (van Wagtendonk 1998). Mortality ranges from less than 20 percent to greater than 80 percent. Patches of high mortality are generally limited to less than 100 acres. The Yosemite patterns are consistent with the work of Taylor and Halpern (1991), Taylor (1993), and Solem (1995). In red fir and lodgepole pine forests on the Inyo National Forest, Millar and Woolfenden (1999) inferred that fire frequency and fire severity varied considerably over time, from no fire for a period over 100 years to high severity, widespread fire (possibly tied to volcanic activity), to a moderate period of frequent low severity fire.

Limited research has been conducted on fire history in subalpine forests in the Sierra Nevada on which to surmise historic fire severity (Skinner and Chang 1996). Observations of current fire patterns indicate that fires tend to burn and kill individual trees or small clumps of trees, although there is one stand of mountain hemlock in the Desolation Wilderness to the west of the Lake Tahoe basin, where all but two trees apparently burned in a fire in the early 1900s.

Seasonality and Extent

Data on seasonality of historic fire is extremely limited in the Sierra Nevada. In one of the few studies that included seasonality, Taylor (1998) reported that over 90 percent of the fires occurred in the dormant season (presumably late summer and fall) on the east shore of the Lake Tahoe basin; the remaining 10 percent occurred in the growing season. This is consistent with the typical lightning patterns observed currently in the basin, with most of it striking in the late summer.

The spatial extent of historic fire is time-consuming to reconstruct, and as a result very few studies have been conducted that include spatial extent. Taylor (1998) examined synchrony of fire events across a portion of the east shore, representing several thousand acres. A fire in 1794 burned through the entire study area. Other widespread fires, where more than 50 percent of the study sites burned, had a median fire return interval of 18.5 years, indicating a relatively high frequency of fires that covered large areas on the east shore.

The only other applicable study that has examined fire extent is that by Solem (1995) in upper montane forests of the Caribou Wilderness in Lassen National Forest. He examined a 4,800-acre area and estimated that seven different fires occurred prior to 1850 within this area, ranging in size from 55 acres to 1,600 acres. Three of these fires were between 200 and 300 acres, three were between 30 and 60 acres, and one was 1,600 acres. This pattern of predominantly small to medium sized fires is similar to current patterns of fires allowed to burn in the red fir forests of Yosemite National Park (van Wagtendonk 1998).

The topography of the basin and wind patterns discussed in the fire risk section of this chapter indicate that fires historically were usually not greater than several hundred or several thousand acres.

Riparian Areas, Meadows, and Wetlands

There is no information on fire regimes in riparian areas, meadows, or wetlands in the basin, except for information on burning practices of the

Washoe tribe in some of these areas (see Chapter 2). Fire history studies in riparian areas are particularly rare in the entire western US Fire history studies in westside mixed-conifer forests on the Eldorado National Forest (Fites-Kaufman 1997) and in the Klamath Mountains on the Shasta-Trinity National Forest (Skinner and Chang 1996) indicate fire presence in riparian areas in montane regions of California. In mixed-conifer forests of the Eldorado, Fites-Kaufman (1997) found that mean fire return intervals in riparian areas varied by the size and landscape position of riparian areas. Fire return intervals for a riparian zone associated with a small, intermittent stream in a dry portion of the landscape (upper slope) was similar to adjacent upland areas. In contrast, fire return intervals for a riparian zone associated with a large perennial stream at the bottom of a slope were considerably longer than other similar upland areas. Historic fire regimes in riparian areas, meadows, and wetlands in the basin likely varied with stream size and landscape position as well. Numerous fire-scarred trees have been observed around Meek's meadow in the basin, indicating either Native American and or lightning-caused fires played a role in some meadows in the basin.

What is the state of knowledge of fire in the ecosystem in the Lake Tahoe basin?

Our knowledge of the effects of prescribed fire in the basin is limited. Some monitoring of prescribed fire is conducted, most extensively by California Department of Parks Parks and Recreation, but the design does not address some key questions, such as the effects of burning on lake clarity or air quality. Secondly, the spatial pattern of fire effects is critical in understanding effects on fire risk, vegetation, and wildlife habitat. Current monitoring protocols are based on randomly placed plots. This scheme was not designed to detect and characterize the spatial patterns of effects. Further, most burn units are smaller and less intensely burned than in the time before European contact.

Increasing our knowledge of the effects of prescribed fire on nutrient transport is probably best achieved through research, because it will require methods not yet developed (see chapters on air and water quality). Effects of fire on vegetation, fire hazard, and some aspects of wildlife habitat may be addressed adequately with monitoring; however, comparisons of effects of fire with other vegetation treatments, such as thinning, would require a more formal experimental design, such as the proposed National Fire/Fire Surrogates Study (Weatherspoon and Skinner 1999).

What is the effectiveness of current prescribed burning and other treatments in reducing fire hazard and risk, and mimicking the process of historic fire?

To evaluate the effectiveness of prescribed burning and other treatments in reducing fuel hazard and mimicking the process of historic fire, an analysis of the scale and spatial pattern of treatment and the actual effects of treatments must be undertaken. Currently, fewer than 1,000 acres are underburned annually in the Tahoe basin. This is in contrast to estimates of historic burning of up to 8,000 acres. (The actual amount of historic burning may be higher because of the lack of detailed fire history data throughout the basin and the conservative means of interpreting fire history data.) The implication is that current burn treatments only superficially mimic the historic process of fire at the landscape scale. Current burn units are smaller and less intensely burn areas before European contact.

Some of the burning that occurs in the Tahoe basin is pile burning rather than underburning. Pile burning is the act of burning piles of thinned trees, pruned branches, cut vegetation, or gathered surface fuels. Sometimes the fire spreads between piles, but the primary purpose is to burn the pile. Underburning refers to the application of prescribed fire across an entire area, although not every location within is necessarily burned. The effectiveness of pile burning in reducing fire hazard and mimicking the process of historic fire is variable, depending on how it is applied. When piles are composed of thinned material from the understory and larger surface fuels on the ground, fire hazard can be reduced, but this does not always reduce smaller surface fuels (Stephens 1998). When piles are composed only of thinned material from the understory, then burning usually has little effect on surface fuels, except under the piles or when the fire creeps a little. The residence time (or duration of heat in one place) during pile burning replicates to some degree that of historic fire or underburns,

where there were accumulations of large wood. However, the spatial extent and quantity of piles is likely much greater than accumulations of large wood historically.

The effectiveness of such burning in reducing fire hazard or likelihood of large, severe, unplanned fire is variable. Recent theoretical modeling by Finney (in preparation) suggests that the proportion of the area treated and the spatial arrangement of the treatments are critical to reducing the rate of spread, fire intensity, and sometimes fire size. In areas where treatments are strategically placed in a given location, such as in Sugar Pine Point State Park or Incline, it is likely that there is a trend toward decreasing fire hazard and reduced likelihood of large or severe unplanned fires. But to draw firm conclusions, more detailed analysis of all mapped locations of treatments and the effects of those treatments on reducing fuels is necessary. Real-time monitoring of activities and their effects would provide this information.

Other treatments to reduce fire hazard and to mimic the process of historic fire involve removing vegetation through thinning or chipping. Little information exists in the basin or elsewhere in the western states on the ecological impacts of mechanical treatments or their effectiveness in reducing fire hazard compared to burning. Researchers have begun a large multidisciplinary, multistate research project (Fire Surrogate Study, Joint Fire Science Program) to address this lack of information (Weatherspoon and Skinner 1999). Another research effort on the Teakettle Experimental Forest in the southern Sierra Nevada also is addressing these questions (North 1998).

The effects of fire on ecosystem composition, structure, processes, and functions are not always well understood (Chang 1996). However, while some effects of fire can be mimicked at least partially by mechanical treatment, there are other effects we know of that cannot. For example, heat or smoke generated by fire that scarifies seeds of some species to germinate is not mimicked by mechanical treatment. There are other more subtle effects of fire in creating spatial heterogeneity in forest structure (patchiness) (Bonnickson and Stone 1991; Taylor and Halpern 1991; Franklin and Fites-Kaufman 1996; Fites-Kaufman 1997) where there is uncertainty of our ability to mimic with mechanical treatment.

While little research exists on the direct effects of different treatments (for example, thinning or burning) on fuel loading and configuration and thus on fire hazard, there are several obvious differences. First, only burning actively reduces duff, litter, and litter layers. Mechanical treatments may redistribute these ground and surface fuels, making them less continuous, but they are not removed. Both fire and mechanical treatments, especially biomass treatments, can reduce ladder fuels in the understory. Fires burn materials that are low to the ground and of small diameter. Biomass operations remove shrubs and small trees to varying degrees, depending on the objective, but with current technology biomass operations are limited to less steep areas.

Issue 4: The Need to Develop a Conceptual Model of Forest Vegetation and Function as a Basis for Identifying Attributes of Integrity

With contributions from David Rizzo and Yiqi Liu

A conceptual model of the basin ecosystem is important because it shows which things to monitor to know the direction and magnitude of changes caused by management actions. Adaptive management requires information about change as early as possible so that management procedures can be altered if necessary. So far, ecologists have had a remarkable lack of success in deciding what to monitor; that is, in deciding what would be the most sensitive, reliable, early indicators of change in such slow-moving ecosystems as forests and deep lakes.

We addressed two questions about a conceptual model of forest health: What are the key ecosystem processes and stressors and what are the potential attributes of integrity that are useful for monitoring.

What are the key ecosystem processes and stressors?

We recognize the following five key ecosystem processes for all vegetation types in the basin. These processes are just the most important or key processes among a much longer list of all processes.

- Nutrient cycling, particularly of carbon, nitrogen, and phosphorus;
- Energy cycling, as expressed by each trophic level's caloric content;
- Water cycling, including transpiration and canopy interception of precipitation;
- Occurrence of disturbance (frequency, intensity, distribution) by such factors as fire, wind, pathogens, bark beetles, and leaf-eating insects; and
- Successional change, as expressed by vegetation structure, canopy closure, population age structure, species composition, and litter chemistry.

The most important stressors (i.e., affectors) (Manley et al. in press) of the key processes above vary with the vegetation type. For forests in the basin, we identified the primary affectors as those listed below, in declining order of importance:

- Changes in the fire regime;
- Active management (thinning, disease control or introduction, prescribed fire);
- Type conversion (ski developments, urbanization);
- Recreation;
- Climate change and episodic extreme fluctuations (drought);
- Atmospheric pollutants;
- Introduction and spread of exotic plants; and
- Livestock grazing.

For wetlands, the sequence of importance in the list of affectors are grazing, recreation, type conversion, climate change, pollutants in surface or ground water flows, and management of adjacent forested lands, such as change in fire regime.

What are the potential attributes of integrity that are useful for monitoring?

Affectors typically modify processes in complex ways, but our objective was to search for relatively simple items to measure that might serve as surrogates for the total effect of the affector. The simple items that are measured and monitored are called "elements" in the terminology of Manley (1997). Table 5-24 lists some elements that could be monitered as surrogates for various processes. Each element also was categorized as being a strong, moderate, or weak surrogate.

As shown in the table, those elements we think most promising for monitoring are litter production, depth, and decomposition rates, nitrogen mineralization rate, tree density or mortality by species and size/age class (in particular young and very old age classes), canopy cover or leaf area index, and the carbon:nitrogen ratio and pH of litter and soil. These elements are relatively easy to quantify by standard techniques, they require minimal training of observers, they are inexpensive to quantify and, should give the earliest indications of ecosystem change.

The key importance of these elements is clear from a conceptual forest health model (Figure 5-23). From the model, one can see that litter decomposition rates impact the lake water chemistry; when fire consumes plant biomass it generates atmospheric pollutants that can inhibit photosynthesis and productivity and can affect water chemistry; and vegetation structure and species composition provides the matrix within which wildlife move and function (that is, vegetation conditions could be a surrogate for wildlife).

Such models sometimes illustrate unexpected relationships. For example, management can increase disease incidence as well as reduce it. Thinning an overly dense forest usually wounds some trees left standing and creates freshly cut stumps. Both wounds and stumps are avenues for pathogens to enter, and, once they are in the root system of the cut or injured trees, they can be carried to healthy trees through natural underground root grafts. A forest with a high density of disease-susceptible tree species, such as white fir (*Abies*

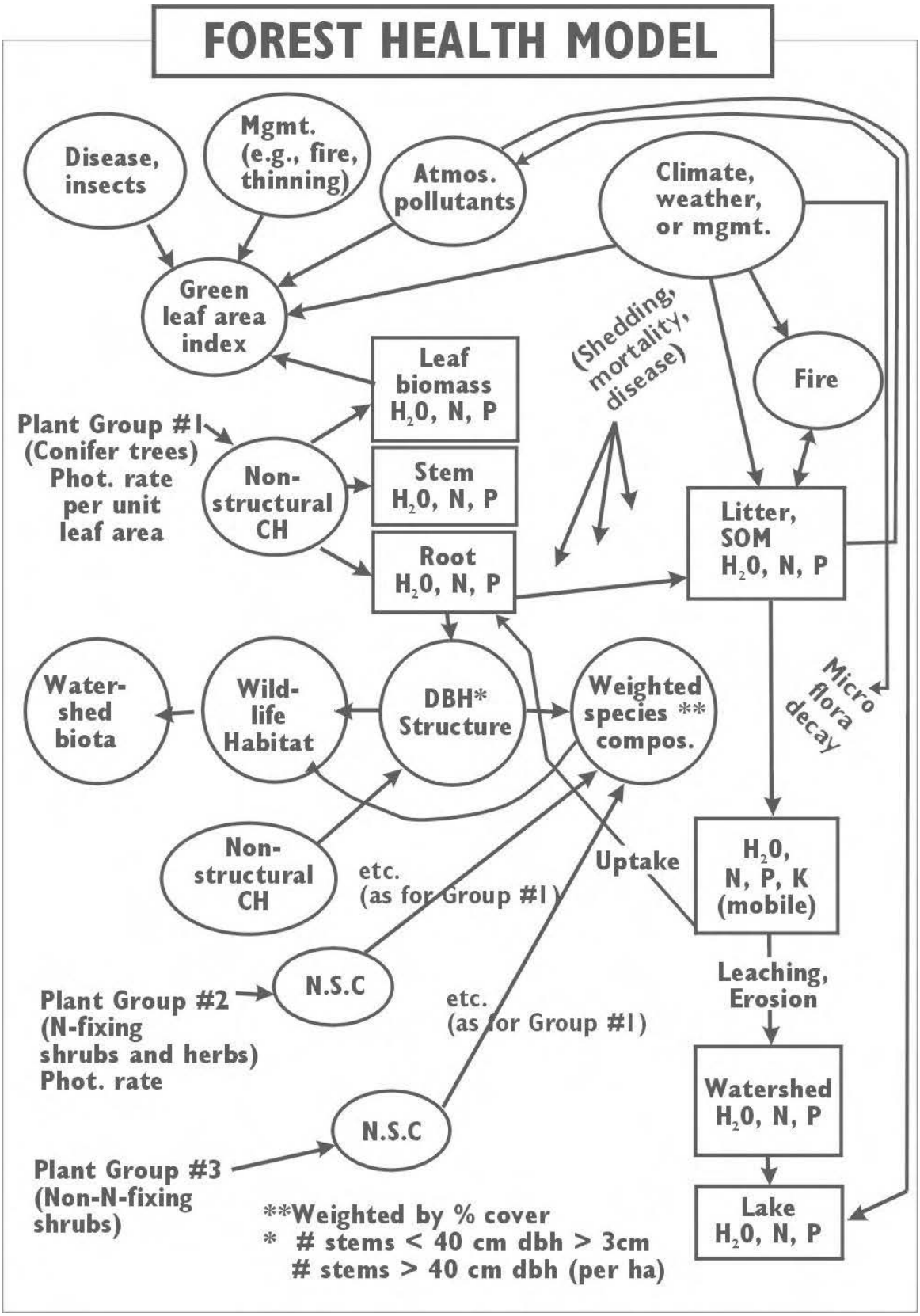


Figure 5-23—Conceptual forest health model.

Table 5-24—Elements that might serve as measurable surrogates for important ecosystem processes. The strength of connection between each element and each process is categorized as "strong," "moderate," or "weak."

Process	Strongly Linked Elements	Moderately Linked	Weakly Linked
Carbon cycling	litter producing, standing biomass	litter decomposition biomass accumulation (change in dbh)	
Nutrient cycling		nitrogen mineralization rate, C:N ratio	P availability, ratio of N uptake:loss by leaching
Disturbance by pests, insects, or pathogens	Incidence (% of trees with symptoms)	tree density and mortality by species and size class	densities of bark beetle or needle engraver beetles
Successional change in spp composition	Abundance or presence of tree, shrub, herb spp; diversity in microbial flora	mortality by species and size class, species richness, species diversity	
Successional change in vegetation structure	Growth form spectrum, tree diameter or age class distribution, seedling survival, shrub decadence	canopy cover, leaf area index, ratio of bacteria:fungi in isoil, tree mortality by size or age class	cone and seed production

concolor), can transmit root diseases faster than can a forest with a lower density of white fir.

The model further suggests that monitoring only three growth forms of plants—three functional groups—can be more effective than monitoring all the hundreds of individual species that occur in these forests. The three functional groups are as follows:

- Conifer trees, which dominate the biomass and create the microclimate for associated shrubs and herbs, therefore their choice as an important growth form to monitor is obvious;
- Nitrogen-fixing shrubs and herbs that modify the nitrogen cycle, enrich the soil, and speed recovery/succession from disturbance, including species in the genera alder (*Alnus*), loco weed (*Astragalus*), *Ceanothus*, mountain mahogany (*Cercocarpus*), *Lotus*, lupine (*Lupinus*), and bitterbrush (*Purshia*); and
- All other shrub taxa, important because they contribute a significant amount of cover (almost 20 percent) and they compete for soil moisture with conifer seedlings, saplings, and overstory trees. Most Sierran shrubs are capable of stump-sprounting after fire; hence, they survive both surface and catastrophic crown fires. In addition, the seeds of nonsprouting ceanothus shrubs are triggered to germinate after a fire by the heat having cracked their seed coats. Shrub dominance after a crown fire can be so extensive as to delay the regeneration and recovery of conifers.

All other growth forms, such as nonnitrogen-fixing herbs, vines, and broadleaf trees, contribute less than one percent of all plant cover; so even though they have high species richness, their impact on forested ecosystems is negligible. We caution, however, that total species richness and the change in abundance of any dominant individual species may be important and that these traits should not be lost by a complete focus on growth forms. Furthermore, functional groups other than the few identified above might turn out to be excellent surrogates for predicting ecological health or total biotic diversity—if we only knew more about them.

Issue 5: The Condition of Aquatic Ecosystems in the Basin

With contributions from Craig Oehrli, Jeffrey Reiner, Jennifer S. Hodge, J. Shane Romsos

Aquatic ecosystems in the Sierra Nevada have been severely degraded in the past two centuries (Moyle 1996), as evidenced by declines in native amphibians (Jennings 1996), fish (Moyle et al. 1996), aquatic invertebrates (Erman 1996), and interruptions in water availability (Kattleman 1996). Many of these changes in aquatic ecosystems have resulted from the introduction of exotic species, grazing, channel alteration, water diversions, and changes in water quality (Moyle 1996). Aquatic ecosystems provide vital habitat for a variety of plant and animal species, indispensable water sources, and important recreational opportunities for people. Although much of the focus on aquatic ecosystems in the Lake Tahoe basin has been on Lake Tahoe itself, an assessment of the status of all of the basin's aquatic ecosystems will assist their preservation and sustainable use.

The following questions were addressed in relation to the condition of aquatic ecosystems:

- What aquatic ecosystems are there currently in the basin?
- How have aquatic ecosystems changed from historic times to the present?
- Which aquatic ecosystems are potentially imperiled or vulnerable to future imperilment in the basin, and what is the state of knowledge about these ecosystems?
- What data gaps were revealed in the process of assessing aquatic ecosystems?
- What monitoring, conservation, and research activities are most appropriate for the focal aquatic ecosystems identified?

What aquatic ecosystems currently occur in the basin?

We used a modified version of Moyle's (1996) aquatic habitat classification scheme to identify and describe the types of aquatic environments occurring in the Lake Tahoe basin. Moyle (1996) identified 66 aquatic types in the Sierra Nevada, which fell into two broad categories: lotic (flowing water) and lentic (standing water) types. His classification divided the Sierra Nevada into two geographic areas: the Sacramento-San Joaquin Province (western slope of the Sierra Nevada; 28 types), and the Great Basin Province (eastern slope of the Sierra Nevada; 38 types). The Lake Tahoe basin is on the eastern slope of the Sierra Nevada, and Moyle (1996) considered Lake Tahoe part of the Great Basin Province. Therefore, we used the Great Basin Province classification to identify aquatic types in the basin, adding the categories of marshes and wet meadows. These two additional aquatic environments contribute significantly to the diversity of aquatic and terrestrial biota in the Lake Tahoe basin.

Many of the aquatic types recognized by Moyle (1996) are defined based on physical conditions and associated biota. Because aquatic ecosystems in the basin have not yet been fully classified, we used our local knowledge of the aquatic ecosystems in the Lake Tahoe basin to identify the types occurring in the basin. Our local knowledge of lotic ecosystems was significantly enhanced by reference to classification data obtained for 36 streams in the basin (USDA, unpublished data) using methods developed by Hawkins et al. (1993), Montgomery and Buffington (1993), and Rosgen (1995).

We identified 17 aquatic ecosystems in the Lake Tahoe basin: nine types of lotic aquatic ecosystems and eight types of lentic aquatic ecosystems (Table 5-25). Lotic aquatic types range from alpine snowmelt streams to small forest or meadow associated streams to large mainstem rivers. Lentic aquatic types range from fens and bogs to small ponds and lakes to Lake Tahoe. The Lake Tahoe basin hosts representatives of almost 45 percent (17 of 38) of all the Great Basin aquatic types. Although we did not have data on the diversity of types in other similarly sized areas in the Sierra Nevada, it appears that the Lake Tahoe basin contains a relatively high diversity of aquatic types for its area and thus contributes significantly to the diversity of Great Basin aquatic types in the Sierra Nevada.

Table 5-25—Aquatic ecosystems of the Lake Tahoe basin, with descriptions adapted from Moyle's (1996) classification for the Great Basin Province (GBP; "C" numbers) and their approximate equivalents in the Sacramento-San Joaquin Province (SSJP; "A" numbers). Examples in the Lake Tahoe basin are included.

Type Name	GBP number, SSJP number	Description	Examples in the basin
Lotic ecosystems			
Spring	C2213 A2413	Springs have constant temperature and flow, fine substrates and clear water and can support unusual/endemic invertebrates. Several unite to form a meadow stream.	Fountain Place in the Cold Creek drainage
Alpine snowmelt stream	C2110 A2110	Small, exposed, high gradient streams mainly above the timberline that exist only when snow is melting.	Fourth Creek Jabu Creek
Alpine stream	C2212 A2411	Most streams above 3,000 m elevation contained no fish until various salmonids were introduced in the late 19th century. Originally dominated by aquatic insects and amphibian larvae.	Round Lake Tributary Upper Truckee River
Conifer forest snowmelt stream	C2120 A2120	Small intermittent streams in conifer forest areas that also exist primarily when snow is melting but whose flows are enhanced by seepage from bogs and meadows. Occasionally important as spawning areas for trout (*Oncorhynchus* spp.).	North Fork Ward Creek
Meadow stream	C2215 A2414	First or second order streams through alpine meadows, low gradient with sinuous or braided channel. Where not heavily grazed, abundant frogs. May have introduced trout populations.	Burton Creek
Trout headwater stream	C2310 A2421	Small alpine streams with meadow systems; originally containing Lahontan cutthroat (*Oncorhynchus clarki henshawi*) or Paiute cutthoat (*O. c. seleneris*) but now usually containing nonnative trout.	Upper Blackwood Creek
Forest stream	C2214 A2412	Second or third order streams in fir, pine, or deciduous forest areas that are too small or too high in gradient to support fish.	Upper Saxon Creek
Stream with trout	C2331 A2422	Coldwater streams containing the typical Lahontan fish community (5-6 species, including Lahontan cutthroat trout).	Lower Meeks Creek
Mainstem rivers and their larger tributaries	C2350 A2441	Large streams that contain complete Lahontan fish fauna, including mountain whitefish (*Prosopium williamsoni*) and large adults of cutthroat trout and Tahoe sucker (*Catostomus tahoensis*). Cutthroat trout are now replaced by nonnative species.	Lower sections of the Upper Truckee River

Table 5-25—*(continued)*

Type Name	GBP number, SSJP number	Description	Examples in the basin
Lentic ecosystems			
Fen	C1241 A1290	Minerotrophic, spongy, spring fed peaty areas located on hillsides and dominated by nonsphagnum mosses and sedges.	Unknown
Sphagnum bog	C1242 A1280	True bogs containing marshy vegetation, including carnivorous plants and ranid frogs.	Grass Lake
Wet meadow	-	Seasonally flooded wetlands where standing water is usually present during the late fall, winter, and early spring and where the water table often drops below the surface during the summer and early fall. Grasses, rushes, and sedges are dominant plants (Caduto 1990).	Burton/Antone Meadows
Marsh	-	Wetlands where standing water, generally less than 2 m, exists year-round, except in the shallower areas during late summer or unusually dry years. Marshes may support the growth of emergent plants, such as cattails, bulrushes, reeds, and sedges, as well as many floating and submergent plants (Caduto 1990).	Pope Marsh
Mountain pond	C1120 A1152	Shallow (<1.5 m deep) ponds or small (<1 ha) lakes in alpine areas that periodically dry up, freeze solid, or become deoxygenated in winter; often associated with meadows or cirques.	Glacial tarns in the Desolation Wilderness
Alpine lake/pond without native fish	C1210 A1210	Small, usually isolated, oligotrophic lakes in high mountain areas usually formed by glaciers or in cones of volcanoes.	Triangle Lake
Alpine lake/pond with native fish	C1311 -	Oligotrophic, permanent lakes with connections to streams with fish.	Cascade Lake Fallen Leaf Lake
Lake Tahoe	C1312 -	A large, deep, extraordinarily clear lake containing complex fish fauna and unusual deep water invertebrates.	Lake Tahoe

How have aquatic ecosystems changed from historic times to the present?

Historical data on changes in environmental conditions are incomplete, but some contemporary accounts contain descriptions that allowed us to infer general trends in ecosystem conditions. Chapter 2 provides a detailed account of environmental and cultural changes in the Lake Tahoe basin over the past 150 years. Here we summarize those changes most relevant to the status of aquatic ecosystems. The majority of the discussion regarding the introduction of exotic species is in Issue 7 and discussion of introductions of fish to Lake Tahoe is in Chapter 4. We describe changes in the condition of aquatic ecosystems and their associated species over the four major periods established in Chapter 2: Prehistoric Era (pre-1860), Comstock Era (1860 to 1900), Post-Comstock Era (1900 to 1960), and Urbanization Era (1960 to present).

Prehistoric Era

From historic accounts, it appears the Washoe people, the only human inhabitants of the basin during this period, had minor effects on environmental conditions in the basin. Elliott-Fisk et al. (1997) suggest that the Washoe used advanced horticultural practices (such as burning, weeding, pruning, copicing, and selective plant harvesting) that could have affected the distribution and characteristics of meadows. It is generally accepted that aquatic ecosystems functioned naturally, with relatively little manipulation by humans (Nevers 1976; Strong 1984).

Comstock Era

Wetlands, meadows, and forest floors throughout the basin were severely affected by grazing animals during this era (McKelvey and Johnston 1992). The Washoe stated that livestock grazing in the basin damaged many plants important to them (Elliott-Fisk et al. 1997). Not only did sheep denude the landscape of grasses, shrubs, and riparian vegetation, but sheepherders burned extensive areas, especially targeting large downed logs, to promote regeneration of forage and to facilitate movement of sheep through the forest. Sudworth (1900) described the basin at the end of this era: "There are practically no grasses or other herbaceous plants. The forest floor is clean. . . . [I]t is evident that formerly there was an abundance of perennial forage grasses throughout the forest in this territory. . . . [I]t would seem that this bare condition of the surface in the open range has been produced only through years of excessive grazing by millions of sheep—a constant overstocking of the range."

During the Comstock Era, many land use practices contributed to the degradation of water quality in both lakes and streams and to the creation of unnatural bodies of water. At least two-thirds of the basin's forests were clear-cut (see Chapter 2); clear-cutting and uncontrolled grazing probably caused the discharge of heavy loads of sediment into regional water bodies (Elliott-Fisk et al. 1997; Heyvaert 1998). In addition, Strong (1984) noted that it was common to dump sawmill waste, such as sawdust, directly into streams and Lake Tahoe. Heyvaert (1998) estimated that sediment deposition rates into Lake Tahoe increased between seven- and 12-fold during this era compared to predisturbance deposition rates. Streams and lakes throughout the basin, such as Marlette and Spooner lakes, were dammed and diverted to maintain a supply of water to logging flumes (Strong 1984; Landauer 1995). This practice created artificial water bodies and changed water levels in existing water bodies such that lowland vegetation and riparian communities were presumably converted to aquatic systems. Some historians speculate that the diversion of streams and the deposition of large quantities of sediment and silt in streams and lakes were partially responsible for the decline of native trout (Scott 1957; Gerstung 1988; Elliott-Fisk et al. 1997).

The depth and clarity of Lake Tahoe's waters were first measured in 1873, and the best uses of Lake Tahoe began to be discussed during this era. John LeConte estimated that Lake Tahoe was between 900 and 1,645 feet deep and measured its clarity using a dinner plate at 108 feet (Landauer 1995). In the 1870s, the first dam on Lake Tahoe was built at the Truckee River outlet, and its use was debated by local residents (Landauer 1995). The dam raised the lake's water level by 2 meters (6 feet) (Elliott-Fisk et al. 1997). Raised lake levels may have altered the dynamics of marshes surrounding the lake and new shoreline inundation probably changed the distribution of riparian-associated plants.

Post-Comstock Era

Specific descriptions of the condition of wetlands from 1900 to 1960 are not available, but contemporary accounts (James 1915, and others in Strong 1984; Landauer 1995) provide some indication of their condition during this era. Grazing was still common in meadows and probably occurred to some extent on wetlands or along their edges (Barnett 1999; Pepi 1999). Rowland's Marsh (currently known as Pope and Barton marshes and the Tahoe Keys in South Lake Tahoe) originally occupied approximately 1,300 acres at the mouth of the Upper Truckee River and extended 4.3 km (2.6 miles) along the shoreline of Lake Tahoe (Landauer 1995). Photographs of Rowland's Marsh taken in 1930 show an extensive and virtually unfragmented

meadow/wetland system (Orr and Moffitt 1971). Many bird species associated with wetlands and meadows were recorded in Orr and Moffitt (1971) during the first half of the twentieth century, suggesting that these areas provided valuable bird habitat in the basin.

During the latter part of this era, the basin's streams again began to experience excessive nutrient loading, this time from excess effluent rather than from erosion and run-off caused by logging (Strong 1984). Throughout the 1940s and 1950s, development put more pressure on the basin's limited sewage disposal system. Sewage effluent was sprayed directly onto the land in many watersheds and subsequently was released into the basin's streams and lakes (Strong 1984).

During this era, controversy arose regarding the fate of the waters of Lake Tahoe itself. Appropriation of "excess" waters from Tahoe for hydroelectric power and reclamation projects in Nevada (necessitating a varying lake level) seemed incompatible with the desire of resorts and navigation interests to maintain a constant high lake level for the tourist industry (Landauer 1995). Landauer (1995) recounts the events surrounding the appropriate use of Lake Tahoe's water, as summarized here. In 1913 the original dam on the lake's outlet at Tahoe City (built in the 1870s) was replaced with a more modern version by a power syndicate supported by the US Department of the Interior. A crisis occurred in 1924 when the lake level dropped so low that no water could leave the lake to supply Nevada farmers with water via the Truckee River. Negotiations led to the construction of Boca Reservoir and the development of alternative supply strategies (specified in the Truckee River agreement of 1934). In 1930 and 1931, at least 20,000 acre-feet of water were drawn from the lake to supplement Nevada's water supply during a drought. In 1955, Congress established a California/Nevada Interstate Compact Commission to determine the most appropriate use of local water. The conflict was not resolved for many years.

Urbanization Era

Wetlands and meadows experienced rapid change from 1960 to the present. Since the mid 1900s, approximately 75 percent of marshes and 50 percent of meadows have been degraded, and around 25 percent of the basin's marshlands were developed between 1969 and 1979 (Western Federal Regional Council 1979, cited in Elliott-Fisk et al. 1997). The Tahoe Keys development, for example, filled, fragmented, and highly altered 750 acres of the once intact Rowland's Marsh (Landauer 1995). The marsh remains the largest extant marsh in the Lake Tahoe basin, but its reduced size limits habitat for species uniquely associated with marshes in the basin, and there are concerns that the hydrologic function of the remaining marsh has been compromised by the Tahoe Keys development (Strong 1999).

Concern for the basin's water quality has steadily increased since the 1960s, as research continues to reveal the impacts of urban pollution, particularly sewage and runoff, on the basin's watersheds and on Lake Tahoe itself (Goldman 1989). Most sources of pollution have long-lasting effects; in the 1970s, Heavenly Creek still carried 60 times the nutrient load of Ward Creek five years after sewage effluent was no longer released around Heavenly Creek (Strong 1984). To address these problems, the TRPA announced a set of environmental thresholds in 1982 that were designed to control nutrient loading and other damage to Lake Tahoe's natural resources (TRPA 1982).

In the 1980s and 1990s, numerous erosion control and stream restoration projects were undertaken. In 1988 the USDA Forest Service began restoring 11 square miles of the watershed at Blackwood Canyon on the west shore and an area at Cold Creek (Landauer 1995). Since the early 1980s, the Burton-Santini program has attempted to purchase and restore environmentally sensitive lands, especially wetlands and sites of significant erosion (Elliott-Fisk et al. 1997). In addition, at least 65 acres of disturbed wetlands had been restored by the Forest Service by 1996, and many other agencies were actively involved in similar efforts (Elliott-Fisk et al. 1997).

Several lakes and reservoirs in the basin were altered in the Urbanization Era; for instance, several dams were built at lake outlets. Spooner Lake, the second largest lake on the east shore, was drained and refilled in the winter of 1996 in an effort to enhance its suitability for trout and improve the

sport fishery. Water from lakes and reservoirs is available for fire suppression efforts and construction projects on National Forest System lands (Organic Act 1897), and is frequently used for such purposes in the Lake Tahoe basin (Derrig 1999), having unknown effects on biological integrity. However, other lentic systems are in the process of being restored, such as the large wet meadow near the mouth of Snow Creek (Insera 1999).

Synthesis of Historical Changes in Aquatic Ecosystems

The aquatic ecosystems of the Lake Tahoe basin have undergone a significant transformation since the arrival of Euroamerican settlers in the 1850s. As with other areas within the Sierra Nevada, the basin was viewed as an area rich in natural resources that were available for extraction. From 1860 until around 1900, uncontrolled sheep grazing virtually eliminated all grass and herbaceous cover throughout the basin, and rivers and creeks were diverted and degraded by logging, grazing, and development. Stocking Lake Tahoe and naturally fishless lakes with exotic fish began in the Comstock Era and continues today. As the mining and timber industries simultaneously declined toward the turn of the century, tourism developed into the base of the region's economy. Increasing settlement in the basin led to reduction in the area of marshes and an increase in the manipulation of aquatic ecosystems (e.g., through draining and damming). Stream channels were altered in various ways over time, with the greatest manipulations occurring during the Comstock and Urbanization eras. During the Urbanization Era, some aquatic ecosystems have been restored.

Implications for Biological Integrity

Alterations to aquatic ecosystems have almost certainly reduced biological integrity in the basin. Probable impacts to aquatic biota include competition from and predation by introduced species, disruption of movement patterns due to stream channel alterations, and habitat loss from increased sedimentation resulting from riparian grazing. Below, we address some specific examples of these phenomena and their likely consequences for biological integrity.

Probably the single greatest impact to biological integrity in the Lake Tahoe basin in recent years was the conversion of much of Rowland's Marsh to the Tahoe Keys. Marshes are among the most diverse and productive ecosystems in California (Kramer 1988) and in the basin, and their destruction represents a staggering blow to biodiversity. Very likely, all of the basin's waterfowl species used the marsh to some degree in the past (see Orr and Moffitt 1971), and all portions of the marsh provided habitat for countless other vertebrates, invertebrates, and plants. The loss and fragmentation of the basin's largest marsh, though not known to have directly caused the extirpation of any species, certainly engendered declines in biodiversity.

Other, more subtle, changes in biological integrity undoubtedly have resulted from the alteration of other lentic ecosystems in the basin. Pond draining has reduced local biological integrity by obliterating aquatic habitat, especially on the east and north sides of the basin, which historically contained relatively few lentic ecosystems. Introductions of exotic trout, bullfrogs (*Rana catesbeiana*), crayfish (*Pacifastacus leniusculus*), and opossum shrimp (*Mysis relicta*) have very likely negatively affected many native fish, amphibian, and invertebrate species through competition and predation. Declines in biological integrity in lotic ecosystems in the basin have been primarily caused by the construction of dams and diversions and the manipulation of riparian vegetation. Dams and diversions have doubtless had impacts on stream fish and invertebrates by preventing daily and seasonal movements and by facilitating increased human recreation (Moyle et al. 1996; Erman 1996). Sheep and cattle grazing in riparian areas has caused sedimentation, reduced vegetative cover, and accelerated the erosion of stream banks (Moyle et al. 1996). Sedimentation caused by grazing and timber harvest has probably adversely affected invertebrates (and likely other animals and plants) by reducing available habitat, inhibiting respiration, and obstructing feeding (Erman 1996).

Several human activities may cause further declines in biological integrity in aquatic ecosystems in the basin. Exotic species continue to negatively affect aquatic communities composed of native species (Jennings 1996; Moyle 1996; Moyle et al. 1996), particularly in lentic systems. Small dams represent a chronic, though perhaps minor, disturbance, sometimes altering flows and movements of biota (Moyle et al. 1996). Grazing may continue to degrade meadow systems and cause more damage to streams in the basin. Finally, several activities in and around lentic systems, such as heavy recreational use and removal of water for fire suppression or road construction, may become problems unless restricted.

Which aquatic ecosystems are potentially imperiled or vulnerable to future imperilment in the basin, and what is the state of knowledge about these ecosystems?

In general, conservation efforts have a dual focus: protect communities and ecosystems of concern and interest and protect species of greatest concern and interest (Noss and Cooperrider 1994). Terrestrial ecosystems of concern have been discussed earlier in this document; we identified 'focal' aquatic ecosystems for the Lake Tahoe basin to address aquatic ecosystems of concern. Ecosystems of concern are generally ones that are rare, that have been degraded by human activity, or that are poorly protected. Our focal aquatic ecosystems represent ecosystems we determined to be potentially imperiled or vulnerable to future imperilment according to their rarity, degree of disturbance, and level of existing protection. Aquatic ecosystems with particularly high ecological value are addressed in Issue 6.

Methods Used to Assess Aquatic Ecosystems

We used Moyle's (1996) aquatic habitat rating approach to determine the status of aquatic ecosystems in the Lake Tahoe basin. Moyle (1996) rated the status of each aquatic type for the entire Sierra Nevada by three criteria: rarity, degree of disturbance, and level of existing protection (Table 5-26). The overall status, based on the sum of the ratings for each criterion, was interpreted as one of four conditions: secure, special concern, threatened, or imperiled (Table 5-27).

The assessment of lotic types was based on empirical data on stream habitat and watershed characteristics within the basin. Data on channel characteristics were gathered by the U.S. Forest Service (unpublished data) from 1989 through 1997 using methods developed by Hawkins et al. (1993), Montgomery and Buffington (1993), and Rosgen (1995). Data on the characteristics of the 36 streams classified in the basin were useful for assessing of the condition of watersheds throughout the basin. The assessment of lentic types was based on digital USGS 1:24,000 topographic feature maps, which displayed the distribution of lentic units, considerations of geology for identification of potential sites for some types, and qualitative local knowledge.

The status of aquatic types was evaluated by orientation (north, south, east, and west) within the basin, as well as across the entire basin (Figure 5-24; Appendix B). The linear and circular landscape of the basin (a thin belt of land between Lake Tahoe and the crests), the diversity of climatic conditions, and the variation in levels of past and present disturbance within the basin has created a different set of conservation concerns and priorities for each orientation. A level of confidence in the ratings was assigned to reflect the state of knowledge regarding the three criteria for each aquatic type (Appendix B).

We ranked lentic and lotic types in order of decreasing concern based on the average of the status values (the sum of values across the three criteria) across all orientations (Table 5-28). The three lotic types of highest concern were mainstem rivers, meadow streams, and forest streams. The three lentic types of highest concern were marshes, fens, and alpine lake/pond with native fish. Across all aquatic types, only mainstem rivers received the rating of highest concern, "imperiled." This rating highlights the rarity and vulnerability of the Upper Truckee River. No other lotic types received the top two concern ratings. A large proportion of types (29 percent) were rated as threatened, the second highest level of concern, and all of these types were lentic types. Nearly 50 percent of the types were rated as of

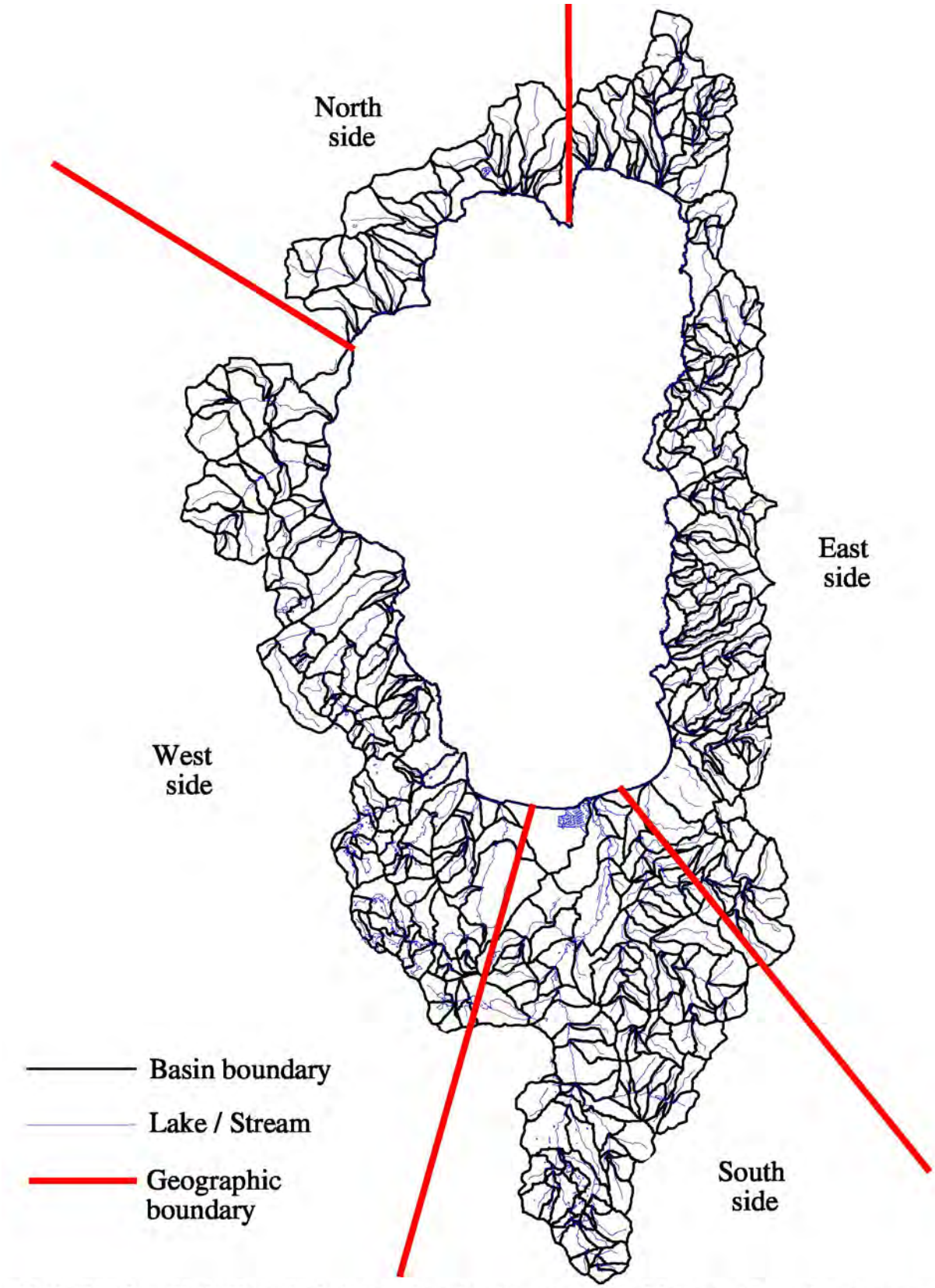


Figure 5-24—Division of the Lake Tahoe basin into four orientations for assessment of the status of aquatic ecosystems.

Table 5-26—Aquatic habitat rating criteria (adapted from Moyle 1996).

Rating	Value	Description
Rarity:		
Absent	0	Does not exist in a particular basin orientation (N,E,S,W)
Unique	1	Only one or two examples exist
Rare	2	Probably only 2-5 examples exist, or a formerly common habitat type in which most examples have been irreversibly altered
Unusual	3	Scattered or infrequent examples exist
Common	4	Examples easy to find
Widespread	5	A major existing habitat type
Disturbance:		
Very high	0	All known examples highly disturbed, not recoverable
High	1	All known examples highly disturbed/altered but some are recoverable to a defined desirable state
Moderate to high	2	All known examples moderately to highly disturbed or altered but most are recoverable
Moderate	3	Most examples disturbed but some relatively undisturbed examples exist, or all known examples moderately to lightly disturbed (recoverable with minimal effort)
Moderate to low	4	Fairly even mixture of disturbed and relatively undisturbed areas or all known examples lightly disturbed
Low	5	Most examples in good condition (relatively undisturbed)
Existing protection:		
No protection	1	No known examples in protected areas (e.g., National Park, wilderness area, research natural area)
Limited protection	2	No known examples in protected areas; mostly on public land; may be just one or two protected examples
Partial protection	3	3-5 protected examples exist but most unprotected or a rare habitat type with partial protection
Moderately secure	4	Several protected examples, many with de facto protection because of such factors as location or a rare habitat type with de facto protection
Secure	5	Many examples in protected areas or with de facto protection or a rare habitat type in protected area

Table 5-27—Status rating system for aquatic ecosystem types (adapted from Moyle 1996).

Status	Sum of ratings	Description
Imperiled	1 to 3	Extirpated, likely to be extirpated, or at risk of significant loss of integrity if protective action is not taken
Threatened	4 to 7	Rapidly declining in abundance and quality
Special concern	8 to 11	Declining in abundance and quality, but many examples still exist or a habitat type with only one or two examples in existence
Secure	12 to 15	Widespread, with many examples in good condition

Table 5-28—Relative ranking of concern from high to low for lotic and lentic aquatic types in the Lake Tahoe basin.

Aquatic type	Average status score across all orientations	Basin-wide status
Lotic types:		
Mainstem river	2.25	Imperiled
Meadow stream	7.50	Special concern
Forest stream	8.50	Special concern
Spring	9.25	Special concern
Stream with trout	10.00	Special concern
Alpine stream	10.48	Special concern
Alpine snowmelt stream	11.25	Secure
Trout headwater stream	11.50	Secure
Conifer forest snowmelt stream	12.00	Secure
Lentic types:		
Marsh	5.00	Threatened
Fen	5.80	Threatened
Alpine lake/pond with fish	6.25	Threatened
Sphagnum bog	6.90	Threatened
Lake Tahoe	7.00	Threatened
Alpine lake/pond without fish	8.40	Special concern
Mountain pond	9.25	Special concern
Wet meadow	10.00	Special concern

Table 5-29—Average values for rarity, disturbance, and protection across all aquatic ecosystem types in the Lake Tahoe basin.

Evaluation criterion	Lentic types (n = 8)	Lotic types (n = 9)	All types
Rarity	1.75	3.06	2.53
Disturbance	2.38	2.81	2.64
Protection	3.13	3.32	3.24
Sum	7.25	9.19	8.42

special concern, the third highest level of concern, and most of these types were lotic. Finally, three aquatic types (18 percent) were rated as secure, the lowest level of concern, and all of these were lotic types.

The relative contributions of the three criteria--rarity, disturbance, and level of protection--to overall levels of concern were assessed (Table 5-29). Rarity was the greatest contributor to levels of concern for lentic types, then disturbance, and finally the level of protection. The three evaluation criteria contributed nearly equally to the overall status of lotic types in the basin. The level of concern for lotic types was nearly 30 percent greater than for lentic types, based on the sum of average values for all three criteria. Across all aquatic types, the same pattern emerged as for lentic types: rarity was the greatest contributor, followed by disturbance and protection.

We assessed the degree to which aquatic types were of concern by orientation in the basin. Aquatic ecosystems on the east side of the basin were of greatest concern, followed by the north, south, and west sides (Figure 5-25). Aquatic ecosystems were rarest on the north and east sides, and most disturbed and most poorly protected on the east side. Aquatic ecosystems on the west side of the basin were most common, least disturbed, and best protected. Although the south side of the basin includes the largest disturbed area (South Lake Tahoe), it also contains a large, relatively undisturbed region of the Upper Truckee watershed. Aquatic ecosystems were moderately disturbed overall on the south side. Across all basin orientations, aquatic ecosystems on the east side were of greatest concern (total score of 6.7), followed by north side ecosystems (7.6), south side ecosystems (8.5), and west side ecosystems (10.4).

The results of our analysis were consistent with historical patterns of land use in the basin, with the north and east sides being most affected and the west side being the least affected by human land use. The north and east sides of the basin were most affected by heavy logging during the Comstock Era and a variety of other human uses because of their proximity to more populated areas in the Carson Valley. In contrast, the west side of the basin had the most secure and least threatened ecosystems because of limited access to upper watershed areas, steep terrain, and the protection granted by the establishment of Desolation Wilderness in 1969. The south side of the basin has been subjected to a level of disturbance intermediate between that of the west and east sides because areas near the lake have been heavily affected by development, but most of the watershed area remains relatively undisturbed.

Finally, we examined the level of concern for aquatic types in the basin relative to the Sierra Nevada as a whole. Aquatic ecosystems appear, on average, to be at greater risk in the Lake Tahoe basin compared to the Sierra Nevada as a whole (Figure 5-26). A greater proportion of the basin's aquatic types was considered "imperiled" or "threatened" than was determined by Moyle (1996) for the same aquatic types across the Great Basin Province or the Sacramento-San Joaquin Province. The apparent greater imperilment of aquatic types in the Lake Tahoe basin compared to the provinces as a whole could be attributed to a couple of factors. First,

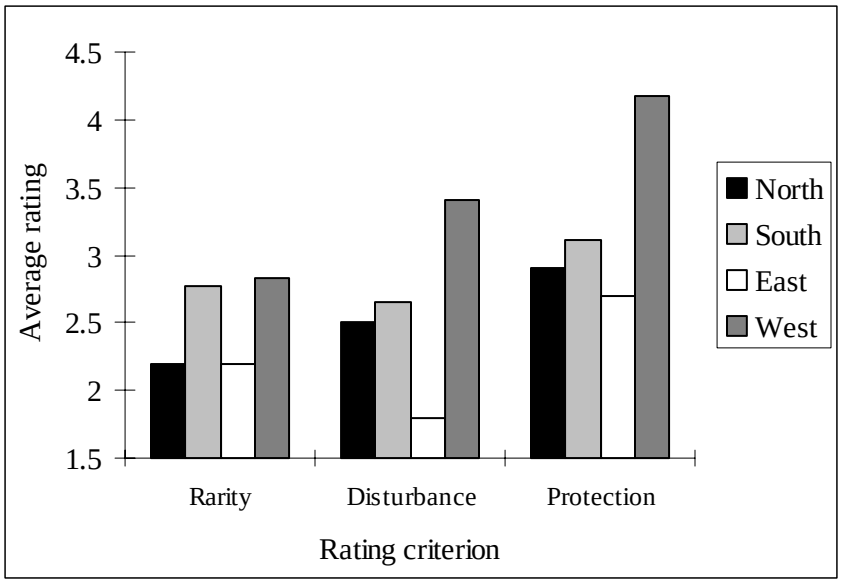


Figure 5-25—Average ratings for rarity, disturbance, and protection of aquatic ecosystem types in the Lake Tahoe basin's four orientations.

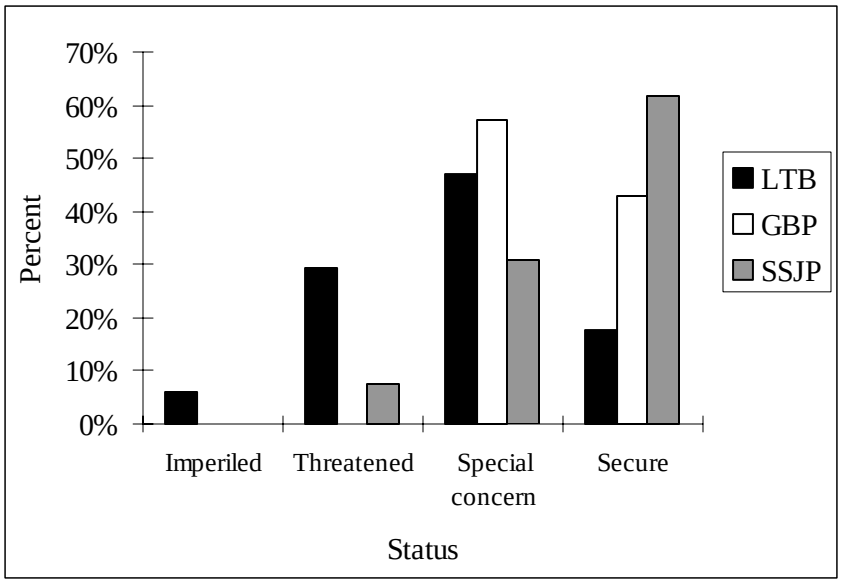


Figure 5-26—Status of aquatic habitat types in the Lake Tahoe basin (LTB), Great Basin Province (GBP) (Moyle 1996), and Sacramento-San Joaquin Province (SSJP) (Moyle 1996).

perhaps aquatic types in the basin are truly at greater risk of degradation or loss of biological integrity than they are in other locations in the Sierra Nevada. Second, smaller scale applications of this approach might yield a more sensitive assessment of aquatic ecosystem status. And third, perhaps we rated the status of types in the basin more conservatively than did Moyle (1996), erring on the side of higher concern. We suggest that the difference results from a combination of greater sensitivity of the approach at smaller scales and a truly greater risk to aquatic types in the basin. At a small geographic scale such as the basin, there are naturally fewer representatives of each aquatic ecosystem type. In addition, the relatively high diversity of types in the basin is expected to be accompanied by increased overall rarity (Brown 1995). Disturbance was the next highest contributor, after rarity, to the high rating of concern associated with aquatic types in the basin, particularly lentic types. The basin is one of the most highly visited locations in the Sierra Nevada, in addition to having a large resident population relative to the rest of the Sierra Nevada. The high human density and high value of aquatic environments as water sources and recreational environments have resulted in significant direct and indirect pressure on aquatic environments in the basin. These pressures are reflected in the disturbance ratings. We are relatively confident that aquatic ecosystems, particularly lentic types, are more imperiled in the basin than in the Sierra Nevada as a whole as a result of their rarity and their level of disturbance.

Focal Aquatic Ecosystems

We identified "focal" aquatic ecosystems to assist in focusing conservation, monitoring, and research efforts on the aquatic ecosystems of greatest concern. To identify focal aquatic ecosystems, we used the status ratings for each aquatic ecosystem type in each orientation (Appendix B). We did not identify specific aquatic ecosystems of cultural importance, as we did for species and populations (Issue 7, below) because we considered all aquatic ecosystems in the basin important to humans for subsistence and recreation. We used a hierarchical cluster analysis (SPSS 1993) on the 17 ecosystem types to identify focal aquatic ecosystems. The cluster analysis was based on ordinal ratings for rarity, disturbance, and level of protection for each type in each of the four orientations (Figure 5-27). For types not occurring in a particular orientation, we assigned a rarity value of "0" and disturbance and protection values equal to the average value for the orientations in which the type did occur. We performed the cluster analysis

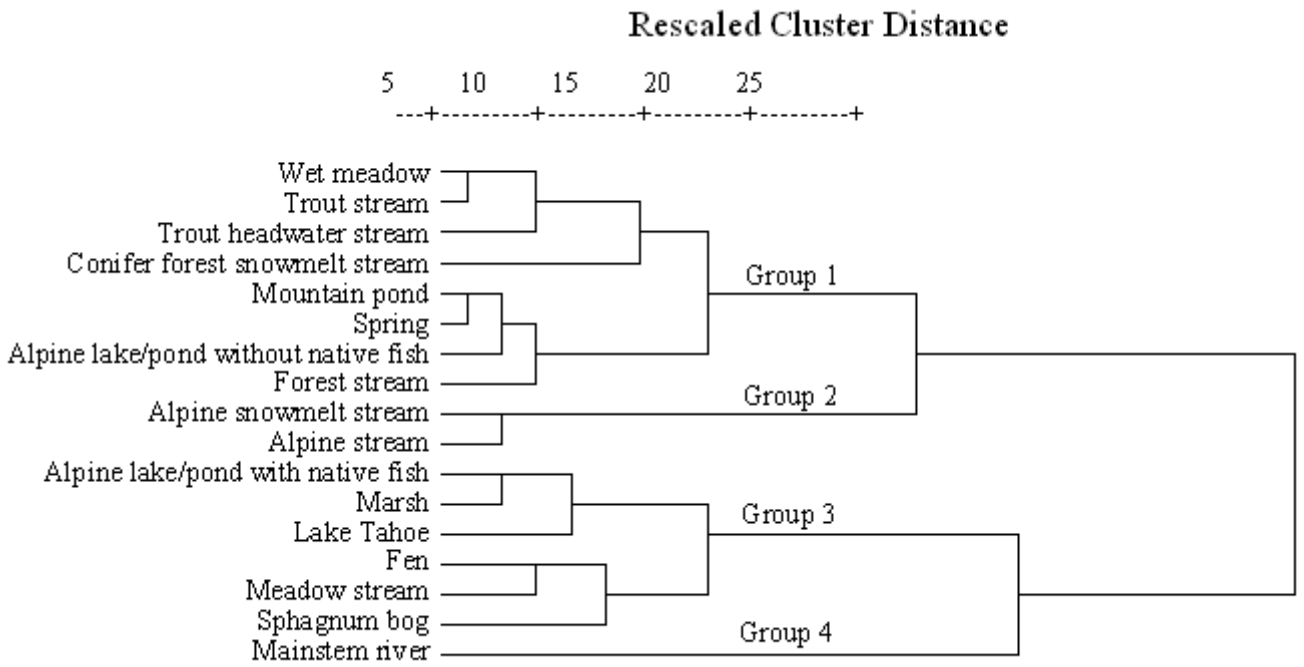


Figure 5-27—Dendrogram resulting from a hierarchical cluster analysis of 17 aquatic ecosystem types in the Lake Tahoe basin. Clustering was based on 12 variables—rarity, disturbance, and level of protection (Moyle 1996)—in each of four orientations in the basin: north, south, east, and west.

using between-groups linkage and the squared Euclidean distance measure (SPSS 1993).

We recognized four groups in the dendrogram resulting from the cluster analysis (Figure 5-27). Group 4 was determined to be of highest concern and consisted of one type (mainstem rivers). Members of Group 4 were present in a single orientation and were uncommon and highly disturbed (Table 5-30). Group 3 was determined to be of the second highest concern and consisted of six types, including meadow streams and most lentic types. Members of Group 3 were uncommon and disturbed in all orientations and were moderately well protected (Table 5-30). Group 1 was determined to be of the third highest concern and consisted of eight types, including wet meadows, mountain ponds, alpine lakes without native fish, and several lotic types. Members of Group 1 were relatively common, moderately disturbed, and moderately well-protected in all orientations (Table 5-30). Group 2 was determined to be of the lowest concern and consisted of two types: alpine snowmelt streams and alpine streams. Members of Group 2 were absent in the north and disturbed in the east, while being generally common, undisturbed, and well protected everywhere else (Table 5-30).

We identified the seven aquatic types in the two groups of highest concern (groups 3 and 4) as focal ecosystems (Table 5-31). In addition, we examined the level of concern by basin orientation for the remaining types, and included five additional types as focal in particular orientations (Table 5-31). Specifically, springs, forest streams, mountain ponds, and alpine lakes without native fish were uncommon and highly disturbed on the north and east sides of the basin, even though they were in the third lowest concern group over all orientations (Appendix B). Alpine streams were rare and highly disturbed on the east side, even though they were in the lowest concern group over all orientations (Appendix B).

Summary

Many aquatic ecosystems were determined to be of concern in the Lake Tahoe basin. In general, lentic types were of greater concern in the basin than lotic types. For lentic types and across all types, rarity was the greatest contributor to the level of concern, followed by disturbance and protection. For lotic types, the three criteria contributed similarly to the level of concern. Aquatic types were rarest on the north and east sides of the basin, with types on the east side being the most disturbed and poorly protected. Aquatic types on the west side of the basin were most common, least disturbed, and best protected. Further, aquatic ecosystems appear to be of greater concern in the Lake Tahoe basin than throughout the entire Sierra Nevada. This pattern is most likely due to the concentration of historic and present day patterns of human use and occupation of the Lake Tahoe basin relative to the rest of the Sierra Nevada. The integrity of aquatic ecosystems, as well as their abundance and distribution, have been shown to be extensively affected by human disturbance; many are in need of protection and restoration.

Accounts of focal aquatic ecosystems were intended to provide a synopsis of the state of knowledge for each ecosystem as a mechanism to assist in furthering appropriate activities in conservation, monitoring, and research. We developed two such accounts, for sphagnum bogs and fens and for the Upper Truckee River. If these accounts prove useful, we suggest that accounts be developed for the remaining focal aquatic ecosystems identified in this issue. We addressed a consistent set of topics in each account (Table 5-32). The accounts are in Appendix C.

What data gaps were revealed in the process of assessing aquatic ecosystems?

In assessing aquatic ecosystems in the basin, we discovered significant data gaps that hindered our evaluation. By identifying these data gaps, we hope to encourage inventory, monitoring, and research efforts that will provide these valuable data.

The lack of definitive information regarding the aquatic ecosystem types occurring in the basin was an obstacle to our assessment. Lotic and lentic types in the basin have not been extensively cataloged, and in several cases we relied on local knowledge of the basin to determine where certain

Table 5-30—Average rarity, disturbance, and protection for four groups resulting from a cluster analysis on 17 aquatic ecosystem types in the Lake Tahoe basin.

Cluster group	n	Average rarity	Average disturbance	Average protection	Average total rank	Level of concern
1	8	3.8	2.8	3.3	3.3	3rd highest
2	2	2.9	3.7	4.3	3.6	Lowest
3	6	1.0	2.2	3.2	2.1	2nd highest
4	1	0.3	1.0	1.0	0.2	Highest

Table 5-31—Focal aquatic ecosystems in the Lake Tahoe basin.

Focal aquatic ecosystem type	Cluster group	Level of concern	Priority orientation(s)
Mainstem river	4	highest	all
Alpine lake/pond with native fish	3	2nd highest	all
Lake Tahoe	3	2nd highest	-
Fen	3	2nd highest	all
Meadow stream	3	2nd highest	all
Sphagnum bog	3	2nd highest	all
Marsh	3	2nd highest	all
Spring	1	3rd highest	north, east
Forest stream	1	3rd highest	north, east
Mountain pond	1	3rd highest	north, east
Alpine lake/pond without native fish	1	3rd highest	north, east
Alpine stream	2	lowest	east

Table 5-32—General outline for aquatic ecosystem and Ecologically Significant Area descriptive accounts.

General
- Distribution in California, Nevada, and the basin
- Source of data for the basin
- Method of inventory

Ecology
- Key physical and biological characteristics (components, structures, processes)
- Contribution to biological diversity in the basin
- Geology, hydrology, soils
- Successional stages
- Response to natural disturbance
- Research needs

Effects of human activities (historic/current/anticipated)
- Impacts of activities
- Current management
- Management objectives
- Response to management scenarios

Conservation
- Current conservation
- Conservation objectives
- Potential conservation measures and priorities

aquatic ecosystem types occurred. For example, fens have not been documented and may not occur in the basin. For other types, such as marshes and wet meadows, it is likely that we have not fully inventoried their occurrence within the basin (USDA 1990). Incomplete inventories resulted in an incomplete accounting of types, and some sites valuable to overall ecological diversity may have been overlooked.

Similarly, our identification of focal aquatic ecosystems would have been improved by better information on the rarity and degree of disturbance of existing aquatic types. The lack of a thorough inventory of types introduced some uncertainty into our assessments of status, particularly in regard to rarity and disturbance. Our disturbance ratings, like Moyle's (1996), were based on local knowledge of the types and locations of disturbance and their relative impact on aquatic systems. Different disturbance agents cause different responses from and impacts to biological diversity. An assessment of disturbance factors acting on aquatic types requires better information about the status of disturbances, such as exotic species, recreation, grazing, timber harvest, and roads, and their interactions with populations of native species. This vital information, ideally based on field assessments, would greatly improve our ability to identify focal aquatic ecosystems and ultimately to develop more specific monitoring and conservation strategies.

What conservation, monitoring, and research activities are most appropriate for the focal aquatic ecosystems identified?

Appropriate monitoring, conservation, and research activities will vary among focal aquatic ecosystems based on the feasible alternatives for conservation, the level of interest shown by managers and the public, and the nature of the aquatic ecosystem. Here, we address general considerations and some specific opportunities for conservation, monitoring, and research regarding focal aquatic ecosystems and discuss basic inventory data needed to design these activities.

Prerequisite Inventory Data

The first step in monitoring and conserving the 12 focal aquatic types is to have an accurate inventory of their number and locations within the basin. With the exception of two aquatic ecosystem types (mainstem river and Lake Tahoe), information about the number and location of types is incomplete and imprecise. Distinguishing among types is an essential step in defining populations that then can be monitored and conserved meaningfully as a group. In addition, a basic inventory describing the number and location of types and some description of their level and type of disturbance is needed to facilitate and prioritize restoration planning.

Inventories can be accomplished in an efficient and cost-effective manner. Existing locations could be used to develop predictive models of environmental features with a high probability of association with these types. Surveys then could be conducted to confirm or reject the prediction of aquatic ecosystem occurrence. This approach would represent a relatively quantitative method of inventorying these types in the basin. As for the more common types, the inventory would consist of classifying the entire population of aquatic units into particular types. An adequately thorough inventory of all aquatic types within the basin probably would not require more than three individuals working for six months, using maps, aerial photo interpretation, and field verification.

Conservation

Conservation measures are an essential component of any strategy to maintain or improve biological integrity. The development of an Aquatic Conservation Strategy (ACS) for conserving aquatic systems throughout larger landscapes has been shown to be an effective mechanism for focusing efforts on priority actions (e.g., FEMAT 1993). Aquatic conservation strategies are essentially aquatic management plans. An ACS was developed for the Northwest Forest Plan (FEMAT 1993), and the USFS is currently developing one for the National

Forests in the Sierra Nevada. The development of an ACS for the basin would serve to bring various interests in the basin together to determine how best to maintain and restore biological integrity and to achieve ecological sustainability for aquatic ecosystems. This assessment has identified aquatic ecosystems that are most at risk or that have been degraded and need to be addressed directly in such a strategy. An ACS for the basin could contain detailed information, including commitments as to the nature, timing, location, and desired outcomes of management and conservation actions. Below we identify some of the key emphasis areas of consideration for inclusion in an ACS for the basin. We do not address conservation considerations for Lake Tahoe here, as they are covered in Chapter 4.

We identified three general types of conservation actions: awareness and education, measures to protect biological integrity, and restoration strategies. Awareness and education can be achieved in a variety of ways, including (but not limited to) concerns highlighted in such publications as this assessment, workshops, campfire talks, web sites, newspaper and radio media, school programs, research symposia, and public involvement in monitoring and conservation efforts. Measures to protect biological integrity include the implementation of actions intended to safeguard aquatic ecosystems or to mitigate impacts to them. Restoration options include measures to improve the quality or quantity of an aquatic ecosystem, including improving physical and biological conditions, restoring natural processes (e.g., fire and flooding), reducing human disturbances, and increasing the number of aquatic units (where feasible). Restoration activities would be warranted only when degradation of an aquatic unit is noted. Conservation of biological integrity will be most successful if all three types of conservation actions are employed.

Awareness and Education—Awareness and education efforts on behalf of aquatic ecosystems would likely be a very effective conservation activity. People value aquatic ecosystems for their aesthetic and recreational appeal. Key messages of an awareness and education effort could be the high ecological and cultural value of aquatic ecosystems, as well as the fragility and vulnerability of these systems, in the basin. An effective and mutually beneficial approach to awareness and education could be the involvement of the public in inventory, monitoring, conservation, and restoration efforts.

Measures to Protect and Restore Biological Integrity—The following types of measures would contribute toward maintaining, protecting, and restoring the biological integrity of focal aquatic ecosystems in the basin. Overall, needs for conservation are greatest for lentic types; however, needs for conservation are also significant for lotic types. The following is a short list of effective measures for consideration in inclusion in an ACS developed by management agencies; many other measures may be appropriate and could be considered for an ACS.

Lentic Types

1. Identifying specific concerns for focal lentic ecosystems by orientation, as well as specifying acceptable and unacceptable activities and management actions by lentic type and orientation. Restoration potential and recommendations for all focal lentic types could be analyzed as part of the ACS.
2. Limiting biological and physical manipulations of lentic types on the north and east sides to conservation and restoration-oriented activities.
3. Protecting and restoring the rarest of the focal lentic types, including sphagnum bogs, fens, marshes, and springs, in all orientations.
4. Minimizing disturbance in all focal lentic types. In general, the most common and powerful agents of disturbance in lentic types in the basin are exotic species, grazing, habitat loss, water diversions, and recreation pressure. A variety of less detrimental manipulations also may pose risks, such as siphoning and dams.
5. Categorizing and describing management activities that have positive, neutral, and negative effects for each focal type.
6. Prioritizing restoration efforts to address the most disturbed units that have the greatest potential to recover. The most disturbed lentic types (disturbance ranking $\leq$ 2) were marshes, fens, and alpine lakes with native fish.

7. Evaluating focal lentic types for the value and potential of eradicating nonnative species. For example, small populations of bullfrogs presently occur in a number of lakes that could serve as points of departure for the further spread of populations within the basin (Manley and Schlesinger, in preparation).
8. Removing nonnative species from focal lentic types where feasible. This includes removing nonnative trout from some units. Fish stocking is an action that has created much debate throughout the Sierra Nevada and elsewhere. Stocking nonnative trout has detrimental effects on many biota, including entire assemblages of aquatic biota (Jennings 1996; Moyle et al. 1996). However, it is an action that has strong public support because of the recreation benefits it confers. Some units of each focal lentic type in each orientation could be made exempt from fish stocking, thereby redirecting them toward other cultural values. The number and location of lentic units that are not stocked could be determined based on considerations of current uses, ability to eradicate existing nonnative trout, current level of biological integrity, and value to focal species of ecological concern. In those units selected for eradication of nonnative fish, other nonnative species also could be removed. Perhaps education could generate interest in a stocking program for native fish species. Specific recommendations on the restoration of populations of native species are addressed in Issue 7.
9. Protecting and restoring marshes within the basin—this is perhaps one of the most influential conservation efforts that could be undertaken on behalf of lentic biological integrity. Creation of the Tahoe Keys not only reduced the area of Rowland's marsh but also created a number of ecological problems in the remaining aquatic environments in and around the Keys. Mitigation measures are limited but could involve eradicating or controlling populations of such exotic species as bullfrogs, fish, and Eurasian watermilfoil (*Myriophyllum spicatum*). Improving or restoring hydrologic function in the remaining portions of Rowland's marsh (and also the Meeks wetland on the west shore) is a topic of much discussion and research by local agencies and universities and we do not address it here, other than to emphasize the importance of such restoration efforts to biological integrity in the basin.

Lotic Types

1. Limiting biological and physical manipulations of all lotic types on the north and east sides to conservation and restoration oriented activities.
2. Protecting the rarest of the focal lentic types, including the mainstem river, meadow streams, and alpine streams, by limiting biological and physical manipulations in all basin orientations to conservation and restoration oriented activities. A specific management plan for the Upper Truckee River (the mainstem river) would be a significant contribution to the ACS.
3. Directing restoration efforts at the most disturbed units that have the potential to recover. The most disturbed lotic types (disturbance ranking $\leq$ 3) were mainstem river, meadow streams, and streams with trout. These types are good candidates for priority restoration; restoration potential and recommendations for all focal lotic types could be analyzed as part of the ACS. In general, the primary sources of degradation in lotic types are dams, diversions, channelization, unmaintained dirt roads, and grazing. Dams and diversions serve to change the magnitude and frequency of flow and the hydrologic function of streams, while the remaining disturbances primarily increase sedimentation and can change channel geomorphology. Significant efforts by the USDA Forest Service already are underway to reduce the number of dirt roads in the

basin, with the intent of decreasing sedimentation loads within streams. Grazing impacts on focal lotic types need to be defined more fully, and mitigation or protective measures need to be identified.

4. Developing conservation measures for wet meadows. Although wet meadows are not a focal type, the integrity of these lentic types significantly influences the integrity of the lotic units with which they are associated. Wet meadows are subject to a number of disturbance factors, including grazing, mountain biking, and off-road vehicle use.
5. Evaluating and prioritizing the value of and potential for eradicating nonnative species from all focal lotic types.

Monitoring

Monitoring designed to describe the status of and changes in the integrity of aquatic ecosystems would provide a wealth of information about their current conditions, how their conditions are changing over time, and basic relationships between their conditions and the changing environment in which they occur. Developing a monitoring scheme entails identifying attributes to describe conditions and designing and implementing data collection and analysis. Monitoring attributes can consist of direct measures of condition as well as indirect measures that serve as indicators of integrity. Indicators can provide a strong signal about conditions with relatively few attributes. The notion of indicators has a long history in the ecological literature (see Griffith and Hunsaker 1994), but successes in using indicators are few. It appears worthwhile to attempt to identify indicators and to monitor their conditions on a trial basis, but it is premature to rely entirely on indicators before their value as a signal is confirmed (USDA Committee of Scientists 1999).

The development of a monitoring strategy would require a more careful evaluation of the potential attributes (both direct and indirect measures), an examination of the questions the attributes would address, and an evaluation of design options. Here, we make some general recommendations as to attributes that would directly measure aquatic ecosystem conditions. First, the monitoring program would need to determine whether all units of a given aquatic type need to be monitored (i.e., a census) or whether a sample can be monitored to represent the condition of all units. More imperiled aquatic types might warrant a census, whereas a sample might suffice for less imperiled aquatic types.

A strong approach to monitoring consists of a balance of physical, biological, and disturbance attributes for each unit selected for monitoring. First we address potential attributes for lentic types. We do not intend that these attributes to apply to Lake Tahoe (refer to Chapter 4 for monitoring considerations regarding Lake Tahoe). Physical attributes consist of abiotic conditions, such as surface area, volume, water chemistry, substrate, and cover. Biological attributes could include occlusion by aquatic vegetation, the relative abundance of various types of aquatic vegetation (e.g., submergent, emergent, and floating), and the presence of water-dependent vertebrate species, select indicator macroinvertebrates, and nonnative species. The high productivity of some lentic types, such as marshes, may justify a more thorough account of biological attributes, such as the relative abundance of taxa, to assess the extent of their contributions to biological diversity over time. Disturbance attributes could include intensity of grazing, presence of dams and diversions, the occurrence of draining, stocking, and pollution events, attributes of fishing and other recreational pressures, timber harvest, fire (prescribed, natural, and accidental), pollutants, and wholesale transformations of conditions.

Appropriate attributes to monitor for lotic types differ somewhat from those identified for lentic types. Physical attributes for lotic types could include changes in channel morphology, sediment transport, and deposition dynamics, water chemistry, temperature, and flow volume. Biological attributes would resemble those of lentic types, including the presence of aquatic vegetation of various types, water-dependent vertebrate species, and select indicator macroinvertebrates. Disturbance attributes for lotic types could include the occurrence of channel alterations and pollution events and attributes of fishing and other recreational pressures.

In addition to monitoring directed toward tracking trends in the biological integrity of focal aquatic types, it would be prudent to track the fate of nonfocal aquatic types, perhaps at a lower level of investment. We identified aquatic types of greatest concern, but few of the remaining types are secure, and their status could decline. Monitoring nonfocal types could be restricted to basic physical attributes, a few biological attributes, and some simple measures of disturbance. Sample sizes and frequency of visits to nonfocal types could be limited to reduce the level of investment in monitoring. A more detailed evaluation of appropriate attributes for all types would need to be conducted to make final selections for monitoring.

Finally, monitoring the success of protective and restoration measures would be highly beneficial. In the context of monitoring, this entails tracking the conditions of individual sites. A complementary research component could entail sampling a number of sites representative of all treatments of a given type and evaluating the treatment's overall effectiveness.

Research Opportunities

The development of an ACS by management agencies will require the involvement of researchers and managers, and it will help to identify priority research opportunities. In general, research should be targeted toward the most crippling of information gaps. In addition, research questions related to the influence of various management actions, such as prescribed fire and timber management, particularly where they appear to have opposing effects on two or more desired outcomes, are a high priority investment in terms of investigating cause-effect relationships.

A few specific research opportunities surfaced in the course of assessing aquatic ecosystem conditions in the basin. The research opportunities identified here represent some activities that could contribute substantially to the conservation of aquatic ecosystems in the basin. They are not intended to represent a comprehensive list of research needs and opportunities.

1. We need to determine the influence of various types of disturbance (e.g., grazing, roads, and prescribed fire) on the biological integrity of lentic and lotic ecosystem types.
2. We need to understand the potential threat of nonnative trout to the successful reintroduction of mountain yellow-legged frogs and native fish to lotic and lentic units in the basin.
3. We need to develop reference conditions for biological diversity in lentic and lotic types.
4. We need to develop and test indicators for monitoring the biological integrity of aquatic ecosystem types.
5. We need to evaluate the effectiveness of various management and conservation measures.
6. Modeling potential "habitat" for rare aquatic types such as bogs, fens, and springs would be beneficial.
7. We need to assess the relative effectiveness of various control measures for Eurasian watermilfoil.
8. Modeling potential habitat for each amphibian species would be beneficial.

Issue 6: The Need to Understand the Identity and Condition of Ecologically Significant Areas in the Basin

With contributions from J. Shane Romsos

Conservation efforts often consist of a dual approach: (1) protect communities and ecosystems of greatest concern and interest and (2) protect species of greatest concern and interest (Noss and Cooperrider 1994). A few criteria have been frequently recommended in the evaluation of priorities for the conservation of communities and ecosystems (Margules and Usher 1981; Kirkpatrick 1983; Soule and Simberloff 1986; Margules et al. 1988; Noss and Cooperrider 1994). These commonly applied criteria, listed here, represent a mix of high ecological value and vulnerability to loss.

- Rarity—communities and ecosystems that naturally occur infrequently or that are uncommon in a given geographic area;

- Area—sites where a community or ecosystem occupies an unusually large area, such as Lake Tahoe;
- Naturalness—sites where a community or ecosystem type has experienced minimal human disturbance, thus having a full complement of native species, intact natural disturbance regimes, and no or few exotic species;
- Representativeness—a suite of sites that together represent a full assortment of community types characteristic of a geographic area or areas that represent the diversity that exists at a number of levels of organization, such as genes, individuals, species, habitats, ecosystems, and landscapes;
- Biological diversity—sites that are extraordinarily high in biological diversity based on native species richness, endemism, and community diversity; and
- Threat of impacts from human activity—communities in imminent danger because of degradation of biological integrity or wholesale loss of area from harvest, development, or recreation.

We identified some Ecologically Significant Areas (ESAs) in the Lake Tahoe basin based on three of the criteria listed above: minimal human disturbance (naturalness), rarity, and biological diversity. The remaining criteria would have required time and resources beyond the scope of this assessment, but would be valuable to apply to the identification of ESAs in the basin. Our purpose in identifying ESAs was to highlight "hotspots" of diversity, rarity, or uniqueness at the organizational level of communities and ecosystems. In some cases, the species associated with ESAs may also be rare or unique, but they were not the impetus for ESA designation. The location and habitat associations of potentially imperiled, vulnerable, or culturally important species are discussed in Issue 7, where the organizational level of species and populations is addressed. Here, we address the uniqueness of community and ecosystem types, both in terms of their physical conditions and biological assemblages.

This issue addresses the following questions:

What are some of the most ecologically unique and biologically intact environments and areas in the basin, and what is the state of knowledge about these areas?

What data gaps were revealed in the process of assessing ecologically significant areas?

What monitoring, conservation, and research activities are most appropriate for the ecologically significant areas identified?

What are some of the most ecologically unique and biologically intact environments and areas in the basin, and what is the state of knowledge about these areas?

We used three specific criteria to identify ESAs in the Tahoe basin: minimal human disturbance, rarity, and biological diversity. We used a variety of methods to identify ESAs, including simple mapping of known ecosystems and complex predictive modeling exercises. Many of the ESAs coincided with Millar et al. (1996) Significant Natural Areas (SNAs) identified within the basin for the Sierra Nevada Ecosystem Project. Discrepancies occurred if the SNAs had been based on nonecological criteria or single-species considerations.

We identified nine types of ESAs (Table 5-33). They represent a range of community and ecosystem types and conditions. The ESAs we identified are not an exhaustive accounting of rare, diverse, and intact communities but are a starting point for conservation. Additional considerations, analyses, and data would lead to identifying a more thorough accounting of ESAs in the basin. The nine types we identified are described in more detail below. The maps we provide on the location and extent of ESAs are approximations based on available information, and their use should be informed by the data limitations described later in this issue.

We used a variety of techniques to identify the location and extent of our nine ESAs within the basin; however, we relied most heavily on remotely sensed data and continuous data coverages ("layers")

Table 5-33—Ecologically Significant Areas (ESAs) in the Lake Tahoe basin and criteria for their identification.

ESA	Minimal human disturbance	Rarity	Biological diversity
Old forests	X		
Bogs and fens		X	
Marshes		X	X
Deep-water plant beds		X	
Cushion plant		X	
Aspen		X	X
Lentic riparian			X
Lotic riparian			X
Community diversity			X

derived from data available on GIS. Continuous data coverages and GIS analysis tools are now commonly used to identify areas for conservation (e.g., Noss and Cooperrider 1994, Davis and Stoms 1996, Davis et al. 1996). GIS allows an investigator to layer different thematic maps, such as vegetation, soil, riparian corridors, and existing reserves of a region of interest to identify high priority areas for conservation.

Minimally Disturbed Ecosystems

The Lake Tahoe basin has a long history of human occupancy (see Chapter 2); as such, very few ecosystems in the basin can be considered undisturbed by humans. We identified a single ecosystem type, the old forest ecosystem, that has been minimally disturbed. Other examples of minimally disturbed ecosystems may occur in the basin and could be explored as a next step in basin management.

Old Forests—As discussed in Issue 1 of this chapter, old forests with minimal current and historical human disturbance provide an important reference for potential old forest characteristics in the basin. Old forests, also known as old-growth or late-successional forests, are forests with a high degree of structural complexity and a high density of large trees, snags, and downed logs (Franklin and Fites-Kaufman 1996). They make an important contribution to biological integrity because their structural complexity and natural disturbance regimes support relatively unique assemblages of biota and natural processes. Old forest acreage has varied greatly over time in the Lake Tahoe basin, due to timber harvest and fire suppression. The 38 old forest stands identified by Barbour and others (see Issue 1, this chapter) and selected here as ESAs range from five to 50 hectares and are located throughout the basin (Figure 5-28).

Rare Communities and Ecosystems

We examined all aquatic ecosystem types, all CalVeg vegetation types (USDA 1991), and SNAs (Millar et al. 1996) to identify rare communities and ecosystems. From Issue 5, we identified four aquatic ecosystem types that were rare in the basin (basin rarity rating of $\leq$ 1.5 on a scale of one to five), as well as throughout the Sierra Nevada (Moyle 1996): sphagnum bogs, fens, marshes, and Lake Tahoe. Associated with Lake Tahoe is an equally rare community type, deep-water plant beds, which we identified as an additional ESA. All of the CalVeg vegetation types had greater than 100 occurrences in the basin, and so none of them was considered rare. Finally, one terrestrial community type identified as an SNA, the cushion plant community, had only one occurrence in the basin and was considered rare (TRPA 1982). Each of the six community and ecosystem types is described briefly below, with the exception of Lake Tahoe which is discussed in detail in Chapter 4.

Sphagnum Bogs and Fens—Bogs and fens are standing water systems occurring on poorly drained soils that contain a buildup of peat. Bogs and fens are comprised primarily of mosses, but also contain sedges, grasses, lichens, shrubs, and some flowering plants (Caduto 1990). They are inherently rare ecosystems and usually consist of unique plant

communities and plant and animal species, including many plant species not occurring in other habitats. We recognized three sphagnum bogs in the basin: Grass Lake (at Luther Pass), Hell Hole, and Osgood Swamp (Figure 5-28). Millar et al. (1996) also recognized Grass Lake and Osgood Swamp as SNAs. Additional small pockets of *Sphagnum* moss apparently occur in the basin (Allessio 1999), but only larger mapped bogs were considered ESAs. We were unsure if fens occurred in the basin; however, Sawyer and Keeler-Wolf (1995) note that bogs and fens are often quite difficult to distinguish from one another.

Marshes—Freshwater marshes represent one of the most productive ecosystems in the basin and in California in general (Kramer 1988). They provide habitat for a multitude of plant and animal species, with some species depending on marshes for their entire life cycles (Kramer 1988). Marshes are rare in the Lake Tahoe basin, occurring at the mouths of creeks on the south shore. Based on the marsh/swamp/muskeg symbols shown on USGS 1:24,000 scale topographic maps and local knowledge of the basin, we identified five marshes in the basin: Baldwin, Barton, Pope, Taylor Creek north, and Taylor Creek south (Figure 5-28).

Deep-water Plant Beds—Frantz and Cordone (1967) noted that deep-water plant beds in Lake Tahoe, which consisted of Bryophyta, Characeae, and algae, are a unique type of ecological community found in few other lakes. The plant beds provide spawning grounds for lake trout (*Salvelinus namaycush*) (Beauchamp et al. 1992) and habitat for invertebrates, including several species endemic to Lake Tahoe (Frantz and Cordone 1966). We identified all known deep-water plant bed communities as ESAs (Figure 5-28), which consisted of two approximate locations (Allen 1999). Comprehensive surveys for deep-water plant beds have not been conducted; therefore, we included a model of potential locations of deep-water plant beds (Hall, in preparation). The model used depth and substrate information from Frantz and Cordone (1967) and Loeb and Hackley (1988), as well as Lake Tahoe bathymetry data (Gardner et al. 1998), to predict the occurrence of deep-water plant beds in the lake. The slight discrepancy between the known locations and potential locations is likely due to the approximate nature of the location of known sites. Preliminary surveys to confirm the presence of modeled deep-water plant beds are planned (Johnson 1999).

Cushion Plant Communities—Cushion plant communities are rare, high-elevation communities consisting of small plants, such as phlox, ragwort, and *Draba* species, specially adapted to high-elevation, tundra-like conditions (TRPA 1982). We considered cushion plant communities ESAs because of their rarity in the basin and elsewhere. Only one cushion plant community has been identified in the basin (TRPA 1982) (Figure 5-28). Millar et al. (1996) also identified this community as an SNA in the basin ("Freel Peak").

Biologically Diverse Ecosystems

We identified areas of high species diversity considering a variety of taxa and using a variety of methods of analysis. After qualitatively evaluating the full range of community types (i.e., aquatic ecosystems and terrestrial vegetation communities), we identified three community types with unusually high species richness: marshes, aspen groves, and riparian areas. Marshes are discussed earlier under rare communities, as they are also rare in the basin.

Aspen—Aspen groves are forest stands dominated by quaking aspen (*Populus tremuloides*), generally occurring in association with streams, meadows, and other wet areas. Aspen groves were selected as ESAs because they have an exceptionally diverse array of associated species (DeByle and Zasada 1980; Verner 1988) and they are uncommon in the Lake Tahoe basin (covering less than 0.5 percent of the basin's land area). We used the 1991 CalVeg vegetation layer (USDA 1991) for the basin to identify the location of aspen groves. We considered as ESAs all aspen stands ≥ 1 ha, yielding 117 stands ranging in size from 1 to 23 ha (2.5 to 57.0 ac) (Figure 5-28). We selected stands ≥ 1 ha only because of the questionable accuracy (dated and low resolution) of the vegetation layer for representing the number and location of smaller

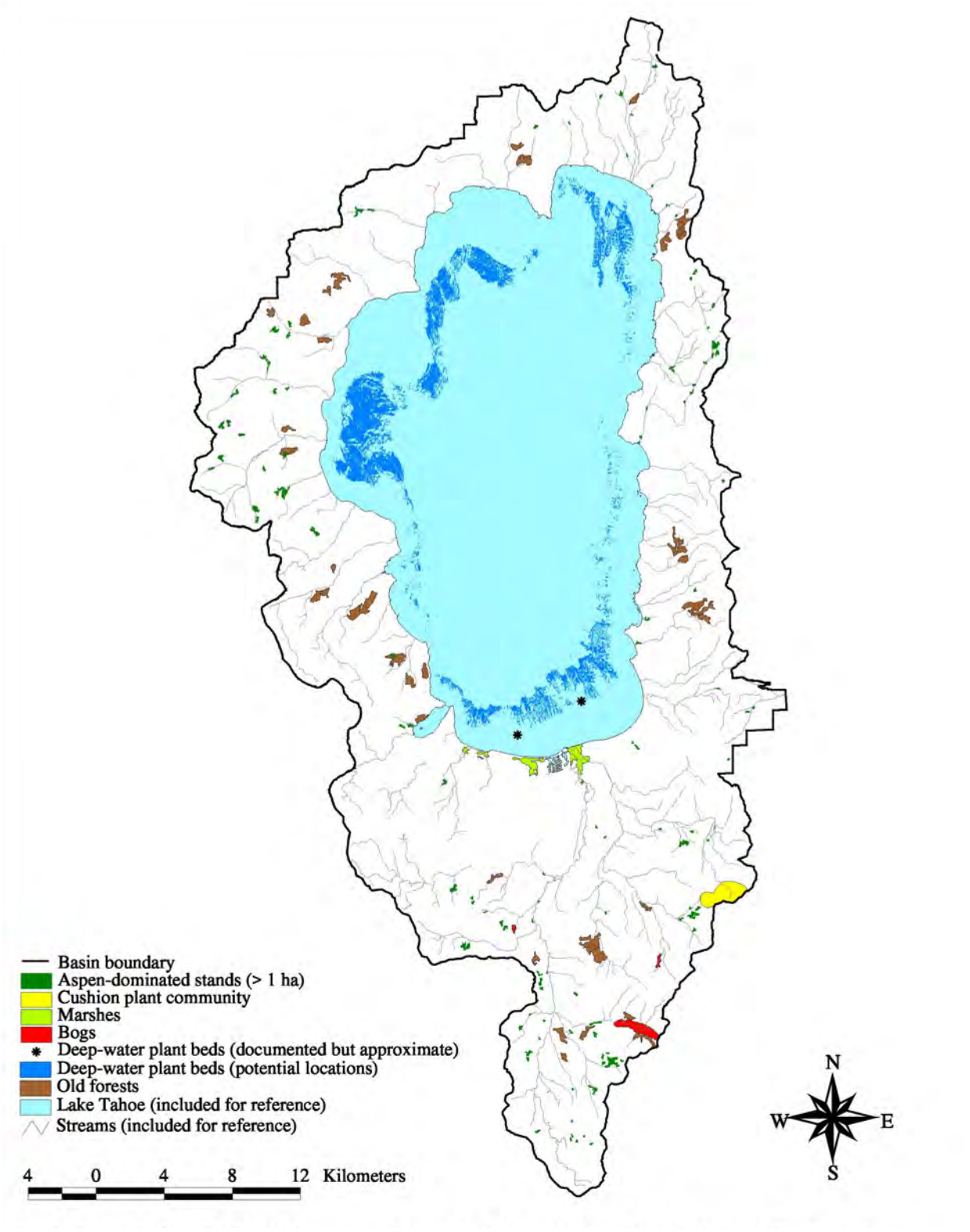


Figure 5-28—Rare and minimally disturbed ecosystems in the Lake Tahoe basin identified as Ecologically Significant Areas.

stands and because the options for managing smaller stands are limited.

Riparian Areas—Riparian areas consist of vegetation commonly associated with lentic (standing) or lotic (running) water, such as willows, alders, aspen, and meadows. They are extremely productive and diverse ecosystems (Kondolf et al. 1996) and provide habitat for a wide range of plant and animal species in the Sierra Nevada, many of which depend on riparian habitats (Graber 1996). In the Lake Tahoe basin, efforts to map riparian areas have been in progress for a number of years (USGS 1994; Butt 1999), and biodiversity studies (e.g., Manley and Schlesinger, in preparation) have helped illuminate the substantial contribution of riparian areas to biological diversity.

Riparian areas occur throughout the Tahoe basin, lining the many miles of streams and surrounding the hundreds of lakes and wet meadows, and occupying approximately 5.5 percent (7325 hectares; 18,605 acres) of the basin. Although basic protective measures for riparian areas are implemented on public lands throughout the basin (e.g., USDA 1988), we know relatively little about the location of especially diverse areas and how to avoid degradation of their values. We modeled the potential biological diversity of lentic and lotic riparian areas throughout the basin to improve our understanding of which areas might be the greatest contributors to biological diversity in the basin.

We used the species richness of a variety of taxonomic groups as our measure of biological diversity, and used regression models to predict species richness based on selected explanatory variables. Empirical data on species richness at a sample of lentic and lotic units, combined with a number of explanatory variables, were used to develop regression models that predicted the richness of each taxonomic group for all lentic or lotic riparian areas in the basin. This modeling exercise served to display patterns of biological diversity in the basin, identify potential "hotspots" of biological diversity that might merit special attention or consideration in management, and highlight parameters that appear to have the greatest influence on species richness for each taxonomic group. Models developed for each measure of biological diversity for lentic and lotic riparian areas are described in more detail below.

Lentic Riparian Areas with High Bird Diversity—Two measures of bird diversity were used to represent the relative potential diversity of lentic riparian areas in the basin: aquatic/riparian bird species richness and total bird species richness. Aquatic/riparian birds are defined as bird species that depend on or are most frequently associated with aquatic, riparian, or meadow habitats. Bird richness data were obtained from Manley and Schlesinger (in preparation), who conducted point counts along the perimeters of 88 lentic units (lakes and wet meadows) in the basin from 1997 to 1998. Bird species that were detected during point counts were classified as aquatic/riparian or upland according to their life history and behavioral characteristics (Ziener et al. 1990a; Ehrlich et al. 1988).

Lentic riparian areas were defined as areas within a fixed distance from lentic aquatic types. Lentic aquatic types consisted of all permanent standing bodies of water, including wet meadows, lakes, ponds, and tarns. The populations of lakes and some wet meadows in the basin were defined by digital versions of USGS 1:24,000 scale topographic maps. Based on local knowledge, wet meadows (as indicated by the marsh/swamp/muskeg indicators) are known to be underrepresented on USGS topographic maps. The wet meadow population estimate was supplemented by including "moist meadows" and "wet meadows" designations from a digital version of a hand-drawn map of riparian areas (the "riparian vegetation layer") derived from professional interpretation of 1:30,000 infrared aerial photographs from 1987 (USGS 1994). A total of 349 lakes and 1,771 wet meadows were identified. Lakes as small as 0.005 hectares and wet meadows as small as 0.004 hectares were present in the population, suggesting that our population of lentic units was a fairly complete accounting of all lentic units in the basin.

Twelve explanatory variables derived from digital map data available on GIS were used as independent variables in a multiple regression analysis to create predictive models for biodiversity in lentic riparian areas. The 12 explanatory variables

included elevation, mean annual precipitation, unit area, percent canopy cover, percent slope, and proportion of land occupied by each of seven vegetation types (shrubs, meadow, wooded riparian, decidious/coniferous riparian, aspen, mixed conifer, and subalpine conifer).

Values for each of the 12 explanatory variables were variously derived to describe lentic units. Elevation and unit area were derived from USGS 1:24,000 topographic maps, and values for each variable were assigned to each lentic sample unit. Elevation was described at the lake or meadow surface. The remaining ten independent variables were described within a 200-meter radius area ("analysis area") around each lentic unit. A 200-meter radius was chosen as an appropriate scale within which to describe environmental variables because it is slightly larger than the distance at which almost all birds are detected from point counts (Ralph et al. 1993). Nearly every bird detected was using habitat within 200 meters of lentic units.

The seven vegetation types were derived by a three step process. First, we combined some of the 12 vegetation types (we excluded water, barren, and urban) identified in the CalVeg vegetation layer (USDA 1991) to represent vegetation at the series level (e.g., Sawyer and Keeler-Wolf 1995), resulting in the identification of 5 types: mixed conifer, quaking aspen, subalpine conifer, shrub, and meadow (Table 5-34). Second, we combined some of the 5 vegetation types identified in the riparian vegetation layer described above (USGS 1994) to represent vegetation at the series level, resulting in the identification of 3 riparian types: wooded riparian, decidious/coniferous riparian, and meadow (Table 5-34). Third, we overlaid the map of the 3 riparian vegetation types on top of the map of the 5 CalVeg vegetation types to derive a combined map, with areas of overlap being assigned the vegetation type from the riparian vegetation layer. The resulting map displayed seven vegetation types because the "meadow" vegetation type occurred on both vegetation maps. The value for each vegetation type for each lentic unit was the proportion of the analysis area occupied by each vegetation type.

Table 5-34—Plant community types used in riparian biodiversity models and the analysis of plant community diversity in the Lake Tahoe basin and their CalVeg (USDA 1991) and riparian vegetation (USGS 1994) GIS layer origins.

Riparian biodiversity models	Original vegetation type[a]	Community diversity model
Shrub	Basin sagebrush (C)	Basin sagebrush
	Huckleberry oak (C)	Huckleberry oak
	Mixed alpine scrub (C)	Mixed alpine scrub
	Montane chaparral (C)	Montane chaparral
Mixed conifer	Jeffrey pine (C)	Jeffrey pine
	Mixed conifer – fir (C)	Mixed conifer
	Mixed conifer – pine (C)	
Quaking aspen	Quaking aspen (C)	Quaking aspen
Subalpine conifer	Red fir (C)	Red fir
	Subalpine conifer (C)	Subalpine conifer
	Water (C)	Water
Meadow	Wet meadow (C)	Meadow
	Moist meadow (R)	
	Wet meadow (R)	
Wooded riparian	Coniferous riparian (R)	Wooded riparian
	Deciduous riparian (R)	
Deciduous/coniferous riparian	Decid/con riparian (R)	Deciduous/coniferous riparian

[a] C = vegetation type from CalVeg vegetation layer (USDA 1991); R = vegetation type from riparian vegetation layer (USGS 1994).

The derivation of values was similar for the four remaining explanatory variables. We obtained mean annual precipitation from PRISM data (Daly et al. 1994; Daly et al. 1997; Daly and Johnson 1999). A slope polygon map was derived by interpreting topographic isoclines. We obtained canopy cover values from the CalVeg data layer. The digital data for all three of these variables represented their values as membership in value classes. Percent slope was reported in 10 classes: 0-5, 6-15, 16-25, 26-35, 36-45, 46-55, 56-65, 66-75, 76-85, and 86 and greater. Percent canopy cover was reported in 9 classes: no canopy cover, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80-89. Precipitation was reported in one-inch increments. To calculate an average value for these variables for each lentic analysis unit, we performed the following steps: 1) calculated the proportion of the total buffer occupied by each class (for example, 10-19 percent slope); 2) multiplied that proportion by the average value of the class (in this example, 14.5) to obtain the contribution to the final value associated with each class; and 3) summed those values across classes to arrive at the final value for each lentic unit buffer.

We performed all possible subsets regression analyses (NCSS 1995; Stevens 1996) on the sample of 88 lentic units, using aquatic/riparian bird richness and total bird species richness as dependent variables and the 12 explanatory environmental variables as independent variables. Independent variables were transformed when needed to make their distributions approximate a normal distribution more closely (Appendix D). For each dependent variable, we selected the regression model with the lowest root mean square error (MSE) (Zar 1984). The regression models then were used as predictive models to assess the potential aquatic/riparian bird richness and total bird species richness of all lentic units in the basin.

We predicted species richness for each lentic analysis unit by applying the predictive regression model to the environmental values assigned to each lentic analysis unit. Values for explanatory variables were described in the same manner for all lentic analysis units as for lentic sample units, with one exception. Wet meadows in close proximity to each other ($\leq$ 400 m) were combined and the cluster treated as one lentic analysis unit. In these cases, the 200-meter analysis area around the clustered lentic units overlapped and formed a single 200-meter wide analysis area around the perimeter of the cluster, and values for the explanatory variables were described for newly delineated analysis area. In treating meadow clusters as single analysis units, we are analyzing them as meadow complexes. The 1,771 wet meadows originally identified in the basin formed 213 wet meadow analysis units, composed of 35 individual wet meadows and 178 meadow clusters.

Once a species richness value was predicted for each lentic analysis unit, three additional steps were taken to derive the final value to represent the relative richness of lentic analysis units. First, we calculated a 90 percent confidence interval for each estimate by subtracting an error estimate of 1.282 (the z-score for a 90 percent level of confidence) times the square root of the model's MSE (see Hogg and Tanis 1983). The value indicating the lower bound of the 90 percent confidence interval was assigned to the lentic analysis unit as the richness estimate, so that 90 percent of the time the true species richness of the unit was likely to be at or above the assigned value. Second, the richness estimate assigned to each lentic analysis unit was standardized so that the richness estimate varied from 0 to 1. When the model predicted negative values of species richness, values for all lentic sample units were rescaled such that the lowest number was zero before they were standardized. Finally, we assigned each lentic analysis unit to one of five richness classes based on the standardized values: high (0.8 to 1.0), moderate-high (0.6 to 0.8), moderate (0.4 to 0.6), low-moderate (0.2 to 0.4), and low (0.0 to 0.2).

Patterns of Aquatic/Riparian Bird Species Richness in Lentic Riparian Areas—Details on the model used to predict aquatic/riparian bird species richness are in Appendix D. In short, nine variables were selected for the regression model (elevation, precipitation, slope, unit area, canopy cover, and four vegetation types), with an adjusted R^2 of 0.70. Richness values were unevenly distributed among the five richness classes, with the majority of lentic analysis units occurring in the moderate (12.3 percent), low-moderate (22.4 percent), and low (14.8

percent) richness classes, and only 14 units (2.5 percent) occurring in the high richness class (Table 5-35, Figures 5-29a and b). Lentic analysis units with high potential aquatic/riparian bird species richness were generally found at lower elevations with an abundance of nearby meadows and minimal nearby forest. These potential hotspots of aquatic/riparian bird diversity were chiefly large areas in basins with gently sloping topography. Areas of low potential richness were high elevation areas in basins with steep topography and either abundant forest cover or a lack of any vegetative cover.

The 12 lakes and two wet meadows in the high richness class were considered potential hotspots of aquatic/riparian bird species richness (Figures 5-29a and b), and their locations are described below:

- The pond west of Tallac Lagoon;
- Four ponds at the Lake Tahoe Golf Course;
- The pond at Tahoe Paradise Golf Course;
- The "Fishpond" south of South Tahoe High School near Highway 50;
- Four lakes and ponds at Edgewood Golf Course;
- The pond at the southeast end of Rabe Meadow near the intersection of highways 50 and 207; and
- Meadows along the Upper Truckee River just south of the northernmost crossing of Highway 50 and near the confluence with Angora Creek.

Table 5-35—Numbers of lakes and wet meadows in five classes of predicted aquatic/riparian bird species richness in the Lake Tahoe basin.

Richness Class	Lakes	Wet Meadows	Total	Percent
Low	42	52	94	16.7
Low-moderate	215	92	307	54.6
Moderate	66	43	109	19.4
Moderate-high	14	24	38	6.8
High	12	2	14	2.5

Patterns of Total Bird Species Richness in Lentic Riparian Areas—Details on the model used to predict total bird species richness are in Appendix D. In short, six variables were selected for the regression model (elevation, slope, unit area, and three vegetation types), with an adjusted R^2 of 0.48. Richness values were unevenly distributed among the five richness classes, with the majority of lentic analysis units occurring in the moderate (18.5 percent) and moderate-high richness (16 percent) classes, and only 57 units (10.1 percent) occurring in the high richness class (Table 5-36, Figures 5-30a and b). Lentic units with high predicted total bird species richness were generally low elevation areas with an abundance of nearby meadow, riparian vegetation, and mixed conifer forest. These lakes and wet meadows were generally large and occurred in basins with gently sloping topography. Areas with low potential richness were high elevation areas in basins with steep topography and a lack of meadow, riparian, or mixed conifer forest cover.

The 21 lakes and 36 wet meadow units in the high richness class were considered potential hotspots of total bird species richness (figures 5-30a and b). All 14 of the lakes and wet meadows identified as hotspots of aquatic/riparian bird species richness were also identified as hotspots of total bird species richness, with the exception of the pond on Tahoe Paradise Golf Course. The additional 44 lakes and wet meadows identified as potential hotspots of total bird species richness are listed below:

- A pond along Blackwood Creek near an OHV staging area;

Table 5-36—Numbers of lakes and wet meadows in five classes of predicted total bird species richness in the Lake Tahoe basin.

Richness Class	Lakes	Wet Meadows	Total	Percent
Low	24	7	31	5.5
Low-moderate	111	51	162	28.8
Moderate	126	68	194	34.5
Moderate-high	67	51	118	21.0
High	21	36	57	10.1

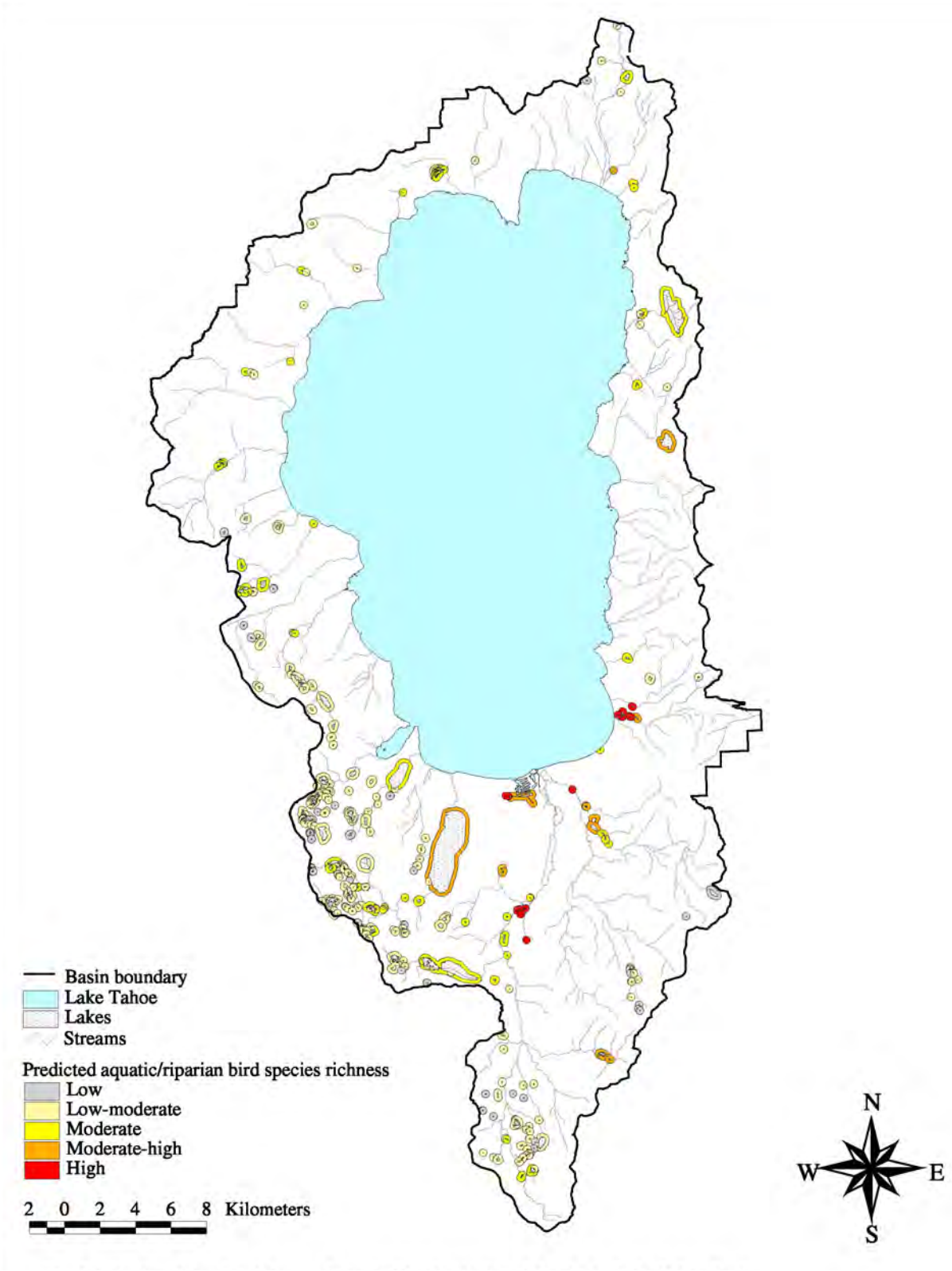


Figure 5-29a—Predicted species richness of aquatic/riparian birds at lakes in the Lake Tahoe basin.

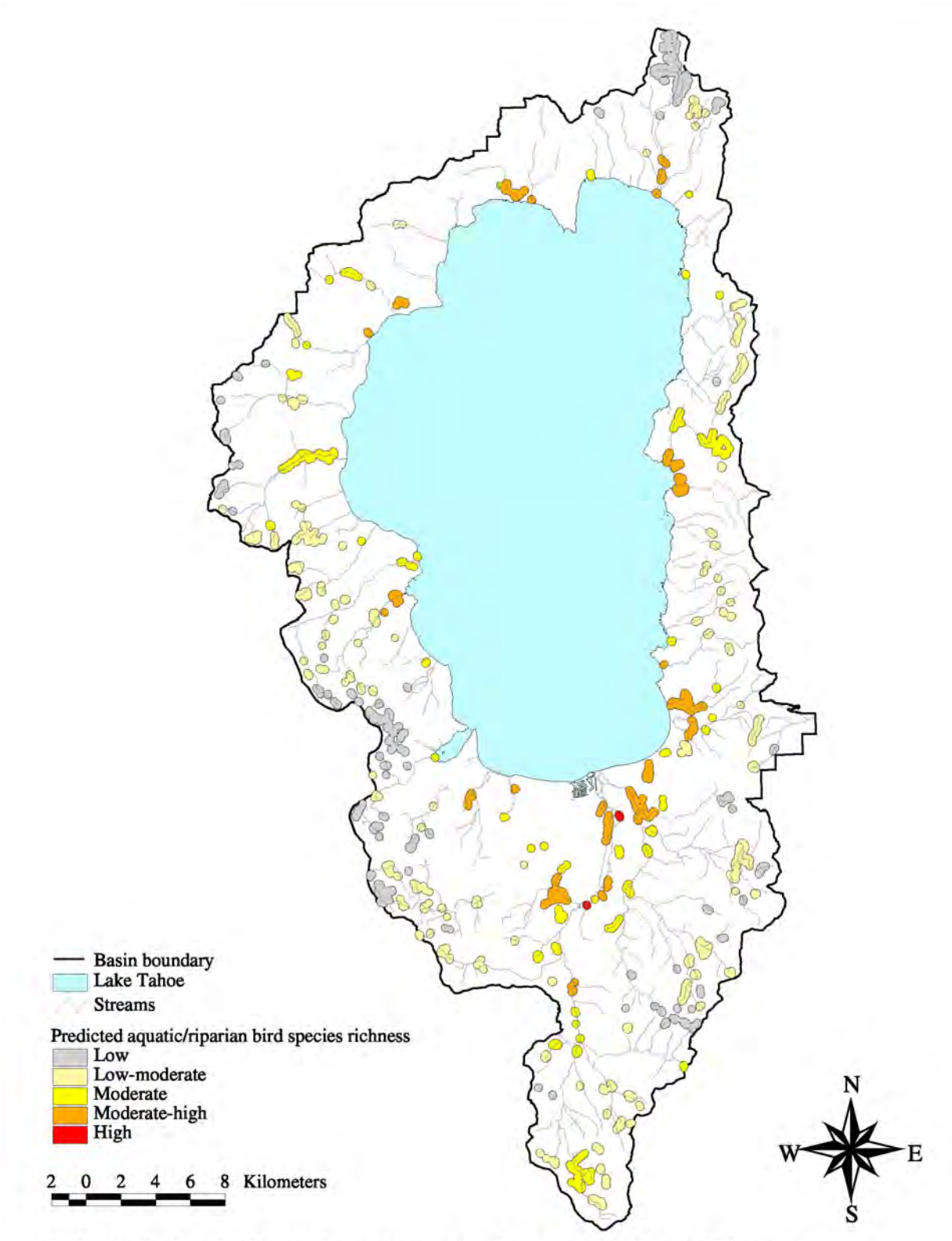


Figure 5-29b—Predicted species richness of aquatic/riparian birds at wet meadows in the Lake Tahoe basin.

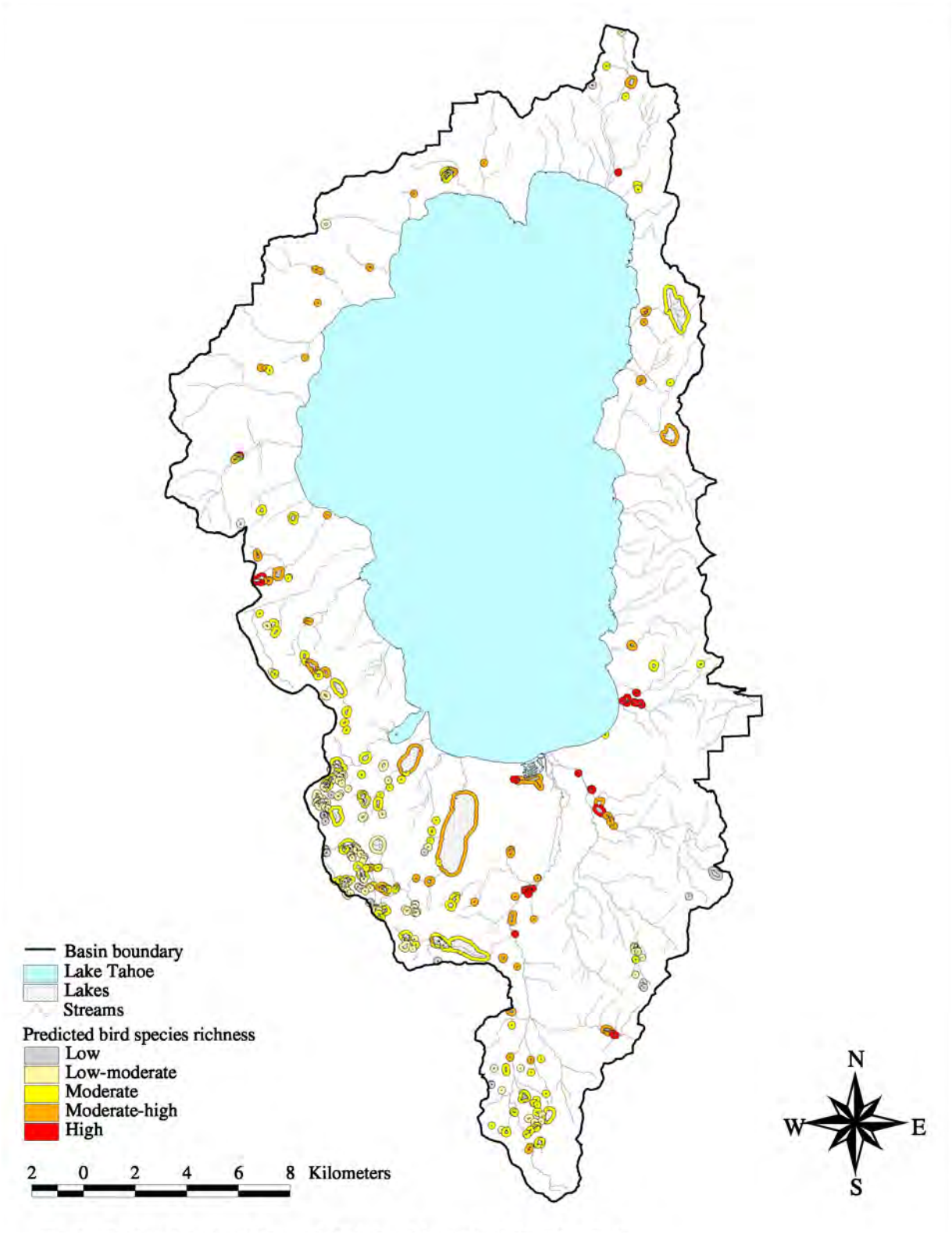


Figure 5-30a—Predicted species richness of all birds at lakes in the Lake Tahoe basin.

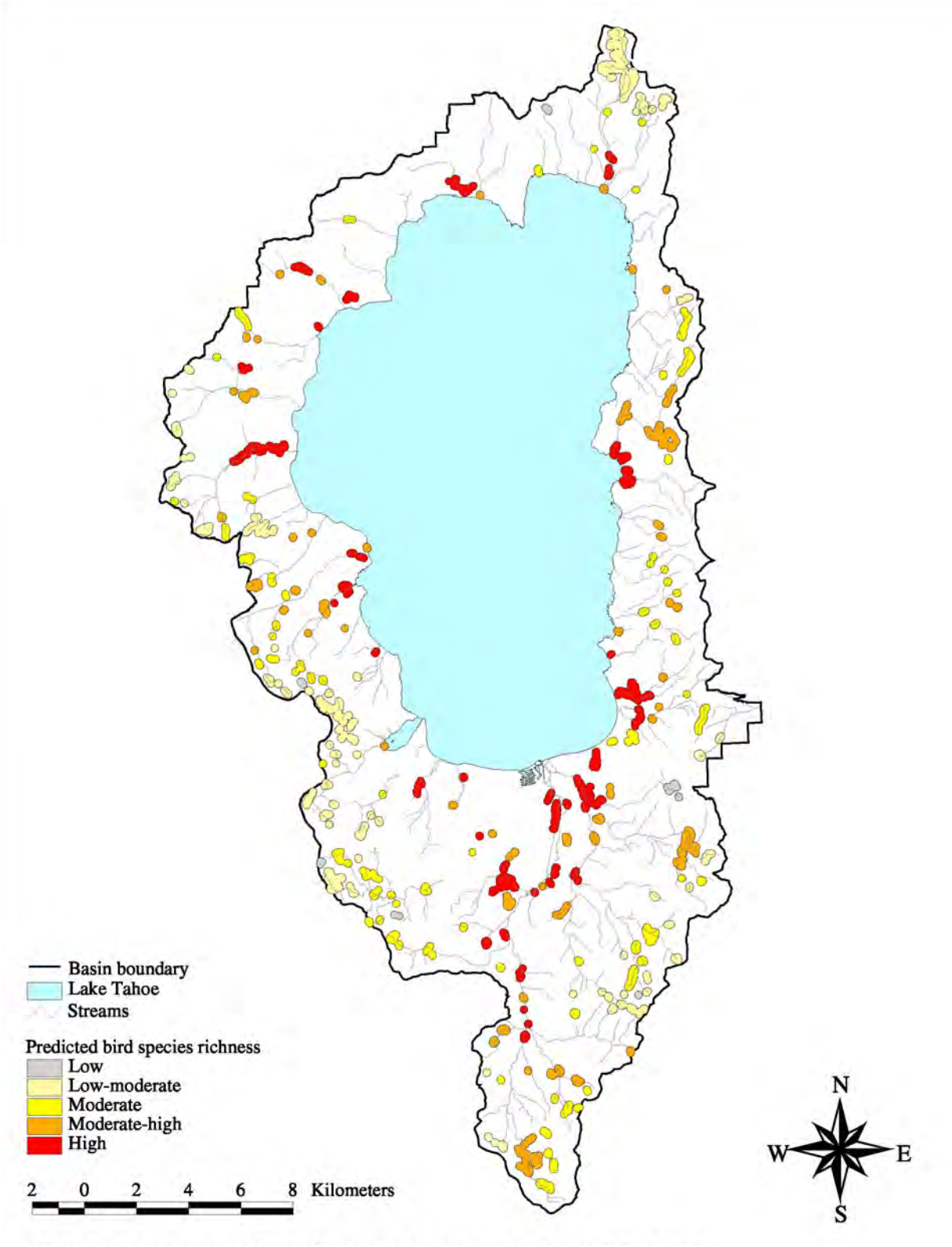


Figure 5-30b—Predicted species richness of all birds at wet meadows in the Lake Tahoe basin.

- Lily Lake in the McKinney Creek drainage and the pond immediately south;
- The pond southwest of the intersection of Highway 50 and Highway 89 in Meyers;
- Lake Christopher;
- The two ponds in the South Tahoe Public Utility District's sewage treatment plant east of the Sierra Tract;
- An additional pond at Edgewood Golf Course;
- Grass Lake at Luther Pass;
- The pond along Incline Creek at Incline Golf Course;
- Meadows along Snow Creek;
- Meadows along Burton Creek near Lake Forest;
- Antone Meadows in Burton State Park;
- A meadow at Tahoe City Golf Course;
- Page Meadows;
- Meadows along Blackwood Creek from near the mouth to past the OHV staging area;
- Meadows near the mouth of General Creek;
- Meeks Meadow;
- A meadow near the mouth of the creek north of D.L. Bliss State Park;
- Meadows along Tallac Creek southwest of Highway 89;
- A meadow along Taylor Creek near Highway 89;
- A meadow south of the junction of Fallen Leaf Lake Road and Tahoe Mountain Road;
- Thirteen meadows and meadow complexes along the Upper Truckee River and its tributaries;
- Meadows along Trout Creek upstream of where Highway 50 crosses it and at its confluence with Saxon Creek;
- Meadows at Bijou Golf Course;
- Meadows at Edgewood Golf Course;
- Rabe Meadow;
- A meadow at the mouth of McFaul Creek;
- Meadows at the mouths of Glenbrook and Slaughterhouse Creeks; and
- Meadows along Third and Incline Creeks near Incline Golf Course.

Lotic Riparian Areas with High Biodiversity—Four measures of biological diversity were used to represent the relative potential diversity of lotic riparian areas in the basin: aquatic/riparian bird species richness, total bird species richness, mammal species richness, and vascular plant species richness. Aquatic/riparian birds were defined using the same criteria and sources as for the lentic diversity analysis. Data were obtained from Manley and Schlesinger (in preparation), who collected data at 80, 300-meter long lotic units (stream reaches) in the basin from 1995 to 1996.

Lotic riparian areas were defined as areas within a fixed distance from 300-meter lengths of permanent streams ("lotic analysis units"). The population of permanent streams was defined by digital versions of USGS 1:24,000 scale topographic maps, with permanent streams indicated on original maps by solid blue lines. The population of all lotic analysis units in the basin was defined by dividing perennial streams into 300-meter lengths, starting randomly in the first 300 meters above the stream mouth (for main stream channels) or confluence with the main stream (for tributaries).

The riparian area delineated around each 300-meter length of stream varied among the measures of biological diversity. Lotic analysis units for aquatic/riparian and total bird richness consisted of a 300-meter radius area around each stream length. Bird data were collected as far as 200 meters from the stream; the 300-meter radius area encompassed all point count stations plus the estimated maximum 100 meter detection distance for most bird species. Lotic analysis units for mammal richness consisted of a 100-meter radius area around each stream length. Mammal data were collected up to 35 meters from the stream; the 100 meter radius area encompassed all detection locations plus a distance equivalent to the radius of the median home range size (56 meters, based on Ziener et al. 1990b) of all the mammals detected. Lotic analysis units for plant richness consisted of a 30-meter radius area around each stream length. Plant data were collected within 30 meters of the stream; the 30 meter radius area matched the survey area for plants.

The number of lotic analysis units varied slightly among each of the analyses for three reasons. First, the population of 300-meter stream lengths was generated *de novo* for the analysis of each

taxonomic group (birds, mammals, and plants) to accommodate the different analysis areas for each group. The random start point created minor variation in the number of units identified. Second, lotic analysis units with ≥ 5 percent of their area falling outside the basin boundary were excluded from the analysis. The larger the analysis unit, the greater the number of units that intersected the basin boundary. Third, data were missing for a small geographic area for one set of variables used in the analysis of plant richness, excluding approximately 35 lotic analysis units in one drainage (Dagget Creek, located in the southwest corner of the basin) from the population. The resulting populations of lotic analysis units were 1,998 units in the analyses of aquatic/riparian bird and total bird richness, 2,018 units in the analysis of mammal richness, and 1,997 units in the analysis of plant richness.

Thirty-one explanatory variables derived from digital map data available on GIS were used as independent variables in multiple regression analyses to create predictive models for biodiversity in lotic riparian areas. Eleven explanatory variables were included in the analysis of bird and mammal richness, including elevation, mean annual precipitation, percent canopy cover, percent slope, proportion of land occupied by 7 vegetation types (wooded riparian, aspen, decidious/coniferous riparian, meadow, mixed conifer, shrubs, and subalpine conifer). For the analysis of plant richness, we also included the proportion of land occupied by each of 20 soil series (Cagwin, Celio, Elmira, Fugawee, Gravelly alluvial land, Graylock, Inville, Jabu, Jorge-Tahoma, Loamy alluvial land, Marsh, Meeks, Meiss, Rockland, Stony colluvial land, Tahoma, Tallac, Toem-Rock, Umpa, and Waca-Rock). All of the explanatory variables were described within the bounds of the lotic analysis unit (as defined above for each species group). Soil series were derived from Rogers (1974), and elevation was converted from a categorical variable (mapped as 30 meter increments) to a continuous variable using the same method applied to slope, precipitation, and canopy cover for the lentic riparian analysis. All other variables were derived from the same data sources as for the lentic models.

We performed multiple regression analyses on the sample of 80 lotic sample units, using the richness measures as dependent variables and the 11 to 31 explanatory variables as independent variables. Independent variables were transformed when needed to make their distributions approximate a normal distribution more closely (Appendix D). We performed all possible subsets regression analysis (NCSS 1995; Stevens 1996) to generate the bird and mammal models, and selected the regression model with the lowest root MSE (Zar 1984). For the vascular plant model, we used backward stepwise regression (SPSS 1993) with an alpha level of 0.10 in lieu of the all possible subsets regression as there were too many variables to use the all possible subsets method.

We predicted species richness for each lotic analysis unit by applying the predictive regression model to the values assigned to each lotic analysis unit for each explanatory variable. Values for explanatory variables were described in the same manner for all lotic analysis units as for lotic sample units. The same procedure as was used for lentic riparian modeling was used to derive the final value to represent the relative richness of lotic analysis units, including assigning the lower bound of the 90 percent confidence interval for richness to the analysis unit, standardizing the values, and then assigning each lotic analysis unit to one of five richness classes (low to high) based on their standardized values.

Patterns of Aquatic/Riparian Bird Species Richness in Lotic Riparian Areas—Details of the model used to predict aquatic/riparian bird species richness are in Appendix D. In short, six variables were selected for the regression model (elevation, precipitation, wooded riparian, meadow, shrubs, and subalpine conifer), with a resulting adjusted R^2 of 0.52. Predicted species richness for most lotic analysis units fell into the low-moderate (48.2 percent) and moderate (30.9 percent) richness classes, with only 3.7 percent (n = 73) of the units in

the high richness class (Table 5-37). In general, predicted species richness of aquatic/riparian birds increased with decreasing elevation and increasing proportion of meadow and wooded riparian vegetation, and most lotic analysis units with high richness were at or near the mouths of streams (Figure 5-31).

Table 5-37—Number and percent of lotic units in each class of predicted aquatic/riparian bird species richness in the Lake Tahoe basin.

Bird Species Richness Class	Number of Lotic Units	Percent of Total
Low	144	7.2
Low-moderate	962	48.1
Moderate	617	30.9
Moderate-high	202	10.1
High	73	3.7

The 73 lotic analysis units in the high richness class were considered potential hotspots of aquatic/riparian bird species richness (Figure 5-31). These 73 lotic units were spatially clumped, representing nine general locations described below:

- Meeks Creek: at Meeks meadow;
- Tallac Creek: mouth at Baldwin Beach south to Highway 89;
- Taylor Creek: mouth at Taylor Creek Marsh south just past Highway 89;
- Upper Truckee River: from the mouth south to the north end of the Lake Tahoe airport, at the south end of the Lake Tahoe Airport, and at its confluence with Angora Creek at Lake Tahoe Golf Course;
- Angora Creek: in Washoe Meadows State Park;
- Trout Creek: near its mouth;
- Edgewood Creek: east of the large pond at Edgewood Golf Course;
- Burke Creek: at its mouth; and
- Glenbrook Creek: the mouth east to Highway 50.

Patterns of Total Bird Species Richness in Lotic Riparian Areas—Details of the model used to predict total bird species richness are in Appendix D. In short, 5 variables were selected for the regression model (precipitation, wooded riparian, meadow, mixed conifer, and canopy cover), with a resulting adjusted R^2 of 0.26. Predicted species richness for most lotic analysis units fell into the low-moderate (26.5 percent), moderate (47.5 percent), and moderate-high richness classes (15.2 percent), with 4.5 percent (n = 90) of the units in the high richness class (Table 5-38). In general, predicted bird species richness decreased with increasing precipitation (which is positively correlated with elevation) and most lotic analysis units with high richness were at or near the mouths of streams (Figure 5-32).

The 90 lotic analysis units in the high richness class were considered potential hotspots of total bird species richness (Figure 5-32). Most of the hotspots of aquatic/riparian bird species richness (identified above) were also hotspots of total bird species richness, with the exception of Meeks Creek and Burke Creek. Two areas were uniquely identified as hotspots for total bird species richness:

- Trout Creek: from its confluence with Cold Creek to its mouth; and
- Third and Incline Creeks: at Incline Golf Course.

Patterns of Mammal Species Richness in Lotic Riparian Areas—Details of the model used to predict mammal species richness are in Appendix D. In short, seven variables were selected for the regression model (elevation,

Table 5-38—Number and percent of lotic units in each class of predicted total bird species richness in the Lake Tahoe basin.

Bird species richness class	Number of lotic units	Percent of total
Low	82	4.1
Low-moderate	572	28.6
Moderate	950	47.5
Moderate-high	304	15.2
High	90	4.5

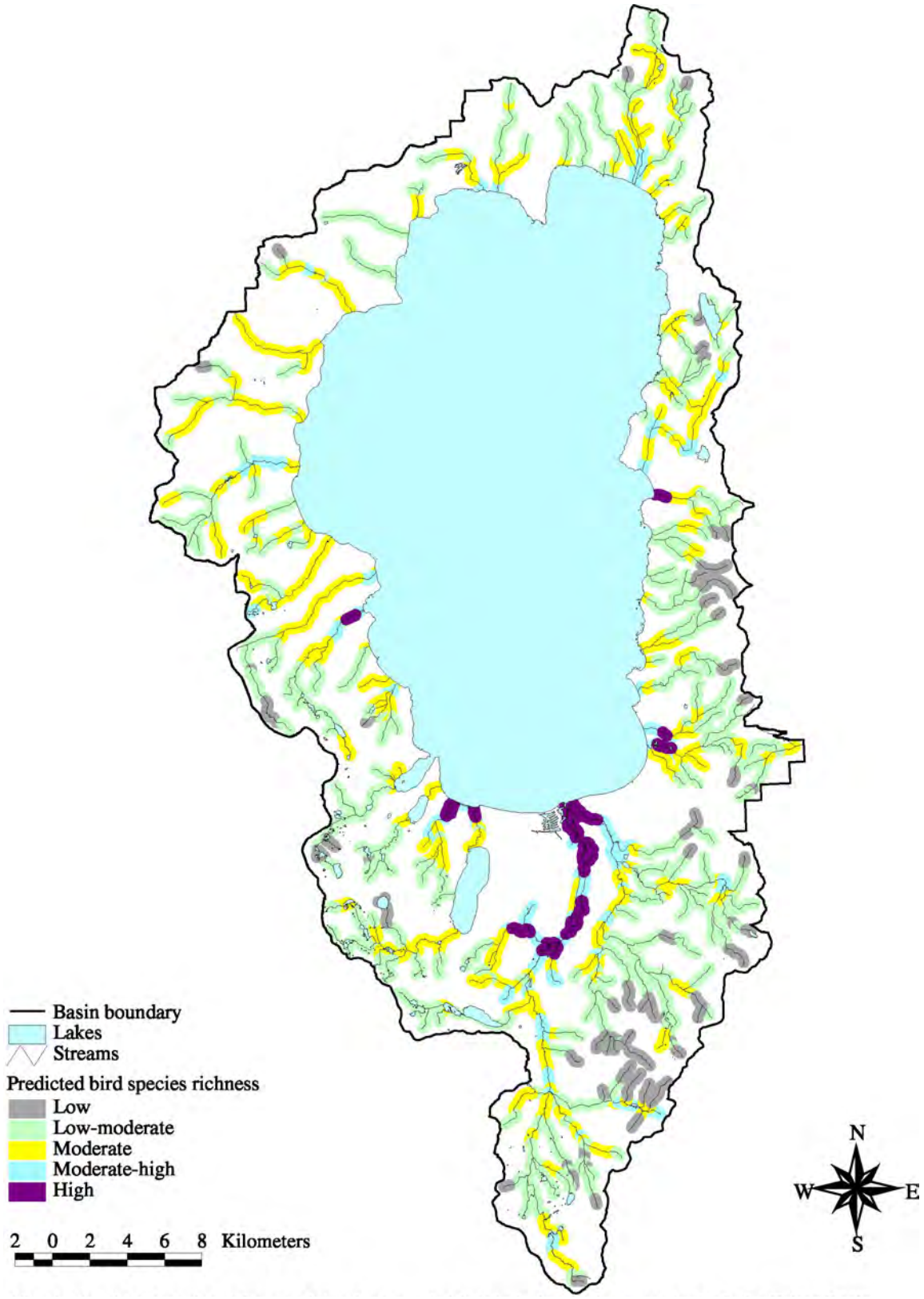


Figure 5-31—Predicted species richness of riparian/aquatic birds in lotic riparian areas in the Lake Tahoe basin.

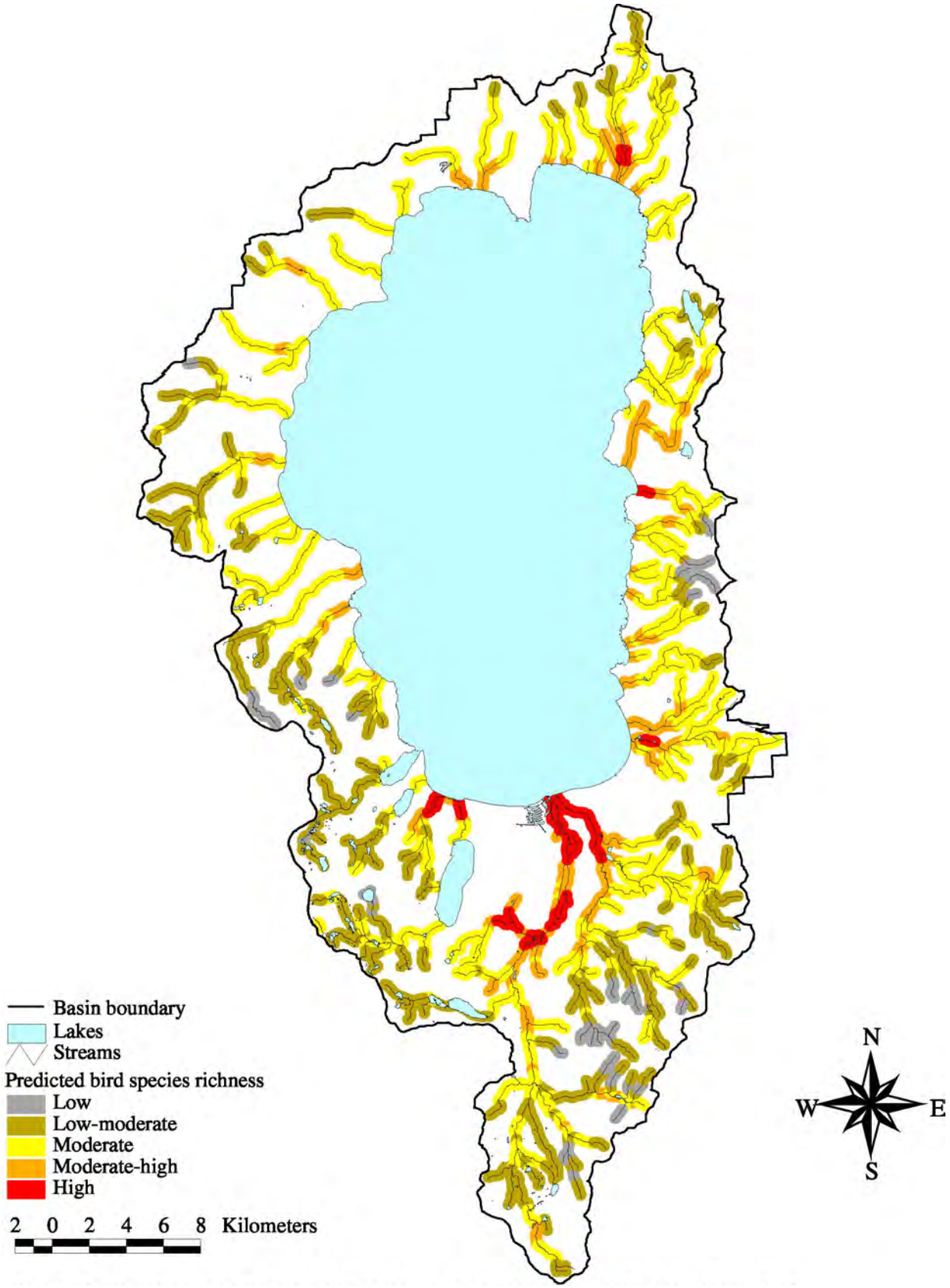


Figure 5-32—Predicted species richness of all birds in lotic riparian areas in the Lake Tahoe basin.

percent slope, wooded riparian, decidious/coniferous riparian, shrubs, mixed conifer, and meadow), with a resulting low adjusted R^2 of 0.15. Predicted species richness for most lotic analysis units occurred in the moderate (43.3 percent) and moderate-high (44.8 percent) richness classes, with 7.6 percent (n = 153) of the units in the high richness class (Table 5-39). Predicted species richness of mammals generally increased with elevation and was greater on east side of the basin (flanks of the Carson Range) than on west side of the basin (flanks of the Sierra Crest) (Figure 5-33).

The 153 lotic analysis units in the high richness class were considered potential hotspots of mammal species richness (Figure 5-33). These 153 lotic units were spatially clumped, representing 12 general locations described below:

- Griff Creek: approximately 1.7 kilometers (one mile) from the headwaters;
- General Creek: southwest of Lost and Duck lakes;
- Cascade Creek: near the headwaters and Kalmia Lake;
- Upper Truckee River: and its tributaries various locations near Benwood Meadow, Grass Lake, Dardanelles Lake, Meiss Lake, and south of Meiss Lake;
- Trout Creek: at Hell Hole and near Fountain Place;
- Cold Creek: upper portions, including High Meadows;
- Heavenly Valley Creek: southwest of Heavenly Valley;
- Edgewood Creek: near Daggett Pass;
- McFaul, Lincoln, Logan House, North Logan House, and Glenbrook Creeks: upper reaches;
- The creek north of Zephyr Creek: upper reaches;
- North Canyon Creek: reaches near Marlette Lake south approximately 3 kilometers (1.8 miles); and
- Incline and Third Creeks: upper reaches.

Patterns of Vascular Plant Species Richness in Lotic Riparian Areas—Details on the model used to predict vascular plant species richness are in Appendix D. In short, ten variables were selected for the regression model, including mean annual precipitation, five vegetation types, and four soil types, with a resulting adjusted R^2 of 0.44. Vascular plant species richness for most lotic analysis units occurred in the moderate (32.9 percent) and moderate-high (52.1 percent) richness classes, with 6.3 percent (n = 125) of the units in the high richness class (Table 5-40). Predicted vascular plant species richness reached its highest values at high levels of precipitation, and was greatest on the west and south sides of the basin (Figure 5-34).

The 125 lotic analysis units in the high richness class were considered potential hotspots of plant species richness (Figure 5-34). These 125 lotic units were spatially clumped, representing 12 general locations described below:

- Watson Creek: northwestern portion;
- Ward Creek: almost the entire length west of the middle of Section 23, including all tributaries west of that point;

Table 5-39—Number and percent of lotic units in each class of predicted mammal species richness in the Lake Tahoe basin.

Mammal species richness class	Number of lotic units	Percent of total
Low	10	0.5
Low-moderate	75	3.7
Moderate	876	43.4
Moderate-high	904	44.8
High	153	7.6

Table 5-40—Number and percent of lotic units in each class of predicted vascular plant species richness in the Lake Tahoe basin.

Plant species richness class	Number of lotic units	Percent of total
Low	23	1.2
Low-moderate	150	7.5
Moderate	658	32.9
Moderate-high	1,041	52.1
High	125	6.3

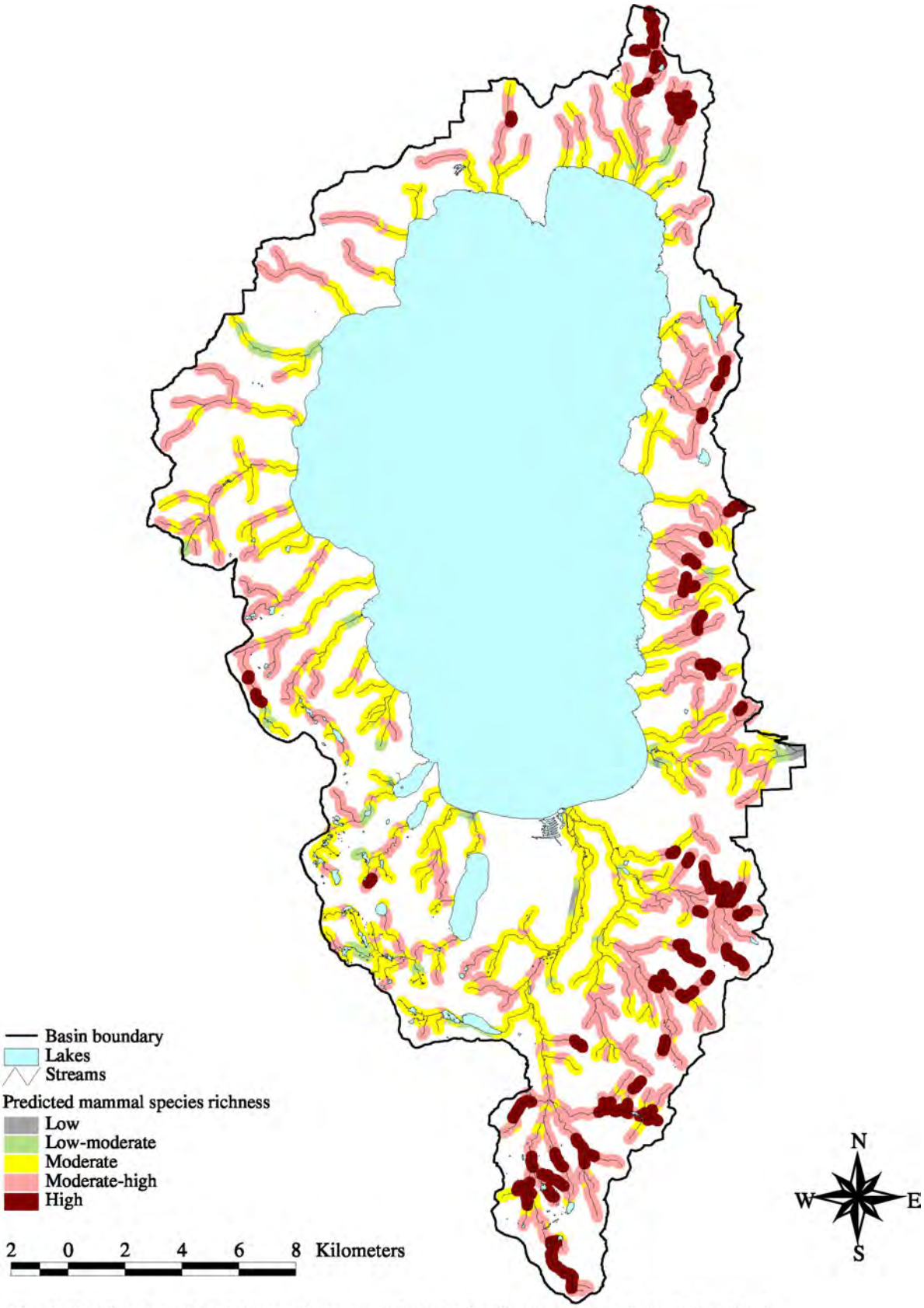


Figure 5-33—Predicted species richness of mammals in lotic riparian areas in the Lake Tahoe basin.

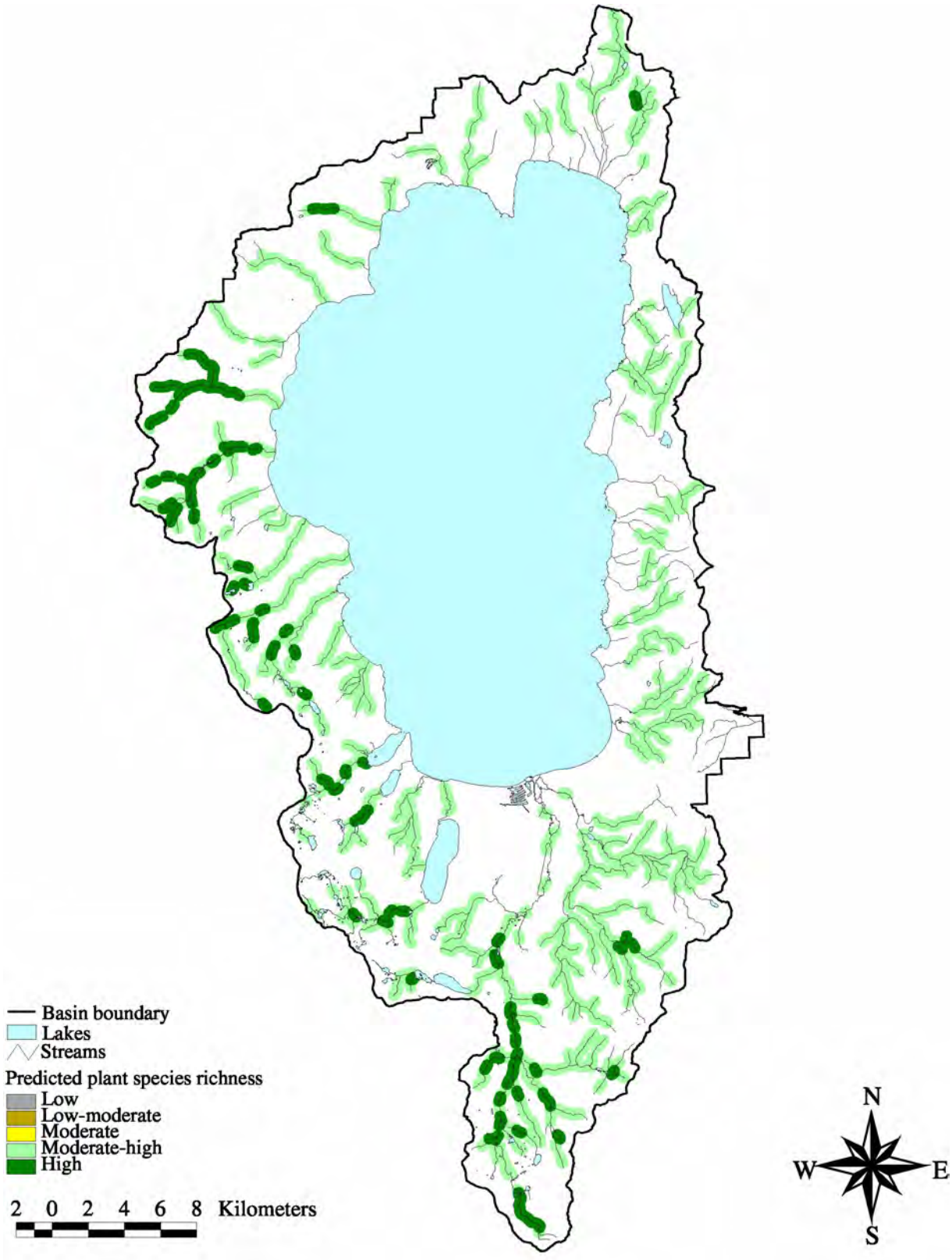


Figure 5-34—Predicted species richness of vascular plants in lotic riparain areas in the Lake Tahoe basin.

- Blackwood Creek: portions along the entire length, including tributaries;
- McKinney Creek: stretches between and around McKinney and Lily Lakes and a portion just south of Buck Lake;
- General Creek: at the junction of the tributary to Lost and Duck Lakes, along the tributary to Lost and Duck Lakes, at the point where the creek bends southeast, and at the headwaters in Desolation Wilderness;
- Meeks Creek: portions above Meeks Meadow inside and outside of Desolation Wilderness, and near Shadow Lake;
- Eagle Creek: just above Emerald Bay, and around Eagle Lake;
- Cascade Creek: at and below the confluence of creeks draining Azure and Snow Lakes;
- Glen Alpine Creek: above Lily Lake and immediately west of Grass Lake;
- Upper Truckee River: and tributaries in Washoe Meadows State Park, west of Upper Echo Lake, at Benwood and Upper Benwood Meadows, near Grass Lake, at Big Meadow, near and south of Meiss Lake, and at many other points along the main channel and tributaries; and
- Trout Creek near Fountain Place; and
- Incline Creek northern portion.

Synthesis and Analysis of Riparian Biodiversity Models—The modeling exercises described above identified many potential hotspots of diversity in riparian areas in the basin. In general, bird, mammal, and vascular plant hotspots were geographically distinct (Figure 5-35). Grass Lake at Luther Pass, and lotic and lentic riparian areas along the Upper Truckee River and its tributaries (particularly from near Celio Ranch to north of Dardanelles Lake) however, stand out as having the potential for high species richness of all three species groups. Other areas that are potential hotspots for multiple species groups include portions of Ward Creek (birds and plants), Blackwood Creek (birds and plants), McKinney Creek (birds and plants), the Upper Truckee River at Highway 50 in Meyers (birds and plants) and from Meiss Lake south (mammals and plants), Trout Creek (mammals and plants), and northern Incline Creek (mammals and plants). The limited overlap among the hotspots for each species group indicates that distinct environmental parameters have different influences on the species richness of each group. For instance, mammal species richness tended to increase with elevation, while bird species richness decreased with elevation, so very few locations were identified as hotspots for both birds and mammals. Only a few areas in the basin, described above, present the appropriate conditions for high richness in more than one group of species.

The varying degrees of success we had in modeling species diversity in riparian areas reflect the explanatory power of the map-based variables. We were able to explain more than 70 percent of the variation in aquatic/riparian bird species richness in lentic riparian areas and more than 50 percent in lotic riparian areas, indicating that our map-based variables were good predictors of aquatic/riparian bird species richness. The unexplained variation is most likely associated with fine-scale environmental characteristics that might influence species richness, such as prey base, water depth, and vegetation structure. The lentic and lotic models for total bird species richness were not as strong (more than 50 percent of the variation explained for lentic riparian areas but only 26 percent for lotic riparian areas) suggesting that some important habitat elements for upland birds were not well represented in our models. Also, the models for lentic riparian areas were based on data from single visits to each site (although in many cases, multiple point counts were conducted), which may not have detected some species associated with the lentic unit. Ideally, one would use data from several visits to each site to characterize the bird fauna more thoroughly. We were able to explain almost 45 percent of the variation in vascular plant species richness. The unexplained variation may lie in such factors as soil moisture and nutrient content, neither of which was available in GIS. The regression model for mammal species richness explained only 15 percent of the variation. Fine-grained habitat elements, such as snags, downed woody debris, and ground cover, were not available on GIS and are likely to influence mammal species richness.

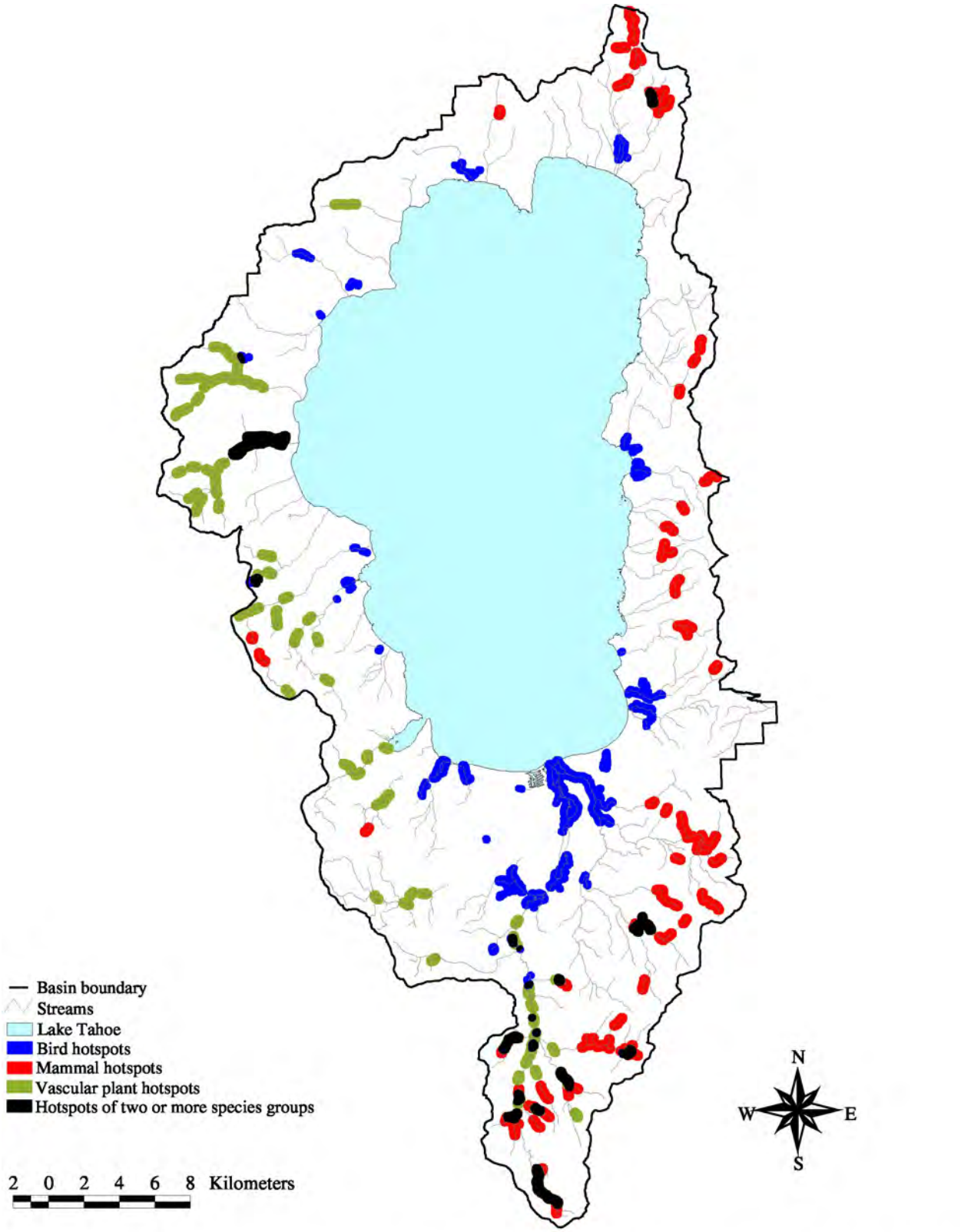


Figure 5-35—Predicted hotspots of bird, mammal, and vascular plant species richness in lentic and lotic riparian areas in the Lake Tahoe basin.

Model predictions may be less accurate than suggested by the 90 percent confidence intervals because human disturbance was not included as an explanatory variable in any of these analyses. For example, many areas predicted to have high bird species richness were in highly disturbed sites such as golf courses; this pattern was probably because of the classification of golf courses as meadows in the vegetation map layer. Bird species richness is positively correlated with meadows, but it is likely that golf courses would support a lower diversity of species because of homogeneity of vegetation structure and composition, use of herbicides, and human visitation. However, golf courses might provide quality habitat for some birds; lentic sites on golf courses were among the most species-rich sites surveyed by Manley and Schlesinger (in preparation). Other human disturbance factors such as recreation, grazing, and timber harvest also were not considered in the modeling exercises.

A few follow-up efforts are suggested by the successful results of these modeling exercises for lotic and lentic riparian areas. The lake and wet meadow maps for the basin may have included some lentic units no longer in existence and omitted some units not currently mapped. Field validation of sites with potential high richness is vital to confirm the existence of lentic units and to test our predictions of species richness. In addition, other species groups, such as amphibians, invertebrates, and fungi, could be modeled in a similar manner based on data from Manley and Schlesinger (in preparation). Finally, models for upland environments could be generated if data become available.

Community Diversity—Communities represent an intermediate level of biological organization between species and landscapes and constitute an important component of biological diversity (Noss 1990). Leopold (1933) observed that areas with a diverse assemblage of plant communities generally supported a rich and diverse assemblage of wildlife species, particularly species that require more than one habitat type. Certainly the same patterns hold for plant species richness, as these communities are defined by shifts in plant species composition. We conducted an analysis to identify areas with high vegetation community diversity as described by the richness of community types and then included them as ESAs.

We identified 13 vegetation community types for use in the community diversity analysis (Table 5-34). The 13 vegetation types were derived by a three step process similar to that used to derive the seven vegetation types in the analysis of biologically diverse riparian areas. First, we adopted the original 12 vegetation types as identified in the CalVeg vegetation layer, with 2 exceptions. We combined mixed conifer - fir with mixed conifer - pine to create mixed conifer because we were not confident that the vegetation layer accurately discerned these two types, and we included water (as identified in CalVeg) as part of the map layer based on the assumption that an aquatic environment would have an effect at least as great as another vegetation type in an area. Second, we treated the riparian vegetation layer in the same manner as it was for the riparian diversity analysis, resulting in 3 riparian types. Third, as with the riparian diversity analyses, we overlaid the map of the 3 riparian vegetation types on top of the map of the 11 CalVeg types to derive a combined map, with areas of overlap being assigned the vegetation type from the riparian vegetation layer. The resulting map displayed 13 vegetation types because the "meadow" vegetation type occurred in both vegetation maps.

The analysis was conducted using a nearest neighbor analysis through ARC/GRID GIS functions. We first converted the vegetation vector layer into a grid layer and specified a 30 square-meter cell size using ARC/INFO GRID (ESRI 1994). To visualize the process, imagine a fishnet draped over a thematic map (e.g., a vegetation map). Where the thematic map intersects with the netting of the fishnet (cells), the integer value from the thematic map is transferred to the cell. In this case, the net was composed of 30 x 30 meter grid cells. The nearest neighborhood analysis systematically searched for community types within a specified search area around each focal cell. The output of the analysis was a map that displayed the number of community types in the vicinity of each cell.

We performed the nearest neighborhood analysis to determine the number of different community types within 120 meters of each cell, an

area of approximately two hectares (5 acres). We chose a two hectare area as the area of influence for the 30 meter cell because it is a large enough area to influence the suitability of the 30 m cell for most animal species, and small enough to be within the dispersal distance of most plant species.

The total number of communities associated with any one cell ranged from one to eight (Figure 5-36). A decreasing proportion of the basin was occupied by cells with higher numbers of communities (Table 5-41). We created five classes of community richness to display the range of community richness among cells: 1, 2, 3, 4, and $\geq$ 5 communities associated with a given cell. Approximately 1,450 hectares (3,580 acres) of the basin occurred in the highest richness class ($\geq$ 5 communities). Areas of high community diversity primarily occurred on the southwest side of the basin, with some additional areas on the north side of the basin (Figure 5-36).

We identified seven hotspots of community diversity, defined as areas $\geq$ 1 hectare that were associated with $\geq$ 7 community types (Figure 5-36). Community diversity hotpots as identified here occupied approximately 18 hectares and their locations are described below:

- Near the mouth of Burton Creek;
- The mouth of Meeks Creek;
- Approximately 1.5 kilometers (0.9 miles) up Cascade Creek from Cascade Lake near the Desolation Wilderness boundary;
- Just north of Upper Echo Lake;
- Just east of Lower Echo Lake; and
- Two areas near the headwaters of the Upper Truckee River.

Table 5-41—Proportion of the basin occupied by areas (as defined by 30 m^2 grid cells) associated with 1 to 8 community types.

Number of neighboring communities	Area occupied (percent of the basin)
1	54.4
2	24.9
3	15.0
4	4.7
5	0.9
6	0.14
7	0.02
8	0.002

We conducted a multiple linear regression analysis to determine the environmental factors driving the diversity of plant community types. Five abiotic variables were used as explanatory variables: elevation, precipitation, slope, distance to stream, and distance to lake. Values for each variable were assigned to each 30-meter grid cell. Elevation, precipitation, and slope were generated in the same manner as for the riparian biodiversity models (above). Distance to stream and distance to lake were obtained from digital USGS 1:24,000 topographic maps.

We used backward stepwise regression (SPSS 1993) with an alpha of 0.10 to derive the regression model. Details of the model are in Appendix D. In short, the model consisted of all five variables ($F_{5,129933}$ = 9938.36, $P < 0.0001$, adj. R^2 = 0.28). Areas with the highest community diversity were those at high elevations, with high annual precipitation, high percent slope, and short distances to streams and lakes. The association of high community diversity with short distance to streams and lakes reflects the strong influence of riparian vegetation on community diversity. Inclusion of soil type and human disturbance (e.g., road density) in the model would likely explain a greater proportion of the variation in community diversity.

We expect hotspots of community diversity to correlate roughly with species richness, given that a diversity of communities is expected to support a wide variety of species (Leopold 1933). We cannot directly compare the community diversity map to the maps of potential species richness in riparian areas because community diversity was calculated for the entire basin while the models of biodiversity were generated for riparian areas only. Nonetheless, it appears that community diversity increases near water (i.e., near riparian areas) and tends to have similar environmental relationships to those for mammal and vascular plant species richness (increasing with increasing elevation and precipitation, respectively). Additional modeling of species richness with data from upland areas would be necessary to compare the two exercises fully.

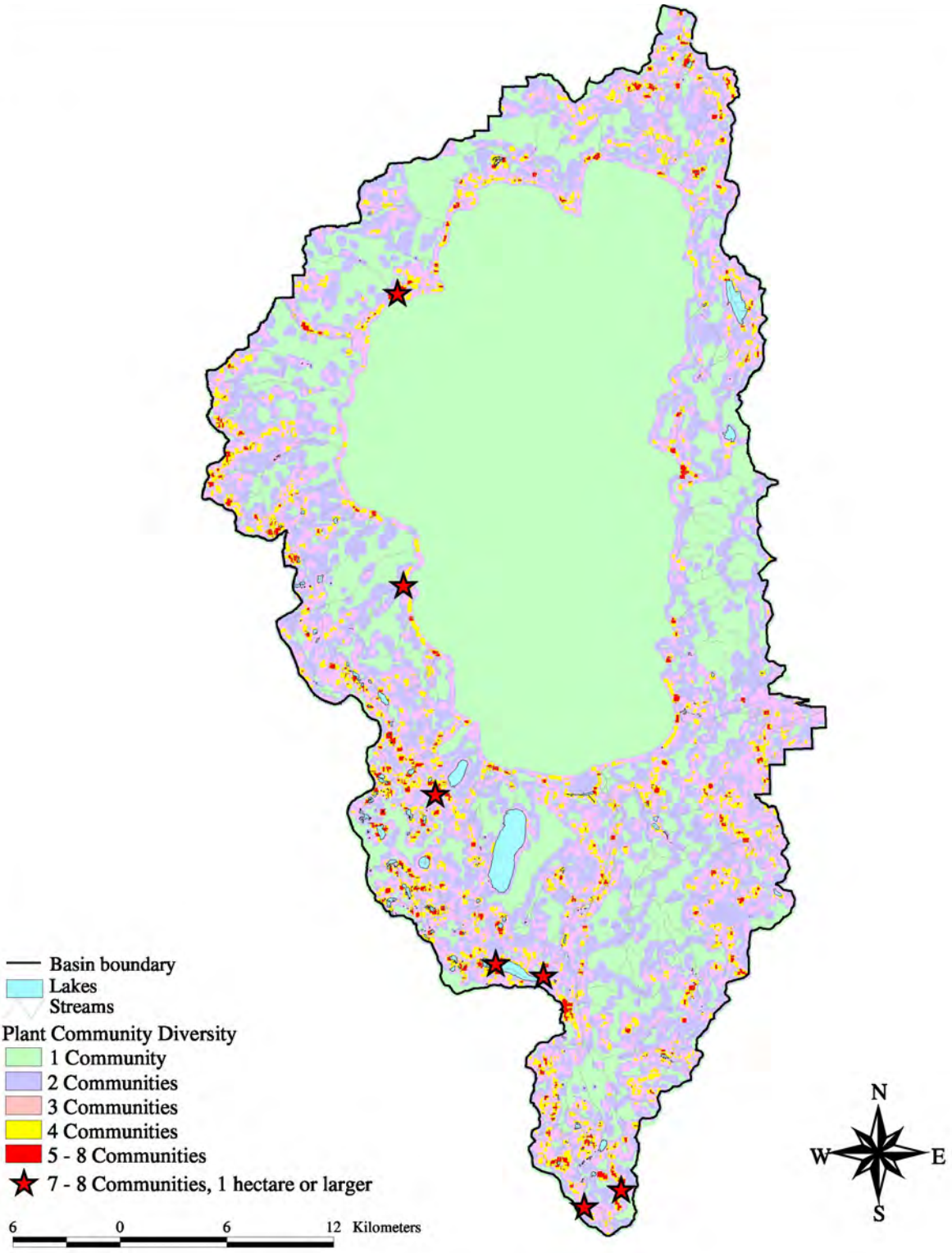


Figure 5-36—Levels of community diversity in the Lake Tahoe basin.

State of Knowledge about ESAs

ESA accounts are intended to provide a synopsis of the state of knowledge about ESAs, which can assist in furthering appropriate activities in monitoring, conservation, and research. We developed such accounts for three ESAs: aspen groves, deep-water plant beds, and *Sphagnum* bogs and fens. If these accounts prove useful, we suggest ESA accounts be developed for the six remaining ESAs identified in this issue, and for any future ESAs that may be identified. We addressed a similar set of topics in each account (Table 5-32). The accounts are in Appendix D.

What data gaps were revealed in the process of assessing ecologically significant areas?

The greatest limitation we encountered in the identification of ESAs in the Tahoe basin was a lack of basic inventory data. First, species richness data representative of the entire basin were not available. Such data would have complemented the riparian diversity assessments by identifying upland sites with potentially high species diversity. Also, we wanted to identify areas with a high diversity of focal species based on various criteria (e.g., rare, exotic) (see Issue 7), but inventory data for these species were not adequate to conduct the analysis.

We had to depend heavily on remotely sensed data for our modeling exercises and the mapping of most ESAs. The accuracy of these remotely sensed data is variable and potentially low. For example, the identification of many ESAs (aspen, high diversity riparian areas, and high community diversity areas) depended on CalVeg (USDA 1991) and riparian vegetation (USGS 1994) GIS layers. Schwind (1998) assessed the accuracy of conifer type classification and canopy cover estimates in the CalVeg vegetation layer for the Lake Tahoe basin and found high variability in the accuracy of vegetation classifications among conifer types. He found that conifer type classifications ranged from 67 to 100 percent accuracy, and canopy cover classifications ranged from 21 to 92 percent accuracy among conifer types. However, his assessment was based on a small sample size, and no confidence intervals were provided for the accuracy estimates. Alternatively, the riparian vegetation layer (USGS 1994) was determined to have relatively high and consistent accuracy, being approximately 80 per cent accurate (USDA 1990). No accuracy assessments have been conducted for shrub and meadow types.

Inaccuracies may also exist in terms of the specific locations and boundaries of some ESAs, such as old forests, deep-water plant beds, marshes, bogs and fens, and the cushion plant community. These inaccuracies could likely be improved in the course of monitoring the status of and changes in these ESAs (see below) and would not warrant a separate field effort.

A number of data gaps regarding specific ecological relationships within the basin hindered our assessment of the value and vulnerability of some ESAs. Basin-specific information on the relationships between biological diversity and the size of aspen groves would have been helpful in determining minimum patch sizes for ecologically significant stands and direction of future conservation efforts. Also, information on the effects of anthropogenic disturbance on ESAs is generally sparse, yet such disturbance poses the greatest threat to the continued integrity of many ESAs. Conservation measures would be greatly informed by empirical data on the influence of various types of anthropogenic disturbance on the biological integrity of ESAs.

What monitoring, conservation, and research activities are most appropriate for the ecologically significant areas identified?

Appropriate monitoring, conservation, and research activities will vary among ESAs based on the feasible alternatives for conservation, the relative level of interest, and the nature of the ESA. Some ESAs are readily defined and identified (e.g., aspen groves), whereas others are derived through models and will require additional work to verify their number, location, and contribution to biological diversity (e.g., riparian areas of high biological diversity). Investments in assessing and maintaining biological integrity can be in the form of conservation, monitoring, or research. Here, we address general considerations and some specific opportunities for conservation, monitoring, and research regarding ESAs, as well as a discussion of inventory data needed to design conservation, monitoring, and research activities. Conservation, monitoring, and research needs for some ESAs were

addressed in previous issues, specifically old forests (Issue 1) and bogs, fens, and marshes (Issue 5); therefore, we address them in less detail here.

Prerequisite Inventory Data

The first step in conserving and monitoring selected ESAs is to take an accurate inventory of their number and locations in the basin. Knowledge is more complete regarding the distribution of some types of ESAs than others. We are relatively confident of the locations of all old forests in the basin because of the work of Barbour and others (see Issue 1, this chapter). Also, aspen communities over 1 hectare are accurately inventoried and reliably mapped. The single identified cushion plant community is well known; however, other cushion plant communities may exist in the basin in such areas as the Mount Rose Wilderness (Allessio 1999). A modeling and validation effort could be conducted to assist in identifying potential locations of cushion plant communities in the basin. Surveys need to be conducted for deep-water plant beds in Lake Tahoe to document their number, location, and species composition.

Conservation

The integrity of the basin's ESAs would best be served if conservation measures were developed, adopted, and implemented for all ESAs in the basin. We identified three general types of conservation actions: (1) awareness and education, (2) measures to protect biological integrity, and (3) restoration options. Awareness and education can be achieved in a variety of ways, including (but not limited to) concerns highlighted in such publications as this assessment, workshops, campfire talks, Internet web sites, newspaper and radio media, school programs, research symposia, and public involvement in monitoring and conservation efforts. Measures to protect biological integrity include implementing actions intended to safeguard ESAs or to mitigate impacts to them. Restoration options include measures to improve the quality or quantity of an ESA, including improving physical and biological conditions, restoring natural processes (e.g., fire, flooding), reducing human disturbances, and increasing the number or area of the ESA (where feasible). Restoration activities would be warranted only if degradation of ESAs were noted. Conserving biological integrity of ESAs will be most successful if all three types of conservation actions are employed. Below, we discuss some options and opportunities for conserving ESAs.

Awareness and Education—Awareness and education efforts in regard to ESAs could convey the high ecological and cultural value of ESAs in the basin; in addition, they could highlight their potential fragility and vulnerability. The public could become involved in inventory, monitoring, and conservation efforts, which could be a powerful mechanism for education and awareness.

Measures to Protect Biological Integrity—Some examples of measures that would contribute toward the maintenance and protection of biological integrity of ESAs in the basin are provided below. They represent a short list of effective measures; many other measures may be appropriate and could be identified in the course of developing a conservation strategy for ESAs in the basin. A conservation strategy for biological integrity and diversity in the basin would facilitate full consideration of appropriate protection and enhancement options and priorities. Here we simply provide some first thoughts.

Bogs and Fens—Simple conservation measures to protect the integrity of bogs and fens include the following: (1) limit trampling from grazing and human visitation, (2) avoid alteration of drainage patterns, (3) avoid subsurface water removal (e.g., wells) in the vicinity of bogs, and (4) avoid any activities that may affect pH (e.g., road salting, addition of nutrients through fertilizers) (Shevock 1999).

Aspen Groves—Curtailing grazing in aspen groves could maintain the natural diversity of herbaceous cover and natural succession pathways (Greenway 1990). In addition, recreation has a high likelihood of disturbing the use of aspen by wildlife. Restricting recreation to well-established hiking trails would minimize this disturbance. Restricting motorized recreation in aspen groves would be the greatest contribution to reducing disturbance from

recreation, particularly from spring to fall. Larger aspen groves (> 5 ha) would be the highest priority for these conservation measures.

Cushion Plant Community—Avoiding any direct interaction (management or recreation) with the cushion plant community is probably the most effective protective measure for this ESA and would help ensure its continued biological integrity. Because the Freel Peak area is used by hikers but no designated trails exist, establishment of designated trails would ensure that dispersed recreation has minimal impacts to cushion plants.

Deep-water Plant Beds—Maintenance of lake clarity is probably the best way to protect the biological integrity of deep-water plant beds. Reducing disturbance to deep-water plants, once their locations are better identified and their vulnerabilities are defined, also will help maintain the integrity of the plant beds.

Old Forests—Old forest ESAs and their natural processes can be readily maintained by curtailing timber management activities and by using prescribed fire to maintain forest structure and vegetation composition. Grazing in old forest ESAs should be reviewed to ensure that no detrimental effects are being incurred.

Riparian Biodiversity Hotspots—Protecting and maintaining biological diversity in riparian diversity hotspots identified as ESAs is best accomplished by allowing such natural processes as flooding and fire to occur and by limiting impacts from livestock and people, including soil compaction, trampling, alteration of woody vegetation, declines in water quality, sedimentation, introduction of exotic species, and the alteration of behavioral patterns resulting from human presence. Published literature (e.g., Kondolf et al. 1996) can be consulted to determine how best to manage riparian areas and their associated aquatic ecosystems to maintain their biological and physical integrity.

Community Diversity—Protecting and maintaining biological diversity in community diversity hotspots, as identified by ESAs, is best accomplished by allowing such natural processes as fire and succession to occur and by limiting impacts from grazing, timber harvest, soil compaction, and the introduction of exotic species. Community diversity also can be maintained and protected by providing incentives for new and existing human developments to maintain native vegetation and a diversity of vegetation types.

Restoration Options

Bogs and Fens—No restoration options for bogs and fens are evident at this time. Bogs and fens are delicate systems that would be difficult to restore.

Aspen Groves—Low- to moderate-intensity burning in and around aspen areas that mimics natural fire regimes would perpetuate aspen communities by improving soil conditions (Cryer and Murray 1992) and eliminating encroaching conifer saplings.

Cushion Plant Community—No restoration opportunities are apparent at the current time, but this could change if new populations are discovered.

Deep-water Plant Beds—Improving the clarity of Lake Tahoe will improve environmental conditions for deep-water plant beds.

Old Forests—Restoring the role of natural fire in old forests is likely to be a strong contributor to restoring integrity and is likely to be a challenging endeavor. Restoring the role of natural fire through the use of prescribed fire is a relatively high priority in the basin, as indicated in Issues 1, 2, and 3 in this chapter.

Riparian Biodiversity—The potential to improve the biological diversity of riparian areas would apply only to areas that have been degraded. The process of assessing degradation involves determining the existing versus potential diversity and falls largely in the realm of research (see below). However, once degraded areas have been identified, appropriate restoration activities could be identified for individual degraded areas. Restoration activities could include planting woody vegetation, enhancing snag and log populations, restoring natural channel routes, altering channel morphologies, eradicating exotic species, reintroducing native species, and enhancing habitat for native species.

Community Diversity—The potential to improve the diversity of communities is probably limited and would apply only to areas that have been degraded. The primary source of degradation is development and it is unlikely that developed areas can be improved in terms of community diversity. A few cases may exist where community diversity has

been degraded in an undeveloped area as a result of heavy recreation use or the conversion from one community type to another (e.g., marsh to meadow). If areas with the potential for restoration were identified and prioritized, a restoration plan could be developed for them. In most cases, the restoration of focal communities (aquatic and terrestrial) will serve to enhance community diversity as well.

Monitoring

Monitoring designed to describe the status of and change in the integrity of ESAs would provide a wealth of information about their current conditions, how their conditions are changing over time, and basic relationships between their condition and the changing environment in which they occur. Developing a monitoring scheme entails identifying attributes to describe conditions, and designing and implementing data collection and analysis. Monitoring attributes can consist of direct measures of condition as well as indirect measures that serve as indicators of integrity. Indicators can provide a strong signal of conditions through the use of relatively few attributes (e.g., Barber 1994). It would be worthwhile to attempt to identify indicators and to monitor their conditions on a trial basis, but it is premature to rely entirely on indicators before the strength of their signal has been validated.

The development of a strong monitoring strategy will require a careful evaluation of potential attributes (both direct and indirect measures), articulation of the questions to be answered, and consideration of effective design options. Here, we make some general recommendations as to attributes that would provide direct measures of ESA conditions.

A strong approach to monitoring the condition of ESAs consists of a balance of physical, biological, and disturbance attributes for each unit selected for monitoring (Table 5-42). Physical attributes consist of abiotic conditions, such as soil, water, and channel conditions. Biological attributes can consist of the frequency or relative abundance of selected plant, vertebrate, invertebrate, and fungal taxa, the vertical and horizontal structure of the vegetation, and snag and downed woody debris characteristics. Disturbance attributes could include intensity of recreation, grazing, timber harvest, fire (prescribed, natural, and accidental), pollutants, and physical disturbances caused by human activities.

Table 5-42—Potential attributes for monitoring status and change of Ecologically Significant Areas (ESAs). Attributes associated with each ESA are indicated.

	Ecologically Significant Areas				
Monitoring attributes	**Bogs, fens, marshes**	**Deep-water plant beds**	**Old forests, aspen, cushion plant**	**Riparian diversity**	**Community diversity**
Physical:					
Substrate	X	X			
Water temperature	X	X		X	
Water depth	X	X		X	
Water clarity		X			
Flooding regime	X			X	
Soil strength				X	
Water chemistry	X	X		X	
Biological:					
Species composition	X	X	X	X	X
Species abundance	X	X	X	X	X
Vegetation structure	X	X	X	X	X
Disturbance:					
Grazing	X		X	X	X
Timber harvest			X	X	X
Prescribed burning	X		X	X	X
Pollutants	X	X	X	X	X
Recreationists	X	X	X	X	X

Issue 7: The Need to Understand the Condition of Species and Populations in the Basin

With contributions from Erik R. Holst, Sheryl L. Ferguson, J. Shane Romsos, and Jennifer S. Hodge

As management and settlement of the basin proceed over the coming years, species and populations are at risk of increasing stress from direct interactions with people and declines in the quality and quantity of their habitats. We assessed the species and population component of biological integrity in the basin by identifying species and populations that might be at greatest risk of future decline or extirpation and that are of particular cultural importance. Many factors can herald the decline of species and populations, including historic population declines, inherent life history characteristics that make species vulnerable to physical disturbances or rapid habitat changes, and excessive or chronic harvesting. We used a number of criteria to identify species of concern or interest within the basin across all species of macrobiota, including vertebrates, invertebrates, vascular and nonvascular plants, and fungi (including lichens). The unique characteristics of individual species of concern require consideration in identifying the appropriate action to take on their behalf. Conservation, management, research, and monitoring are all actions that are necessary to maintain and restore native and desired nonnative species and populations as part of our effort to conserve biological integrity and achieve ecological sustainability in the Lake Tahoe basin.

Our assessment of species and populations in the Lake Tahoe basin addresses the following questions:

- What species currently occur in the basin?
- How has species composition changed from historic times to the present?
- Which species should be of special focus within the basin based on ecological and cultural criteria?
- What is the status of our knowledge about select focal species of greatest interest to local agencies and organizations?
- What data gaps were revealed in the process of assessing species and populations?
- What monitoring, conservation, and research activities are most appropriate for the focal species identified?

What species currently occur in the basin?

We compiled lists of species occurring in the Tahoe basin by taxonomic group: vascular plants, nonvascular plants, vertebrates, invertebrates, and fungi. An accurate determination of current biotic composition in the basin was challenged by incomplete information for some taxonomic groups, and multiple, sometimes obscure sources of data with varying levels of reliability for data on all groups. Information on vertebrates and vascular plants was relatively comprehensive, and we believe the species lists we compiled are fairly accurate and complete. Information on nonvascular plants, invertebrates, and fungi was sparse, and therefore the species lists we compiled are a starting point for further work.

We include both native and nonnative (exotic) species in the species tallies presented here. Detrimental impacts from exotic species can include nest parasitism, resource competition, overgrazing, habitat conversion or degradation, disease transmission, and increased predator pressure (Atkinson 1989). In later sections of this issue, we treat exotic species separately from native species to discuss considerations unique to native and nonnative species.

The sources consulted for basin species occurrences varied in their reliability. We assigned reliability ratings to the documentation of species occurrence in the basin based on the source(s) of the information. The highest reliability rating (high) was given to a species if its occurrence was confirmed by a scientific study, inventory, or museum collection. Ratings reflecting lower confidence in the data (moderate and low) were assigned to species whose occurrence in the basin were documented in nonscientific sources or personal communications or whose occurrence was suggested for a general region (e.g., the Sierra Nevada) without any records in the basin. These ratings are noted in association with each species (appendices E through I) and were useful in identifying gaps in our knowledge of the basin's species composition as well as interpreting historical trends.

Vascular Plants

Vascular plants are plants with veins and include all flowering plants; they comprise the most well-known division of plants, the Anthophyta (Wilson and Loomis 1967; Hickman 1993). Given the large area, complex topography, and lack of extensive plant surveys in the basin, developing a definitive list of plant species was difficult. We compiled a list of vascular plant species known to occur and potentially occurring in the Lake Tahoe basin (Appendix E).

We consulted a variety of sources for identifying plants occurring in the Lake Tahoe basin. Occurrences documented by a specimen (i.e., museum, university, or agency collection) or through a scientific source (e.g., scientific studies) were considered confirmed. Three data sources were available for confirmed sightings: Smith (1973, 1983), Manley and Schlesinger (in preparation), and USFS ecology plot data (USDA 1995a). Smith (1973, 1983) confirmed the occurrence of 923 taxa in the Lake Tahoe basin. Field surveys from Manley and Schlesinger (in preparation) in the basin identified 490 taxa. Finally, the USFS (USDA 1995a) noted 232 plant species. Between these three sources, a total of 1,077 taxa were confirmed to occur in the basin.

Species identified as potentially occurring in the basin but without documented sightings (e.g., some species from the CalFlora database) were considered unconfirmed. Three sources were consulted for species potentially occurring in the basin but lacking confirmed sightings: CalFlora database (Dennis 1995), Rarefind database (CDFG 1999), and the Forest Service manual (USDA 1995b). We queried the CalFlora database (Dennis 1995) for plants that occur in the Tahoe region (Sierra, Nevada, Placer and El Dorado counties east of the Sierra Nevada crest) above 1,880 meters (6,200 feet), which added 361 taxa (species, subspecies, and varieties) to the list. We were not able to query efficiently for the small portion of Alpine County that occurs in the Lake Tahoe basin (approximately 15.5 square kilometers [six square miles]), nor were similar databases available for the Nevada side of the basin. Two species were added from the Forest Service Manual (USDA 1995b). Hickman (1993) and Munz (1968) were consulted to aid in identifying ranges, elevational limits, and current nomenclature.

A few species were removed from the list of potentially occurring species based on consultation with local botanists. We removed three taxa that USDA Forest Service botanists (Taylor 1999; Urie 1999) determined were unlikely to occur in the basin: Dog Valley mousetail (*Ivesia aperta* var. *canina*), mountain lady's slipper (*Cypripedium montanum*), and Sierra Valley mousetail (*Ivesia aperta* var. *aperta*). Truckee barberry (*Berberis aquifolium* var. *repens*) was removed from the list because of data that suggest it is not a distinct variety (Taylor 1999; Urie 1999).

The final list of plants for the Lake Tahoe basin consisted of 1,308 species. Of these, 957 species were identified to the species level only, while 351 species were further identified to subspecies or varieties. The list contains 481 subspecies and varieties, for a total of 1,438 unique taxa. The final plant list is based on the nomenclature and taxonomy of Hickman (1993).

Nonvascular Plants

Our treatment of nonvascular plants included plants commonly referred to as bryophytes. Other taxonomic groups are sometimes included (e.g., lichens), but only bryophytes are formally considered nonvascular plants (USGS 1997; Goodman 1996). Bryophytes are classified into three divisions: Bryophyta (mosses), Hepatophyta (liverworts), and Anthocerophyta (hornworts). They are multicellular, eukaryotic organisms that possess chlorophyll (Richardson 1999).

Data on the nonvascular plants of the Lake Tahoe basin were sparse and incomplete. However, some data have been collected, and confirmations of recent species occurrences do exist (e.g., Manley, unpublished data; UCB 1999a), as well as documentation of species occurring in the Sierra

Nevada (Shevock 1996). We identified 110 species and 5 additional genera, for a total of 115 unique taxa, recorded or potentially occurring in the basin (Appendix F). Our list of nonvascular plants recorded or potentially occurring in the basin is undoubtedly lacking many taxa but is intended to serve as a working hypothesis about the nonvascular plant flora of the Lake Tahoe basin (Appendix F).

Vertebrates

Vertebrates include mammals, birds, reptiles, amphibians, and fish. Throughout this document, we make the distinction between "terrestrial" vertebrates and fish for sake of simplicity, recognizing, however, that many terrestrial species, such as amphibians, also use aquatic habitats. To our knowledge, no complete list of vertebrates in the Lake Tahoe basin has been previously compiled. Numerous lists of one or more vertebrate groups (clades) exists, but none have addressed all vertebrates. Published research and local knowledge about the basin's vertebrates varies widely by taxonomic group; the basin's birds have been studied scientifically and watched by amateurs more than the other vertebrate groups, but fish have attracted almost as much attention because of widespread interest in sport fisheries. Reptiles and amphibians (herpetofauna), on the other hand, are generally more cryptic, are of less interest to the general public, and are the focus of fewer scientific studies. Therefore, the basin's birds are best known, followed by fish, then mammals, and finally herpetofauna.

We consulted the following primary data sources: Orr (1949), Miller (1951), Moyle (1976), Cordone et al. (1971), Orr and Moffitt (1971), TRPA and USDA (1971a, b), Beauchamp et al. (1994), Hall (1995), Tatum (1998a, 1998b), Pierson (1998), the Lake Tahoe basin bird species pamphlet (Eastern Sierra Interpretive Association ca. 1993), and recent sightings generated by scientific studies (e.g., Keane and Morrison 1994; Manley and Schlesinger, in preparation) and agency field personnel (USDA, unpublished data). A complete listing of all sources consulted for each taxonomic group accompanies the species list in Appendix G.

Many additional sources could have been consulted to determine other vertebrate species potentially occurring in the basin. However, the references we consulted represent the primary sources of information on vertebrate species occurrences in the basin. A few additional sightings undoubtedly could be garnered by querying more tangential data sources, but it is improbable that they would substantively change the vertebrate species list or conclusions regarding general trends in species composition over time. In addition, we could have gone beyond confirmed species sightings and used range maps and habitat associations to predict vertebrate species occurrence, which would have yielded many additional species. We felt that such an extrapolation would only obscure patterns of change that might be apparent from examining species records. Therefore, our species list represents only documented vertebrates.

Based on the data sources consulted, we estimate that the basin has 312 vertebrates as residents or regular, if not frequent, visitors ("current" species; Appendix G). This total represents 217 bird, 59 mammal, five amphibian, eight reptile, and 23 fish species. An additional 57 species have been recorded in the basin and are considered accidental visitors or extirpated from the basin. Considerations for extirpated species are addressed in later portions of this issue even though extirpated species are not considered to be current.

Invertebrates

Invertebrates for purposes here, include insects, crustaceans, and spiders. Although data on the invertebrate fauna of the Lake Tahoe basin are sparse and incomplete, some data have been collected and confirmations of recent species occurrences do exist. We consulted the following data sources: Frantz and Cordone (1966, 1996), SFSU (1999a), NAMC (1999), Storer and Usinger (1963), and Manley and Schlesinger (in preparation). Other sources (e.g., Powell and Hogue 1979, Milne and Milne 1988, Borror and White 1970, Furniss and Carolin 1977, Baker 1994, UCR 1999, Hanson and Walker 1999, FUNET 1999, USDA 1999a) were consulted to provide additional or supportive information. A total of 810 unique taxa have been recorded in the basin or potentially occur there, including 379 families, with many of their genera and species identified (Appendix H). These families and

the other taxa listed in Appendix H include taxa that are documented or potentially occur in the Lake Tahoe basin. Taxa described as potentially occurring are those that have been recorded in the Sierra Nevada but not in the basin. This list of taxa is intended to serve as a working hypothesis about the invertebrate fauna of the Lake Tahoe basin (Appendix H).

Fungi and Lichens

Members of the kingdom Fungi are multicellular eukaryotic organisms (UCB 1999b). These plant-like organisms generally lack chlorophyll and so obtain their food through saprophytic or parasitic absorption of nutrients from other organic matter (Arora 1986). Fungi typically take the form of thread-like filaments called hyphae (that collectively form the mycelium) and reproduce by means of microscopic spores. The spores are produced in a reproductive structure or fruiting body, which is commonly known as a mushroom. Lichens are classified as members of the kingdom Fungi but consist of a unique symbiotic relationship between algae (tiny photosynthetic plants) and fungi. They have three alternative growth forms: crustose (forming thin crusts on rocks and other substrates), foliose (leaf-like structures attached to plants and rocks), and fruticose (stiff hair-like structure attached to and often hanging from plants) (Hale and Cole 1988). Life cycles of fungi and lichens can be extremely complex and vary considerably among taxa.

Data on the fungi and lichens of the Lake Tahoe basin are sparse and incomplete. However, some data collection has been conducted (Ryan 1990; Manley, unpublished data), and confirmations of recent occurrences do exist. In addition, various works (e.g., Desjardin 1997, SFSU 1999b) have identified species, genera, families, and orders known to occur in the Sierra Nevada. We have noted 612 unique taxa of fungi and lichens as documented or potentially occurring in the Lake Tahoe basin (Appendix I), consisting of 573 species from 300 genera plus 39 additional genera. Known varieties are indicated on the table. This list of recorded and potentially occurring taxa is intended to serve as a working hypothesis about the potential fungi and lichens of the Lake Tahoe basin.

How has species composition changed from historic times to the present?

Historical data were limited for most biota; however, data sources for vertebrates were available to evaluate coarse changes over time. Orr (1949) and Orr and Moffitt (1971) compiled species records for the basin and Grinnell et al. (1937) and Hall (1995) included some basin sightings, all of which were valuable in describing the historical occurrences of birds and mammals. We considered only current species, excluding those considered especially uncommon, because addressing species that do not have an established population in the basin would have obscured major patterns of change. Details on how we derived this subset are described later in this issue. We describe the status of information and changes in vertebrate species composition over the four major time periods established in Chapter 2: Prehistoric Era (pre-1860), Comstock Era (1860 to 1900), Post-Comstock Era (1900 to 1960), and Urbanization Era (1960 to present). Discussion of introductions of fish to Lake Tahoe appear in Chapter 4. For the more recent eras, the availability of more detailed data facilitated separate treatment of native and nonnative (referred to as exotic [Allaby 1994]) species.

Prehistoric Era

No formal inventories of terrestrial and aquatic species were conducted during this period, so a lack of data is noted for most vertebrates for this era (Appendix J). Nevers (1976) noted that Washoe history mentions the presence of mountain sheep (*Ovis canadensis californiana*) in the basin. In addition, a few references to fish species do exist for this era. Historic accounts often mention the abundance of Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*), mountain whitefish (*Prosopium williamsoni*), and "abalone" (species unknown) during this era (Nevers 1976) (Appendix J). More recent research suggests that tui chub (*Gila bicolor*), Lahontan redside (*Richardsonius egrefius*), speckled dace (*Rhinichthys osculus*), Tahoe sucker (*Catostomus tahoensis*), and Piute sculpin (*Cottus beldingi*) were also common in Lake Tahoe prior to the arrival of European settlers in the basin (see Elliott-Fisk et al.

1997) (Appendix J). Although few records exist for the Prehistoric Era, it is likely that native plants and animals documented in the Comstock Era were also present during the Prehistoric Era.

Comstock Era

Information on species composition during the Comstock Era is available but incomplete. In terms of terrestrial species, we were able to find documentation of 66 bird species during this era, but records of mammals, reptiles, and amphibians were not available for this time period (Appendix J). The composition of native species of mammals, reptiles, and amphibians in this era was probably very similar to the composition of native species during the Post-Comstock Era because conditions varied more within than between these eras. Variation in population sizes is likely to be the greatest source of change within and between these eras in response to the major shifts in environmental conditions. However, no data exist on population sizes.

Changes in fish species composition were evident in the Comstock Era, with the introduction of nonnative species constituting the greatest known change (Appendix J). The eastern brook trout (*Salvelinus fontinalis*) was probably the first non-native fish species to be introduced into the streams and lakes of the Lake Tahoe basin (Miller 1951; Elliott-Fisk et al. 1997). Circa 1880, brook trout were first planted in Marlette Lake (Scott 1957), and from 1891 to 1893 large numbers were introduced into Lake Tahoe itself (CDFG 1957). In 1895, the Fish Commission (later to become the California Department of Fish and Game) planted 65,000 Great Lakes mackinaw (*Salvelinus namaycush*) fingerlings from a fish hatchery near Mount Shasta into lakes above Meeks Bay (Scott 1957). By the 1920's, mackinaw trout were established in Lake Tahoe, having migrated down Meeks Creek from lakes in the upper Meeks Creek drainage (Scott 1957).

Post-Comstock Era

Native Species—Fifty-seven species of mammals and 135 species of birds were recorded in the basin during the Post-Comstock Era by various observers and biologists (Appendix J). The increased number of bird species recorded in the Post-Comstock Era compared to the Comstock Era is probably reflective of increased field effort and greater abundance of historical accounts rather than true increases in native species richness in the basin. For example, naturalists such as George Wharton James (James 1915) wrote accounts about the basin, describing the character of the forests and noting the occurrence of certain "charismatic" species in a series of his anecdotes and observations. He noted that bald eagles (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*) were often seen, but apparently nested outside the basin, mountain lions (*Felis concolor*) and black bears (*Ursus americanus*) sometimes preyed upon flocks of sheep, and rangers in the forest reserve reported infrequent but significant outbreaks of porcupine (*Erethizon dorsatum*) damage to trees (James 1915).

The dynamics of aquatic communities changed significantly during this era, and declines in populations of native fish species became apparent. James (1915) noted that in smaller lakes in the basin, native trout were becoming rare, but in Tahoe itself they did not seem to have been "driven out" by introduced species. However, populations of the native Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*) declined steadily even after the California legislature banned commercial fishing in regional lakes and streams in 1917 (Gerstung 1988).

Exotic Species—Successful introductions and invasions of exotic aquatic species were numerous during the Post-Comstock Era. In a major effort to enhance Lake Tahoe's fishery, over 14 million nonnative fish were planted in the lake from 1944 to approximately 1960 (Strong 1984). Kokanee salmon (*Oncorhynchus nerka kennerlyi*) were first introduced in 1944 and were released in greater numbers after 1950 (Cordone et al. 1971). Adult Lahontan cutthroat of the Heenan Lake strain were introduced annually in Taylor Creek and the Upper Truckee River from 1956 through 1964 (Strong 1984).

Data on the distribution and abundance of exotic terrestrial vertebrates are limited to the European starling (*Sturnus vulgaris*). It was first recorded in the basin in 1959 (Orr and Moffitt

1971). During this era, starlings were undergoing a range expansion on a continental scale, typically occupying environments subject to human disturbance (Ehrlich et al. 1988). The arrival of starlings in the basin is most likely the result of a combination of their general range expansion and an increasing proportion of the basin occupied by human dominated environments (see Chapter 2 for descriptions of historic environmental changes).

Urbanization Era

Native Species—Many native species declined or were apparently extirpated during this era. One hundred forty-five bird species, 54 mammals, five amphibians, and eight reptiles were recorded in the basin during the Urbanization Era (Appendix J). Wolverines (*Gulo gulo*) and northern leopard frogs (*Rana pipiens*) appear to have been extirpated, and grizzly bears (*Ursus arctos*) and mountain sheep no longer occur in the basin. Twenty-three species of fish were recorded in the Urbanization Era (Appendix J); the Lahontan cutthroat trout was temporarily extirpated from the basin but was subsequently reestablished during this era (Reiner 1999). Populations of mountain whitefish and Tahoe suckers are suspected to be at extremely low numbers (Elliott-Fisk et al. 1997). The Tahoe yellowcress (*Rorippa subumbellata*), a plant endemic to the basin, was so threatened by shrinking habitat, unnatural manipulation of lake levels, and recreational disturbance of the shoreline (TRPA 1996).

Exotic Species—For the Urbanization Era, documentation of exotic species was much more detailed than in earlier periods. At least seven exotic terrestrial vertebrate species were first recorded in the basin during the Urbanization Era, including the bullfrog (*Rana catesbeiana*), rock dove (*Columba livia*), wild turkey (*Meleagris gallopavo*), and beaver (*Castor canadensis*) (Appendix J). Four additional species possibly could be considered exotic species, as they are native to the US but occur in the basin outside their typical geographic and elevational ranges: brown-headed cowbird (*Molothrus ater*), common raven (*Corvus corax*), western gray squirrel (*Sciurus griseus*) (Jameson and Peeters 1988), and California quail (*Callipepla californica*) (Ahlborn 1990a) (Appendix J).

The growth of sport fishing as a recreational activity and associated further development of marinas and boat launching facilities precipitated the introduction of many exotic aquatic species. Six species of exotic fish, including three species of trout, were introduced into Lake Tahoe (Appendix J). Three strains of "wild" rainbow trout (Kamloops, Pyramid Lake, and Williams Lake) (*Oncorhynchus mykiss*) and domestic trout were released between 1960 and 1963. The success of exotic fish species may have been aided by the introduction and proliferation of exotic aquatic plants, such as Eurasian watermilfoil (*Myriophyllum spicatum*), by increasing water temperatures associated with inland marinas (Kilgore et al. 1989), and the intentional introduction of exotic food sources (Frantz and Cordone 1996). Between 1963 and 1965, approximately 333,000 mysid shrimp (*Mysis relicta*), also referred to as opossum shrimp, were introduced at various locations around Lake Tahoe in an effort to improve the food supply for the mackinaw trout (Frantz and Cordone 1996). These shrimp are suspected to have caused declines in native invertebrates (Goldman et al. 1979).

Synthesis and Analysis of Historical Changes

Impacts of past land uses on biological diversity are unknown and difficult to quantify because site-specific information is scarce, especially for periods prior to 1900. One can only speculate, based on historical descriptions of the landscape, on the extent to which humans have influenced changes in species composition. Elliott-Fisk et al. (1997) and McKelvey and Johnston (1992) provide a thorough review of available information on historical land uses in the basin, while several sources (e.g., Orr 1949; Orr and Moffitt 1971; Hall 1995) contain accounts of vertebrate species that were also helpful in attempts to describe the occurrence of birds and mammals in the basin. Only within the past 25 years have comprehensive surveys and monitoring efforts begun to document and thus increase our

understanding of species composition in the basin (Manley and Schlesinger, in preparation; Keane and Morrison 1994; USDA unpublished data).

The apparent decline in abundance and distribution of many native species in aquatic communities has been attributed to reduction of species' historic ranges, destruction of spawning habitat, and introduction of exotic species (Strong 1984; Gerstung 1988). Many aquatic ecosystems in the basin did not contain fish historically and it is possible that introductions of nonnative trout have reduced or eliminated populations of aquatic amphibians as is suspected to have occurred throughout the Sierra Nevada (Moyle 1996). In addition, disturbances that have degraded aquatic habitats in the past, such as development and recreation, may have been more pronounced within the basin because of the greater concentration of human activity compared to the rest of the Sierra Nevada (see Issue 5, this chapter).

We evaluated shifts in species presence across the eras to identify potential or known additions to or extirpations from the vertebrate fauna of the basin (Table 5-43). The apparent additions or extirpations (based on trends in presence and absence across the eras) were evaluated further by considering information on the species' residential status (i.e., regular resident versus vagrant), population trend (i.e., declining or stable), and the reliability of the data (i.e., limited historical data available, present data represented by one or many sightings). All determinations of gains or losses are made in the context of the data consulted and are simply intended to serve as points of further clarification.

Changes in the Bird Fauna—The current species composition of birds in the basin is relatively well documented. Thus, the possibility of extirpation was evaluated for any species not recorded as present in the Urbanization Era. Four bird species were considered potentially extirpated from the basin because they were present in previous eras but were not recorded in the Urbanization Era: peregrine falcon (*Falco peregrinus*), savannah sparrow (*Passerculus sandwichensis*), Lewis's woodpecker (*Melanerpes lewis*), and canyon wren (*Catherpes mexicanus*) (Table 5-43). The peregrine falcon is noted as having occurred within the basin during the Post-Comstock Era by Reed (1981), but her sources were not documented. No peregrine falcons have been sighted in the basin in the Urbanization Era, with the exception of those individuals involved in an unsuccessful effort to reestablish the species in the late 1980s and early 1990s (TRPA 1996; USFS, unpublished data). The savannah sparrow was noted in Orr and Moffitt (1971) as a common summer visitor, Lewis's woodpecker was noted in Orr and Moffitt (1971) as an irregular summer visitor, and the canyon wren was noted by Orr and Moffitt (1971) as rare or irregular. All four of these species were considered only potentially extirpated because it is unknown if they ever established populations in the basin. Finally, 30 species of birds described by Eastern Sierra Interpretive Association (ca. 1993) as "accidental" or "rare" were documented in the Comstock and Post-Comstock eras but not in the Urbanization Era (Table 5-43); these species were not considered extirpations because they may never have established populations in the basin.

Twenty-seven species of birds were recorded only in the Urbanization Era, including six known additions and three potential additions (Table 5-43). Five of the six known additions were exotic species: wild turkey, European starling, California quail (*Callipepla californica*), rock dove (*Columba livia*), and house sparrow (*Passer domesticus*). The brown-headed cowbird is the sixth known addition. It is a brood parasite that has expanded its range from east of the Mississippi to the west coast this century in response to changing land use patterns (Ehrlich et al. 1988).

Three species that may have populated the basin in the Urbanization Era are common raven, spotted owl (*Strix occidentalis*), and downy woodpecker (*Picoides pubescens*). All three of these species have been recorded only in the Urbanization Era and are relatively easy to detect. In addition, changes in ecological conditions (i.e., regeneration of forests, high density of trees, large numbers of snags [see Issue 1]) over the past 150 years suggest that habitat conditions for these species have improved based on their basic habitat associations (Zeiner et al. 1990a). The specific circumstances related to each species are discussed below.

Table 5-43—Potential or verified extirpations ("lost") and additions ("gained") to the vertebrate fauna of the Lake Tahoe basin. Potential changes are indicated by a "maybe" in the "lost" or "gained" column. The era in which species' presence has been verified is indicated by an X (n.d. = no data available for the era).

Common Name	Scientific Name	Exotic	Prehistoric Era (pre-1860)	Comstock Era (1860-1900)	Post-Comstock Era (1901-1960)	Urbanization Era (1961-present)	Lost[a]	Gained
Birds[b]:								
California Quail	*Callipepla californica*	X	n.d.		X	X		Yes
Canyon Wren	*Catherpes mexicanus*		n.d.	X	X		Maybe	
Rock Dove	*Columba livia*	X	n.d.			X		Yes
Common Raven	*Corvus corax*		n.d.			X		Maybe
Peregrine Falcon	*Falco peregrinus*		n.d.		X		Maybe	
Lewis's Woodpecker	*Melanerpes lewis*		n.d.	X	X		Maybe	
Wild Turkey	*Meleagris gallopavo*	X	n.d.			X		Yes
Brown-headed Cowbird	*Molothrus ater*		n.d.			X		Yes
House Sparrow	*Passer domesticus*	X	n.d.		X	X		Yes
Savannah Sparrow	*Passerculus sandwichensis*		n.d.		X		Maybe	
Downy Woodpecker	*Picoides pubescens*		n.d.			X		Maybe
Spotted Owl	*Strix occidentalis*		n.d.			X		Maybe
European Starling	*Sturnus vulgaris*	X	n.d.		X	X		Yes
Mammals[c]:								
Beaver	*Castor canadensis*	X	n.d.	n.d.		X		Yes
Wolverine	*Gulo gulo*		n.d.	n.d.	X		Maybe	
White-tailed hare	*Lepus townsendii*		n.d.	n.d.	X		Maybe	
Mountain sheep	*Ovis canadensis californiana*		X				Maybe	
Canyon mouse	*Peromyscus crinitus*		n.d.	n.d.	X		Maybe	
Heather vole	*Phenacomys intermedius*		n.d.	n.d.	X		Maybe	
Western gray squirrel	*Sciurus griseus*		n.d.	n.d.		X		Yes
Grizzly bear	*Ursus arctos*		n.d.	n.d.	X		Yes	
Sierra Nevada red fox	*Vulpes vulpes necator*		n.d.	n.d.	X		Yes	
Amphibians[d]:								
Bullfrog[c]	*Rana catesbeiana*	X	n.d.	n.d.	?	X		Yes
Northern leopard frog	*Rana pipiens*	?	n.d.	n.d.	X		Maybe	

Table 5-43—*(continued)*

Common Name	Scientific Name	Exotic	Prehistoric Era (pre-1860)	Comstock Era (1860-1900)	Post-Comstock Era (1901-1960)	Urbanization Era (1961-present)	Lost[a]	Gained
Fish[e]:								
Goldfish	*Carassius auratus*	X				X		Yes
Lake whitefish	*Coregonus clupeaformis*	X		X	X			Yes
Carp	*Cyprinus carpio*	X				X		Yes
Mosquito fish	*Gambusia affinis*	X				X		Yes
Brown bullhead	*Ictalurus nebulosis*	X				X		Yes
Bluegill	*Lepomis macrochirus*	X				X		Yes
Largemouth bass	*Micropterus salmoides*	X				X		Yes
Smallmouth bass	*Mircopterus dolomieui*	X				X		Yes
Golden shiner	*Notemigonus crysoleucas*	X				X		Yes
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*		X	X	X		Yes[f]	
Rainbow trout	*Oncorhynchus mykiss*	X			X	X		Yes
Kokanee salmon	*Oncorhynchus nerka kennerlyi*	X			X	X		Yes
Chinook salmon	*Oncorhynchus tshawytscha*	X		X	X			Yes
White crappie	*Pomoxis annularis*	X				X		Yes
Black crappie	*Pomoxis nigromaculatus*	X				X		Yes
Golden trout	*Salmo aquabonita*	X		X	X	X		Yes
Atlantic salmon	*Salmo salar*	X		X	X			Yes
German brown trout	*Salmo trutta*	X			X	X		Yes
Brook trout	*Salvelinus fontinalis*	X		X	X	X		Yes
Mackinaw (lake) trout	*Salvelinus namaycush*	X		X	X	X		Yes
Arctic grayling	*Thymallus arcticus*	X		X	X			Yes

[a] Losses and gains were determined by reviewing the pattern of presence by era, resident status, exotic status, and population trends.
[b] Data sources for birds included Orr and Moffitt (1971), Keane and Morrison (1994), Manley and Schlesinger (in preparation), and USFS (unpublished data). Because there was virtually no documentation of bird occurrence prior to the arrival of Euroamerican settlers, no attempt was made to guess at bird species occurrence during the Prehistoric Era. However, in situations where a bird was not recorded between 1901 and 1959 but was recorded before and after this period, we assumed that that species occurred between 1901 and 1959.
[c] Data sources for mammals included Grinnell et al. (1937), Orr (1949), Keane and Morrison (1994), Manley and Schlesinger (in preparation), and USFS (unpublished data). We did not find written documentation of mammal occurrence prior to 1901.
[d] Data sources for amphibians and reptiles included Museum of Vertebrate Zoology, University of California, Berkeley, Keane and Morrison (1994), and Manley and Schlesinger (in preparation).
[e] Data sources for fish included Miller (1951), Moyle (1976), Beauchamp et al. (1994), Tahoe Regional Planning Agency (1971a), Cordone et al. (1971), Manley and Schlesinger (in preparation.), and S. Lehr (1999.).
[f] The Lahontan cutthroat trout was extirpated from the basin and subsequently reintroduced.

The spotted owl was only recorded in the Urbanization Era. It has a large home range, requiring approximately 3,420 acres of suitable habitat per pair (Zabel et al. 1992). If the basin consisted entirely of suitable habitat, it could at best support 57 pairs of owls. It is plausible that the spotted owl was present in the basin prior to the Comstock Era. However, during the Comstock Era, much of the basin was logged, with the exception of portions of the west side of the basin. In light of the lack of documented occurrence, we assumed that no owls resided in the basin during this era. In the Post-Comstock and Urbanization eras, forested areas regenerated, and today many large trees occur in the basin once again (see Chapter 2). Surveys have identified an increasing number of breeding pairs of birds in the basin, with recent estimates at six pairs (USDA Forest Service, Lake Tahoe Basin Management Unit, unpublished data). These data suggest that the spotted owl may have reestablished a population in the basin that was lost during the Comstock Era.

The common raven was also only recorded in the Urbanization Era. It is a large conspicuous bird that is common in both wilderness and areas with an urban/wildland interface (Ehrlich et al. 1988). It is unlikely that such a conspicuous bird would go unnoticed if present in previous eras. In our evaluation, the common raven was considered an addition to the basin's avifauna and we attributed its current presence to the increase in human-dominated environments in the basin (see Chapter 2).

The downy woodpecker is the smallest-bodied woodpecker found in the basin and is a common inhabitant of forests on the west side of the Sierra Crest. Woodpeckers are conspicuous because of their frequent vocalizations and drumming (Terrill 1983). The downy woodpecker tends to forage on smaller diameter woody material than the larger-bodied woodpeckers also occurring in the basin (e.g., hairy woodpecker (*Picoides villosus*) and pileated woodpecker (*Dryocopus pileatus*) (Zeiner et al. 1990a). As forests regenerated during the Post-Comstock and Urbanization eras and fire suppression became a standard practice, large stands of densely forested areas, including many younger trees whose growth was suppressed, became prevalent (see Chapter 2). Present day forest stand structure and conditions in the basin correspond with suitable habitat for the Downy Woodpecker (Ziener et al. 1990a), perhaps facilitating the species' establishment. In our evaluation, the Downy Woodpecker was considered a likely addition to the basin's avifauna.

Many species recorded only in recent eras were not considered additions to the bird fauna. The green heron (*Butorides striatus*) was recorded by Keane and Morrison (1994) only (Appendix J); it is not considered an addition because it is most likely a vagrant in the basin. An additional 17 species described by Eastern Sierra Interpretive Association (no date) as "accidental" or "rare" that were recorded only in the Urbanization Era (Appendix J) were not considered additions because they may not have established populations in the basin. An additional 79 species recorded in the Post-Comstock and Urbanization eras but not earlier (Appendix J) were not considered additions because of the paucity of data from earlier eras.

Changes in the Mammal Fauna—Historical data on mammals were limited to the two most recent eras. As such, it was difficult to determine any trends in occurrence for individual species. However, a few changes were discernible, including one known extirpation, six potential extirpations, and two potential additions. These species are discussed in more detail below.

The evidence and conclusions varied among the seven species absent from the Urbanization Era: grizzly bear, Sierra Nevada red fox (*Vulpes vulpes necator*), wolverine (*Gulo gulo*), white-tailed hare (*Lepus townsendii*) heather vole (*Phenacomys intermedius*), canyon mouse (*Peromyscus crinitus*), and mountain sheep. The grizzly bear extirpation is certain because this species is known to have been extirpated from the entire Sierra Nevada (Graber 1996). The Sierra Nevada red fox also may have been extirpated from the entire Sierra Nevada, based on the lack of current records and the failure to confirm individuals despite considerable survey effort (Zielinski 1999). The wolverine was documented in the basin by Grinnell et al. (1937) with a single record but subsequent inventories and studies have not detected it; it is treated as a likely extirpation because it has not been detected in over 60 years and it is

known to have declined in the Sierra Nevada (USDA 1999b). The white-tailed hare was noted by Orr (1949) as "relatively rare" in the basin and has not been documented since. The species is known to have declined in the Sierra Nevada as well (USDA 1999b). Sufficient surveys have not been conducted to conclude that the species has been extirpated from the basin, so it is considered only a potential extirpation. The heather vole was noted by Orr (1949) as extremely rare in the basin, and it has not been detected in the Urbanization Era despite inventory efforts designed to detect small mammals (e.g., Keane and Morrison 1994; Manley and Schlesinger in preparation). The canyon mouse was detected in the basin during the Post-Comstock Era (Museum of Vertebrate Zoology, University of California, Berkeley); however, it has not been detected during the Urbanization Era. Both the heather vole and canyon mouse are considered only potential extirpations because they may never have established populations in the basin. The mountain sheep was documented as occurring in the basin by the Washoe Tribe (Nevers 1976), and to the north of the basin in the Truckee River basin in the mid-1850s (Hall 1995). It has not been documented in the current era and is considered a potential extirpation because the quality of data documenting its historical occurrence is poor. Finally, the black-tailed hare (*Lepus californicus*) has not been detected in the Urbanization Era (Appendix J) but was not considered an extirpation because Orr (1949) considered the species to be a vagrant in the basin.

Two species of mammals were identified as potential or known additions to the mammal fauna in the Urbanization Era: western gray squirrel and beaver. The western gray squirrel is a conspicuous animal that commonly occupies open habitats (Burt and Grossenheider 1980) and was not detected before the Urbanization Era. It tends to fare well in urban/wildland interfaces, but the basin is above its typical elevational limit (Jameson and Peeters 1988). It is highly likely that the western gray squirrel is a new addition to the mammal fauna in the basin, facilitated at least in part by the increase in settlement around Lake Tahoe. The beaver is generally considered exotic to the Sierra Nevada, recently introduced for the purpose of fur trapping (Graber 1996). Consideration of the beaver as a recent addition to the basin is supported by Orr (1949), who did not list the beaver as occurring in the basin.

Four other species with records in the Urbanization Era only were not considered additions. The Brazilian free-tailed bat (*Tadarida brasiliensis*) and California myotis (*Myotis californicus*) were not considered additions because extensive surveys for bats were not conducted until the Urbanization Era. The least chipmunk (*Tamias minimus*) and desert woodrat (*Neotoma lepida*) were detected only by Manley and Schlesinger (in preparation), but both species were uncommon in their surveys (20 and two detections, respectively). Furthermore, both species were detected only on the east side of the basin, where historical records are sparse. It is likely that both species were present in earlier eras but were not detected because of their apparent rarity; therefore, they are not considered additions to the mammal fauna of the basin.

Changes in the Herpetofauna—Historical data on amphibians and reptiles were limited to the two most recent eras. One potential extirpation and one addition to the herpetofauna are suggested based on the data (Table 5-43). The northern leopard frog may have been extirpated from the basin. Historical occurrence of northern leopard frogs is documented by several records on the south shore (Appendix J), and the species formerly occurred in numerous locations throughout the northern Sierra (Jennings and Hayes 1994). Although the species has experienced population declines in the Sierra Nevada, it is debatable if the northern leopard frog ever had established a population in the basin, and if it did, it may have been introduced by humans (Jennings and Hayes 1994). The only addition to the amphibian fauna in the basin is the bullfrog. The bullfrog is exotic west of the Rocky Mountains (Stebbins 1985) and has been expanding its range rapidly over the past 100 years or so (Moyle 1973). The bullfrog typically occurs only below 1,220 meters (4,000 feet) in the Sierra Nevada (Morey 1988), but it has been able to establish populations at the lowest elevations in the basin (1,880 meters;

6,200 feet) in lakes and the mouths of streams that empty into Lake Tahoe (Manley and Schlesinger, in preparation). Two additional species, the southern alligator lizard (*Elgaria multicarinata*) and the common garter snake (*Thamnophis sirtalis*), which were recorded only in the Urbanization Era (Appendix J), were not considered additions because very few surveys for reptiles were conducted in earlier eras.

Changes in the Fish Fauna—Historical data on fish species in the basin are relatively comprehensive, with historical accounts dating back to the Prehistoric Era. One extirpation and 16 additions have occurred in the fish fauna of the basin according to the historical record of the past 150 years (Table 5-43). The Lahontan cutthroat trout is the only fish species known to have been extirpated from the basin. Of the 20 species of exotic fish that were introduced into lakes and streams in the basin, 16 currently maintain populations within the basin. Most of these fish species have been introduced to support sport fishing (Scott 1957).

Driving Forces of Observed Changes

The potential and known vertebrate species extirpations and additions within the basin appear to be have been caused by multiple factors. Factors that may be responsible for vertebrate extirpations include larger-scale declines, fire suppression, and topographic isolation. Larger-scale (i.e., regional or continental) population declines are likely responsible for the loss of red fox, grizzly bear, wolverine, white-tailed hare, and northern leopard frog. The exclusion of fire has changed forest structure and composition in the basin, as well as the composition and productivity of shrublands, meadows, and forested vegetation types with shrub or grass understories (e.g., lodgepole pine) (see Issues 2 and 3, this chapter). The exclusion of fire may be responsible for potential losses of the savannah sparrow, Lewis's woodpecker, canyon wren, heather vole, and canyon mouse. The high elevation topographic features creating the basin serve as a selective barrier to the movement of some biota, thus lowering immigration and emigration rates for some species compared to rates in unrestricted landscapes (Udvardy 1969; Brown 1995). For some species, a slowed immigration of new individuals, combined with the limited amount of suitable habitat for many species (resulting from the relatively small area of the basin and the linear distribution of terrestrial environments), may result in smaller population sizes and decreased rates of reestablishment if populations become extirpated (Udvardy 1969; Brown 1995).

The notion that the topographic features creating the lake basin serve as a barrier for some species is further suggested by the lack of species that would be expected to occur in similar but less isolated environments. For example, species with limited mobility, such as the western pond turtle (*Clemmys marmorata*), western skink (*Eumeces skiltonianus*), western rattlesnake (*Crotalus viridis*), and California newt (*Taricha torosa*), could find suitable habitat at low elevations in the basin (Zeiner et al. 1988) but apparently have never occurred in the basin. Their absence is likely the result of the inability to disperse across the high elevation terrain that surrounds the basin.

Many factors may have caused the addition of certain species of vertebrates: direct introductions, fire suppression, an increased level of settlement, increased abundance of large trees, and topographic isolation. Direct introductions are responsible for the addition of bullfrogs and all exotic fish. Fire suppression, while potentially responsible for some vertebrate extirpations, also may be responsible for the potential establishment of downy woodpecker populations. The increased level of settlement in the basin has shifted a greater proportion of the basin's ecological communities, particularly those in proximity to Lake Tahoe, to human-dominated landscapes (see Chapter 2). These changes have increased the suitability of environments around the lake for some native species, specifically brown-headed cowbird and common raven, as well as a number of exotic species, specifically European starling, house sparrow, and rock dove. The regrowth of forests during the Post-Comstock and Urbanization eras resulted in the recurrence of large trees (Strong 1984), which may have facilitated the apparent reestablishment of a spotted owl population. Finally, smaller population sizes and the

absence of some species (possibly excluded by the topographic barriers surrounding the basin) may concomitantly reduce levels of competition such that new species arriving in the basin have a greater probability of successfully establishing a population. Lower species richness and abundance can reduce competition below typical levels, enabling species to establish populations where they would otherwise be outcompeted (Elton 1958). This phenomenon has been witnessed on oceanic islands, such as Hawaii, as well as landscape islands (Atkinson 1989). In the basin, the western gray squirrel, California quail, bullfrog, European starling, and house sparrow have all established populations at elevations higher than those at which they typically occur throughout their range. Although most of these species are also generalists, it is possible that they would not have successfully established populations at this elevation in a less isolated, more competitor-rich environment.

The physical and biological factors identified as potential causes of extirpations and additions of vertebrate species undoubtedly have similar implications for the presence, distribution, and abundance of other biota in the basin. We suspect that some species of native and exotic plants, invertebrates, and fungi have been extirpated or added to the fauna as the result of the factors discussed above. In addition, decreases in the quantity and quality of aquatic ecosystems such as marshes and lakes have certainly changed the distribution and abundance of many aquatic species of plants, animals, and fungi. For example, lack of fire has apparently increased the abundance of some conifer species, such as white fir (*Abies concolor*), and decreased the abundance of other species, such as sugar pine *(Pinus lambertiana*) (see Issue 1). Another example is an apparent increase in the abundance of species that can flourish in landscapes altered by humans, such as the coyote (*Canis latrans*), Steller's jay (*Cyanocitta stelleri*), and California ground squirrel (*Spermophilus beecheyi*).

Implications for Biological Integrity

The implications for biological integrity of these documented and suspected changes in species composition can be inferred but are difficult to ascertain. One thing is certain in regard to species and populations: the Lake Tahoe basin has declined in biological diversity and, concomitantly, in biological integrity. Many of the extirpated species were members of high trophic levels (i.e., grizzly bear and Sierra Nevada red fox), had relatively specific habitat requirements (e.g., Lahontan cutthroat trout), or were associated with habitats that are becoming increasingly rare in the basin (e.g., Lewis's woodpecker). All of these traits contribute significantly to biological integrity. For instance, the loss of higher trophic level species can have dramatic consequences for populations of species lower on the food chain (Carpenter et al. 1985; Power et al. 1996). Species gained represent generalists or exotic species and as the proportion of generalist species increases, beta diversity (the degree to which species composition changes along environmental gradients; Whittaker 1972) decreases because of the reduction in diversity of life history traits and habitat requirements represented among species. In addition, as generalists and exotic species become more common, the basin's contribution to biological diversity across the Sierra Nevada declines.

Which species should be of special focus within in the basin based on ecological and cultural criteria?

Criteria for Identifying Focal Species

Biologists involved with regional assessments and monitoring programs have often focused on a subset of species to address the critical elements of biodiversity, recognizing that such assessments and programs cannot address the viability of all species in a management area. These subsets of species were termed "special species" in the Southern Appalachian Assessment (Southern Appalachian Man and the Biosphere 1996), "emphasis species" in the Southern California Mountains and Foothills Assessment (USDA, in preparation), and "focal species" by the USDA Committee of Scientists (1999). Among the "special" and "emphasis" species in the two regional assessments mentioned above were the following: federal and state threatened, endangered, and special concern species, other species with viability concerns (due for example to population declines or very specific habitat requirements), game species, and species of high management or public interest.

"Focal species," as defined by the USDA Committee of Scientists (1999), included a broader suite of species including those intended to represent the integrity of ecosystems as well as species of concern. The USDA Committee of Scientists (1999) recognized that information about the ecological function of species is often sparse and that designations of species as focal serve only as working hypotheses until more data are collected through research and monitoring. Here, we identify focal species using criteria more similar to those of the two large-scale assessments mentioned above and do not intend for our focal species to serve as indicators of ecosystem conditions. Additional analyses would be necessary to identify indicator species and the associated validation monitoring required.

Often, species prioritization exercises (e.g., Millsap et al. 1990; Manley and Davidson 1993; Given and Norton 1993) have combined criteria for potential imperilment and potential vulnerability into a single analysis, occasionally including management (or "action") variables as well. A species that has declined (i.e., is potentially imperiled) and that also possesses a characteristic that might lead to further decline (i.e., is potentially vulnerable) is usually of greater concern than a species that has declined only. This reasoning has led some investigators to combine the two factors in their analyses. However, our goal was not to prioritize species, but rather to generate an inclusive list of species of concern and interest that could be assessed to determine appropriate conservation, restoration, and management measures for each species. In light of this goal, we believed it was important to identify all imperiled and potentially vulnerable species, and to maintain the distinction between these two criteria in our analysis.

We selected focal species using two main sets of criteria: ecological and cultural. Ecological criteria included some or all of the following, depending on the taxonomic group: extirpated and potentially extirpated species, potentially imperiled species, potentially vulnerable species, rare species, endemic species, and exotic, domestic, and native ecological pest species. Cultural criteria included some or all of the following, depending on the taxonomic group: harvested species, watchable species, human conflict species, and management agency emphasis species. These criteria are described in more detail below.

Ecological Criteria

Extirpated—Extirpated species represent a loss of biological diversity. Because this assessment addresses the potential for restoring biological diversity in the basin, we wanted to recognize that extirpated species can be restored to the basin's fauna. Therefore, all species determined to be extirpated or potentially extirpated were considered focal species. We were able to analyze extirpated species for vertebrates only (Table 5-44), because data on historical trends in species occurrence were available for that group only (see previous question).

Potentially Imperiled—We defined imperiled species as those with recognized population declines and/or range contractions. We identified potentially imperiled species using one or both of the following two criteria: listing by the federal and state governments as threatened, endangered, or special concern and having very small populations, recognized population declines and/or range contractions in the Sierra Nevada. We analyzed population and range characteristics to identify potentially imperiled species in addition to "listed" species because the political process of listing often lags behind the availability of scientific data (the most relevant data here being knowledge of species' declines). Population characteristics are useful for identifying imperiled species because species with small populations are more vulnerable to extinction from phenomena such as reduction of genetic diversity (through inbreeding or genetic drift) and environmental and demographic stochasticity (random events) than species with large populations (Rabinowitz 1981; Diamond et al. 1987; Kattan 1992; Karron 1997; Cody 1986). Range contractions often accompany population declines and species with small ranges are especially vulnerable to extirpation (Millsap et al. 1990). Clearly, this approach will not work for all species in all situations; there are examples of species with large populations going extinct and species with small populations persisting. Our method therefore represents an estimate of which species are most

Table 5-44—Criteria used to identify focal species in each of six taxonomic groups in the Lake Tahoe basin.

	Ecological Criteria									Cultural Criteria	
		Potentially Imperiled		Potentially Vulnerable							
Taxonomic group	Extirpated	T, E, SC	Pop/ Range	Life History	Rare	Endemic	Exotic	Harvested	Watchable	Human Conflict	Agency Emphasis
Vascular plants		X	X		X	X	X	X		X	X
Nonvascular plants		X			X	X					X
Terrestrial vertebrates	X	X	X	X		X	X	X	X	X	X
Fish	X	X	X			X	X	X	X		X
Invertebrates		X	X			X	X	X	X		X
Fungi		X			X	X		X			X

imperiled based on one set of criteria. We included listed species in all taxonomic groups as focal and analyzed population and range characteristics for vascular plants, terrestrial vertebrates, fish, and invertebrates only; population and range information was not available for nonvascular plants or fungi (Table 5-44).

Potentially Vulnerable—We define vulnerable species as those susceptible to declines in population size or range, that is, those species most likely to become imperiled. We assessed potentially vulnerable species using one or more of three criteria, depending on the taxonomic group: possession of life history characteristics associated with vulnerability, association with old forests, and rarity.

Several life history characteristics have been connected to increased vulnerability to extirpation or extinction: high degree of habitat specificity (Rabinowitz 1981; Kattan 1992; MacNally and Bennett 1997), large home range (Terborgh 1974), poor dispersal ability, or mobility (Burbridge and McKenzie 1989; MacNally and Bennett 1997), tendency to migrate (Terborgh 1974; Reed 1995), high degree of population concentration (Terborgh 1974; Millsap et al. 1990), and low rate of population increase (Millsap et al. 1990). We analyzed the potential vulnerability of species based on three habitat-related life history characteristics: habitat specificity, home range size, and mobility. Each of these parameters represents a facet of species' life histories related to the species' ability to cope with habitat disturbance; species with a large home range, low mobility, or high habitat specificity are more likely to be affected by reductions in the quantity or quality of habitat than species with small home ranges, high mobility, or low habitat specificity (Terborgh 1974; Burbridge and McKenzie 1989; MacNally and Bennett 1997; Rabinowitz 1981; Kattan 1992). Other characteristics also might be good predictors of vulnerability, such as susceptibility to cowbird parasitism (Reed 1995) or human activities, but these were not addressed here because of the difficulty of applying these criteria across vertebrate groups and the lack of available data. We conducted an analysis of life history characteristics for vertebrate species only, as data were not available for other taxonomic groups (Table 5-44).

Old forests in the Sierra Nevada and elsewhere have generated a great degree of public interest because of their high cultural value and importance to many species (USDA 1998a). Old forests, also known as late-successional, late-seral, or old-growth forests, are forests with a high degree of structural complexity and a high density of large trees, snags, and logs (Franklin and Fites-Kaufman 1996; Issue 1, this chapter). They are now much less abundant in the basin than they were in pre-settlement times, primarily due to timber harvest and fire suppression activities (Issue 1, this chapter). Identifying species dependent on old forests will aid in managing these ecosystems in the basin and determining whether their biological integrity is being maintained. Only vertebrates have been identified as dependent on old forests (Table 5-44).

Rarity is commonly used as an indication of vulnerability to extirpation or extinction (e.g., Williams and Given 1981, Perring and Farrell 1983, Gaston 1994). The term rarity has a variety of meanings in common usage (Harper 1981), but rare species are generally regarded as those having low abundance, small ranges, or small population sizes. They differ from species imperiled because of population characteristics as a matter of degree. Reveal (1981) states, "rarity is merely the current status of an extant organism which, by any combination of biological or physical factors, is restricted either in number or area to a level that is demonstrably less than the majority of other organisms of comparable taxonomic entities." Schoener (1987) uses rarity to mean occurrence in relatively few censuses and/or at relatively low abundances. The California Native Plant Society (CNPS) assigns rarity ratings to plants based on each species' distribution and frequency of occurrence (Skinner and Pavlick 1994; Dennis 1995). Rarity by itself does not indicate a species risk of extinction, but is undoubtedly highly related to a species risk of extirpation or extinction (Gaston 1994). In this sense it provides a reasonable criterion for identifying species most in need of conservation. We used the CNPS rarity rating system to identify rare plants in our assessment; rarity data were not available for other taxonomic groups (Table 5-44).

Endemism—Endemic species are those found only in a particular region and nowhere else (Meffe and Carroll 1994) and are most relevant to

conservation planning in regard to species with very limited ranges (Terborgh and Winter 1983; Gentry 1986). Endemism is a consideration in the conservation and assessment of biological diversity because endemics often contribute significantly to the species richness of a given area (Gentry 1992) and because their typically limited population sizes and ranges make them vulnerable to extirpation and extinction (Cody 1986; Nott and Pimm 1997). We included endemic species in all taxonomic groups as focal (Table 5-44).

Exotics, Domestics, and Native Ecological Pests—Exotic species are "species that occur in a given place, area, or region as the result of direct or indirect, deliberate or accidental introduction of the species by humans and for which introduction has permitted the species to cross a natural barrier to dispersal" (Noss and Cooperrider 1994). The successful invasion of an exotic species and its subsequent effects on a native ecosystem are difficult to predict and depend on complex interactions among many characteristics of the species and the ecosystem in question (Meffe and Carroll 1994). In most cases documented so far, exotic species have had a negative effect on native biological diversity, displacing local species through such processes as predation, resource competition, and habitat degradation (Atkinson 1989). However, this is not always the case (Lugo 1994). Exotics differ in their potential to invade an area, and communities differ in their susceptibility to invasion, resulting in varying degrees of threat posed by exotic species (Meffe and Carroll 1994). We included exotic vascular plants, terrestrial vertebrates, fish, and invertebrates as focal; data were not available for nonvascular plants or fungi (Table 5-44).

Domesticated species, which are typically nonnative species tamed for human use, often have ecological consequences similar to those of exotic species. However, for the most part, domesticated species have not established populations in the wild. We have included domesticated species as a special subset of exotic species. This category applied to terrestrial vertebrates only.

Native ecological pests are species native to an area that can become unusually abundant as a result of human activities and disturbance. Species that thrive in environments altered by humans may have further exacerbated the negative effects of disturbance on native species. At typical abundance levels, these species are a natural part of the ecosystem, but at unusually high abundances they can pose threats to ecosystem integrity. Potential ecological pests are often predators and generalist species that benefit from anthropogenic changes in the environment and, because of their natural history characteristics, can take an inordinate toll on the survival and reproductive success of a wide variety of other species. Only vertebrates were considered native ecological pests.

Cultural Criteria—Some species are of special interest primarily because of their importance to humans rather than their contribution to biological diversity. For example, species that are hunted or observed for pleasure, like deer, contribute toward people's experiences of nature and appreciation of biodiversity. Other species, such as squirrels or bears, may occasionally detract from the quality of life for humans by damaging property or by posing potential threats to pets or children. Local management and regulatory agencies also have recognized the importance of some species to humans and have listed species of special interest for ecological and cultural reasons. One or more of the following criteria were considered in the identification of culturally important species: harvested species, watchable species, human conflict species, and management agency emphasis species.

The four cultural criteria varied widely in the cultural values they represented. Harvested species include all species consumed for any purpose, including food, medicine, products, religious purposes, or sport. Watchable species (Clark 1992) are those species whose beauty, behavior, size, or color are generally appealing to the general public. Human conflict species are those that represent a potential liability to humans or a potential barrier to some desired condition. Conflicts

can range from interference with or damage to property (such as houses, yards, or personal possessions) to potential or actual bodily harm to individuals. Management agency emphasis species are species identified as deserving special emphasis by the local land management and regulatory agencies: the USFS and the TRPA. Other local agencies, such as California State Parks, and Nevada State Parks, do not have special emphasis species outside of state listed species, which we address as an ecological criterion. Agency emphasis is considered as a cultural criterion because of the highly variable reasons USFS and TRPA choose to emphasize species in management. TRPA's list of special interest species consist of species that are "typically uncommon and/or have a high degree of aesthetic appeal to visitors and locals" (TRPA 1982, p. 32). The latter portion is clearly a cultural criterion. USFS's list of sensitive species consists of species "for which population viability is a concern," (USDA 1995c, p. 12). The criteria used to identify species of concern include global, national, and state criteria, but these tend to vary over time. The USFS criteria for sensitive species are generally ecological criteria, but in order to give equal consideration across agencies, we consider agency emphasis a cultural criterion. We included all agency emphasis species as focal (Table 5-44).

Summary of Criteria Used to Identify Focal Species—We identified focal species of concern and interest using a variety of ecological and cultural criteria (Figure 5-37). The criteria we used depended on the taxonomic group being considered (Table 5-44) because the major taxonomic groups considered (vascular plants, nonvascular plants, terrestrial vertebrates, fish, invertebrates, and fungi) differed widely in terms of available data. We were able to address terrestrial vertebrates using the widest variety of criteria, while we addressed fish and vascular plants at moderate levels of detail. The least information was available for nonvascular plants, fungi, and invertebrates; we identified focal species for these taxa using only a few criteria.

Focal Vascular Plants

Ecological Criteria—Ecological criteria for vascular plants included potential imperilment, potential vulnerability, endemism, and exotic status.

Potentially Imperiled Vascular Plants—Species were determined to be potentially imperiled based on their listing as endangered, threatened, or of special concern by federal and state governments and based on population trends. One species in the Lake Tahoe basin, Tahoe yellowcress (*Rorripa subumbellata)*, is state-listed as endangered (Table 5-45). Seven plant species identified as species of concern by the USFWS, including Tahoe yellowcress, also occur in the basin (Table 5-45). No quantitative data were available for population trends across all plant species in the basin. We considered a single species, whitebark pine (*Pinus albicaulis*), as focal because of qualitative observations of population declines (Urie 1999).

Potentially Vulnerable Vascular Plants—Species we considered potentially vulnerable were those that are rare in California. The CNPS has identified rare plants in California and rated them based on their distribution and frequency of occurrence (Skinner and Pavlick 1994; Dennis 1995). CNPS divided rarity into three categories: rare but stable, rare - limited occurrence, and rare - highly restricted. "Rare but stable" was defined as " . . . rare, but found in sufficient numbers and distributed widely enough that the potential for extinction is low at this time." A total of 21 plants with this designation currently occur in the basin, but they were not included as focal species because they were considered the least vulnerable at this time. "Rare - limited occurrence" was defined as " . . . distributed in a limited number of occurrences, occasionally more if each occurrence is small." A total of 8 plants with this designation currently occur in the basin, and they were considered focal species (Table 5-46). "Rare – highly restricted" was defined as " . . . distributed in one to several highly restricted occurrences, or present in such small numbers that it is seldom reported." A total of 16 plants with this designation currently occur in the basin, and they were considered focal species (Table 5-46).

Endemic Vascular Plants—Four hundred and five vascular plant taxa are endemic to the Sierra Nevada (Shevock 1996), 70 of which occur in the

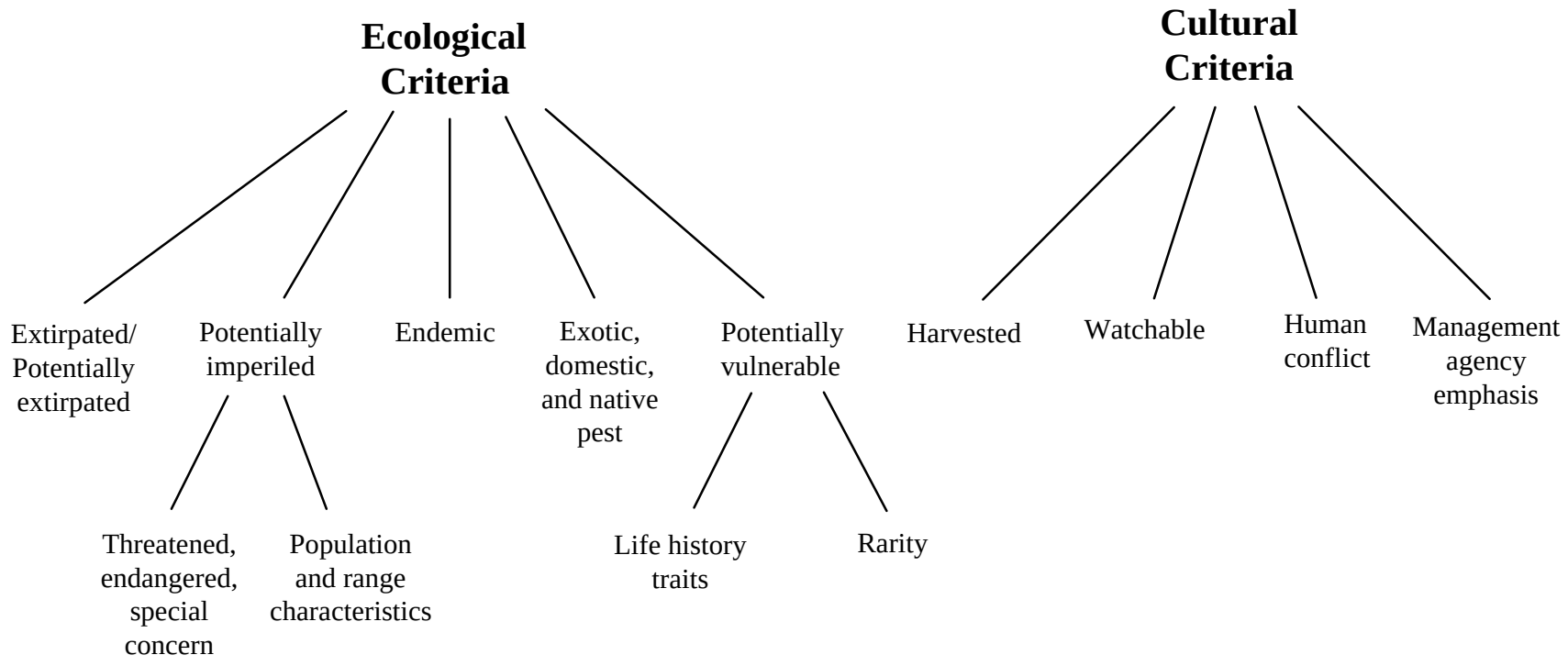


Figure 5-37—Criteria used to identify focal species for the Lake Tahoe basin.

Table 5-45—Vascular plant species occurring in the Lake Tahoe basin identified as threatened, endangered or of special concern by the US Fish and Wildlife Service or the Natural Resources Agency for the State of California.

Common Name	Scientific Name	Federal Listing Status	State Listing Status
Federal and State Threatened and Endangered:			
Tahoe yellowcress	*Rorippa subumbellata*	Species of Concern	CA and NV Endangered
Federal Species of Concern:			
Galena rock cress	*Arabis rigidissima* var. *demota*	Species of Concern	
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	Species of Concern	
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*	Species of Concern	
Oregon fireweed	*Epilobium oreganum*	Species of Concern	
Plumas mousetail	*Ivesia sericoleuca*	Species of Concern	
Webber's ivesia	*Ivesia webberi*	Species of Concern	
Long-petaled lewisia	*Lewisia longipetala*	Species of Concern	

Table 5-46—Rare vascular plant species of the Lake Tahoe basin, as designated by the California Native Plant Society (Skinner and Pavlick 1994) and determined to occur in the basin. Species included here are those with designations of "rare - limited occurrence" and "rare - highly restricted."

Common Name	Scientific Name
Rare - limited occurrence:	
Twin arnica	*Arnica sororia*
Mud sedge	*Carex limosa*
Starved fleabane	*Erigeron miser*
Close-throated beardtongue	*Penstemon personatus*
Ribbonleaf pondweed	*Potamogeton epihydrus* ssp. *nuttallii*
Water bulrush	*Scirpus subterminalis*
Marsh skullcap	*Scutellaria galericulata*
Woolly violet	*Viola tomentosa*
Rare - highly restricted:	
Mountain bentgrass	*Agrostis humilis*
Galena Creek rockcress	*Arabis rigidissima* var. *demota*
Green spleenwort	*Asplenium trichomanes-ramosum*
Trianglelobe moonwort	*Botrychium ascendens*
Lake Tahoe draba	*Draba asterophora* var. *asterophora*
Cup Lake draba	*Draba asterophora* var. *macrocarpa*
Subalpine fireweed	*Epilobium howellii*
Marsh horsetail	*Equisetum palustre*
Buckwheat	*Eriogonum ovalifolium* var. *vineum*
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*
Webber's ivesia	*Ivesia webberi*
Long-petaled lewisia	*Lewisia longipetala*
Tahoe yellowcress	*Rorippa subumbellata*
American scheuchzeria	*Scheuchzeria palustris* ssp. *americana*
Smooth goldenrod	*Solidago gigantea*
Grey-leaved violet	*Viola pinetorum* ssp. *grisea*

Lake Tahoe basin (Appendix E). Of these 70 species, five are endemic to the Truckee River Basin (the Calwater river basin in which the Lake Tahoe basin resides) (Shevock 1996) and occur in the Lake Tahoe basin (Table 5-47). These five plant species were designated as focal because they may be vulnerable to extinction because of their restricted range. Of these five species, only the Tahoe yellowcress is endemic to the Lake Tahoe basin.

We chose to identify only a subset of Sierra Nevada endemics as focal species—specifically, those recognized as rare—because of the large number of Sierra Nevada endemics. Based on the CNPS designation of rarity (Skinner and Pavlick 1994), we identified 13 additional Sierra Nevada endemics that are rare (Table 5-47).

Exotic Vascular Plants—Eighty-four plant species have been introduced to the basin in recent history and are considered exotic (Hickman 1993, Appendix E). Many exotic plants exist without drastically affecting native species, while others have severe effects on the natural environment because they are highly invasive, have fast growing populations, and are therefore able to out-compete and reduce populations of local native species (Hickman 1993). Exotic plants with severe negative environmental effects are commonly termed "noxious weeds" by the USDA (1995b). The USDA (1995b) defines noxious weeds as "generally possess[ing] one or more of the following characteristics: aggressive and difficult to manage, poisonous, toxic, parasitic, a carrier or host of disease and being nonnative or new to or not common to the Unites States or parts thereof."

We identified only those exotic plants recognized by USDA as noxious weeds as focal because of the large number of exotic plant

Table 5-47—Focal endemic vascular plant species, including species endemic to the Truckee River basin and rare Sierra Nevada endemics.

Common Name	Scientific Name	Truckee River Basin Endemic	Rare Sierra Nevada Endemic
Galena Creek rockcress	*Arabis rigidissima* var. *demota*	X	
Austin's milkvetch	*Astragalus austiniae*	X	
Balloon pod milkvetch	*Astragalus whitneyi* var. *lenophyllus*	X	
Davy's sedge	*Carex davyi*		X
Sierra clarkia	*Clarkia virgata*		X
Lake Tahoe draba	*Draba asterophora* var. *asterophora*		X
Cup Lake draba	*Draba asterophora* var. *macrocarpa*		X
Subalpine fireweed	*Epilobium howellii*		X
Starved fleabane	*Erigeron miser*		X
Sierra fleabane	*Erigeron petrophilus* var. *sierrensis*		X
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*		X
Plumas mousetail	*Ivesia sericoleuca*		X
Long-petaled lewisia	*Lewisia longipetala*		X
Close-throated beardtongue	*Penstemon personatus*		X
Bacigalupi's perideridia	*Perideridia bacigalupii*		X
Tahoe yellowcress	*Rorippa subumbellata*	X	X
Lake Tahoe serpentweed	*Tonestus eximius*	X	X
Woolly violet	*Viola tomentosa*		X

species in the Lake Tahoe basin. We identified 12 species as focal exotic species (Table 5-48). The two species not recognized as noxious weeds, but included as focal exotic species, were Eurasian watermilfoil and tall whitetop (*Lepidium latifolium*). Eurasian watermilfoil is recognized by the Lahontan State Water Quality Control Board as having potential long-term detrimental environmental impacts in Lake Tahoe (Ferguson 1999). Eurasian watermilfoil can choke waterways, deplete dissolved oxygen in the water, and reduce invertebrate species populations (USGS 1999). Tall whitetop appears to be a recently introduced species and is considered potentially noxious (Benoit 1997). TRPA recently noted occurrences of tall whitetop at Incline Village and along the south shore of Lake Tahoe (Benoit 1997).

Specific data on the timing of the introductions of these exotic species are lacking, but most of the introductions probably occurred in the Urbanization Era (1960 to present). All the focal exotic species are herbaceous, and the most likely transmission vectors to the basin are personal vehicles, watercraft, or heavy-duty construction equipment and/or material transport associated with residential and road building projects (Taylor 1999).

Cultural Criteria—Cultural criteria included harvest status, human conflict, and management agency emphasis. Further efforts could identify "watchable" plants, such as wildflowers and large trees, but we were unable to conduct such an analysis for this assessment. Species identified as focal in each of the three categories are described below.

Harvested Vascular Plants—People are highly dependent on plants for survival, and the range of uses of plants by people in general and within the basin is vast. As such, it was difficult to develop a definitive list of plants used for various purposes. The list of plants presented here represents only a subset of commonly harvested species.

Plants harvested for medicinal uses were identified by consulting numerous sources (Chatfield 1997; Anderson 1993; Beckstrom-Sternberg et al. 1995a, 1995b; Blackburn and Anderson 1993; Hill 1972; LaLande 1993). Based on these sources, we identified 393 plant species as having medicinal properties (Appendix E). Given this large number, we chose to highlight those medicinal plants whose populations are considered rare by CNPS (Skinner and Pavlick 1994) as an indication of their vulnerability or potential imperilment. This analysis produced four plant species (Table 5-49).

Eight vascular plant species are commercially harvested in the basin and all of them are conifers: white fir (*Abies concolor*), red fir (*A. magnifica* var. *magnifica*), incense cedar (*Calocedrus decurrens*), lodgepole pine (*Pinus contora* var. *murrayana*), Jeffrey pine (*P. jeffreyi*), sugar pine (*P. lambertiana*), western white pine (*P. monticola*), and ponderosa pine (*P. ponderosa*) (Parsons 1999). All of these were considered focal species.

Table 5-48—Focal exotic vascular plant species of the Lake Tahoe basin.

Common Name	Scientific Name
Cheatgrass	*Bromus tectorum*
Plumeless thistle	*Carduus acanthoides*
Musk thistle	*Carduus nutans*
Diffuse knapweed	*Centaurea diffusa*
Spotted knapweed	*Centaurea maculosa*
Bullthistle	*Cirsium vulgare*
Scotch Broom	*Cytisus scoparius*
Klamathweed	*Hypericum perforatum*
Tall whitetop	*Lepidium latifolium*
Dalmatian toadflax	*Linaria genistifolia* ssp. *dalmatica*
Eurasian watermilfoil	*Myriophyllum spicatum*
Scotch thistle	*Onopordum acanthium* ssp. *acanthium*

Table 5-49—Rare medicinal plants identified as focal vascular plants in the Lake Tahoe basin.

Common Name	Scientific Name	Rarity category		
		Stable	Limited	Highly Restricted
Brown-margined buckwheat	*Eriogonum ovalifolium* var. *eximium*	X		
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*			X
Marsh skullcap	*Scutellaria galericulata*		X	
Smooth goldenrod	*Solidago gigantea*			X

The Washoe tribe has used wild plants in the basin for centuries. Many of these culturally important plants have been documented based on the Washoe tribe and the investigative work of many individuals (Rucks 1999). The names of 52 plants have been translated to current taxonomy; 41 of these species occur or potentially occur in the Lake Tahoe basin (Appendix E). Many of these plant species are common in the basin and do not merit focal species status. We chose to recognize these traditionally used plants as focal if they were also rare species according to CNPS (Skinner and Pavlick 1994). We identified one species, long-petaled lewisia (*Lewisia longipetala*) as focal because it is "rare - highly restricted" and because the Washoe use plants of the genus *Lewisia*.

Human Conflict Vascular Plants—The Eurasian watermilfoil, an exotic plant (see exotic species section above), is identified here as a human conflict species. This invasive plant occludes waterways and poses a significant problem for several marinas around the lake. It is recognized by the Lahontan State Water Quality Control Board as having potential long-term detrimental economic impacts in Lake Tahoe (Ferguson 1999).

Management Agency Emphasis Vascular Plants—Five plants are currently identified by TRPA and 16 by the USFS as sensitive species in the Lake Tahoe basin (Table 5-50). Four species were identified by both agencies, for a total of 17 focal species based on management agency emphasis.

Summary—Fifty-seven focal vascular plants were identified (Appendix K), 25 as focal based solely on ecological criteria, 11 as focal based solely on cultural criteria, and 21 as focal based on both ecological and cultural criteria.

Focal Nonvascular Plants

The incomplete and broad geographic nature of the data available on nonvascular plants made it difficult to conduct a thorough and meaningful analysis of focal species for the Lake Tahoe basin. We considered a limited set of ecological and cultural criteria in the identification of focal nonvascular plants (Table 5-44).

We considered three ecological criteria in identifying focal nonvascular plants: potential imperilment, potential vulnerability, and endemism (Table 5-44). No species of nonvascular plants currently listed as threatened or endangered by the federal or state government are known or suspected to occur in the Lake Tahoe basin. Potential vulnerability was assessed based on rarity. Shevock (1996) identified 17 rare species of nonvascular plants in the Sierra Nevada. Of the 17 rare mosses, *Mielichoferia tehamensis* could not occur in the basin because it is endemic to Lassen National Park. The remaining 16 species potentially do occur in the basin, and were considered focal species (Table 5-51). Two species of mosses are known to be endemic to the Sierra Nevada: *Grimmia hamulosa* and *Orthotrichum spjutii*. They have not been confirmed but could occur in the Lake Tahoe basin. They were both considered focal species (Table 5-51).

We considered one criterion in identifying cultural focal nonvascular plants: agency emphasis species. None of the local agencies currently designate any nonvascular plants as emphasis species.

Sixteen nonvascular plant species were identified as focal in the Lake Tahoe basin. All species were focal based solely on ecological criteria.

Table 5-50—Vascular plant species identified as sensitive by the TRPA or the USFS (TRPA 1982; USDA 1998).

Common Name	Scientific Name	TRPA	USFS
Galena Creek rockcress	*Arabis rigidissima* var. *demota*		X
Anderson's aster	*Aster alpigenus* var. *andersonii*		X
Trianglelobe moonwort	*Botrychium ascendens*		X
Mariposa sedge	*Carex mariposana*	X	
Lake Tahoe draba	*Draba asterophora* var. *asterophora*	X	X
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	X	X
Subalpine fireweed	*Epilobium howellii*		X
Oregon fireweed	*Epilobium oreganum*		X
Starved fleabane	*Erigeron miser*		X
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*		X
Plumas mousetail	*Ivesia sericoleuca*		X
Webber's ivesia	*Ivesia webberi*		X
Long-petaled lewisia	*Lewisia longipetala*	X	X
Close-throated beardtongue	*Penstemon personatus*		X
Tahoe yellowcress	*Rorippa subumbellata*	X	X
American scheuchzeria	*Scheuchzeria palustris americana*		X
Grey-leaved violet	*Viola pinetorum grisea*		X

Table 5-51—Focal nonvascular plant species in the Lake Tahoe basin. All species are mosses and are focal based on ecological criteria.

Scientific Name	Rare	SN Endemic
Andreaea nivalis	X	
Bruchia bolanderi	X	
Campylium stellatum	X	
Distichium inclinatum	X	
Grimma mixleyi	X	
Grimmia hamulosa	X	X
Hydrogrimmia mollis	X	
Lescuraea pallida	X	
Mnium arizonicum	X	
Myurella julacea	X	
Orthotrichum euryphyllum	X	
Orthotrichum spjutii	X	X
Polytrichum sexangulare	X	
Racomitrium hispanicum	X	
Tayloria serrata	X	
Tortula californica	X	

Focal Terrestrial Vertebrate Species

In identifying focal vertebrate species, we first created a list of *candidate* focal species consisting of those species with some evidence to suggest they have an established a population in the Tahoe basin (Millsap et al. 1990; Gaston 1994), plus species that are confirmed or potentially extirpated from the basin. All confirmed and potentially extirpated species were identified earlier in this Issue. Current populations of vertebrates were assessed to confirm the potential for established populations. For mammals, reptiles, and amphibians, any current records (Urbanization Era) of occurrence in the basin were considered sufficient evidence of potential populations in the basin. However, birds are far more mobile than other terrestrial vertebrates, and the record of an occurrence in the Tahoe basin does not necessary suggest the occurrence of a population. A variety of specific criteria (Appendix L) were used to identify bird species likely to be only occasional visitors, which were eliminated as candidate focal species. Thus, the list of candidate focal species included all extirpated species and excluded 68 bird species. In total, we considered 229 terrestrial vertebrate species as candidates for focal species designation: 149 birds, 66 mammals, six amphibians, and eight reptiles (Appendix G). A range of ecological and cultural criteria were applied to candidate focal species (Table 5-44) to derive the final list of focal species. Each of the criteria and its application are described in detail below.

Ecological Criteria—We considered five ecological criteria to identify focal terrestrial vertebrates: known or potential extirpation, potential imperilment, potential vulnerability, endemism, and exotic, domesticated, or ecological pest status.

Extirpated and Potentially Extirpated Terrestrial Vertebrates—The analysis of historical changes in the basin's species composition resulted in the identification of 12 extirpated and potentially extirpated terrestrial vertebrate species: four birds, seven mammals, and one amphibian (Question 2, Table 5-43).

Potentially Imperiled Terrestrial Vertebrates—Species in the Lake Tahoe basin with potentially imperiled populations were identified based on their status at local and range-wide scales, including the Sierra Nevada physiographic region, the states of California or Nevada, and the entire United States. No specific data were available for population trends in the basin. Species whose populations are potentially imperiled at larger geographic scales (e.g., the Sierra Nevada) are likely to be imperiled in the Lake Tahoe basin. In addition, the Lake Tahoe basin plays an important role in supporting viable populations at larger geographic scales. Because of the lack of data on population trends specifically for the basin, we were unable to address species that may have declined in the basin but not elsewhere.

Species were determined to be potentially imperiled in the Sierra Nevada if they were listed as endangered, threatened, or of special concern by federal and state governments, or if they were recognized as having declining populations, contracted ranges, and/or small population size.

Listed Species—Eight species were classified as threatened or endangered and 22 species were classified as Species of Special Concern by the federal government or by the states of California or Nevada (Table 5-52).

Potentially Imperiled Because of Population or Range Characteristics—Three variables were used to assess species potentially imperiled because of population characteristics: Sierra Nevada population size, population trend in the Sierra Nevada, and range change in the Sierra Nevada (Keane and Zielinski, in preparation). Data were obtained from the Sierra All Species Information (SASI) database (USDA 1999b) and were based on expert opinion acquired through questionnaires sent to taxa experts familiar with the Sierra Nevada (Appendix L). Each variable consisted of five or six categories, which were combined into three categories for this analysis: low, moderate, and high imperilment (Appendix L). All 229 candidate terrestrial vertebrate species were included in the analysis and their scores for each of the three variables appear in Appendix M.

Species were considered focal if they were highly imperiled for one or more of the three variables or if they were moderately imperiled for all three variables (n = 43). Species that were

Table 5-52—Listed terrestrial vertebrates of the Lake Tahoe basin.

Common Name	Scientific Name	Federal Listing Status	State Listing Status[a]
Federal and State Threatened and Endangered:			
Birds:			
Willow Flycatcher	*Empidonax traillii*		CA Endangered
Peregrine Falcon	*Falco peregrinus*		CA, NV Endangered
Bald Eagle	*Haliaeetus leucocephalus*	Threatened[b]	CA, NV Endangered
Bank Swallow	*Riparia riparia*		CA Threatened
Mammals:			
Wolverine	*Gulo gulo*	Special Concern	CA Threatened
Mountain sheep	*Ovis canadensis californiana*	Endangered	CA Threatened
Grizzly bear	*Ursus arctos*	Threatened	
Sierra Nevada red fox	*Vulpes vulpes necator*	Special Concern	CA Threatened
Federal and State Special Concern:			
Birds:			
Cooper's Hawk	*Accipiter cooperii*		Special Concern
Northern Goshawk	*Accipiter gentilis*	Special Concern	Special Concern
Sharp-shinned Hawk	*Accipiter striatus*		Special Concern
Golden Eagle	*Aquila chrysaetos*		Special Concern
Barrow's Goldeneye	*Bucephala islandica*		Special Concern
Northern Harrier	*Circus cyaneus*		Special Concern
Yellow Warbler	*Dendroica petechia*		Special Concern
Common Loon	*Gavia immer*		Special Concern
California Gull	*Larus californicus*		Special Concern
Osprey	*Pandion haliaetus*		Special Concern
American White Pelican	*Pelecanus erythrorhynchos*		Special Concern
Spotted Owl	*Strix occidentalis*	Special Concern	Special Concern
Mammals:			
Pallid bat	*Antrozous pallidus*		Special Concern
Mountain beaver	*Aplodontia rufa*	Special Concern	Special Concern
Sierra Nevada snowhoe hare	*Lepus americanus tahoensis*	Special Concern	Special Concern
White-tailed hare	*Lepus townsendii*		Special Concern
Fisher	*Martes pennanti*	Special Concern	Special Concern
Long-eared myotis	*Myotis evotis*	Special Concern	
Fringed myotis	*Myotis thysanodes*	Special Concern	
Yuma myotis	*Myotis yumanensis*	Special Concern	Special Concern
Lodgepole chipmunk	*Tamias speciosus*	Special Concern	
Amphibians:			
Mountain yellow-legged frog	*Rana muscosa*	Special Concern	Special Concern
Northern leopard frog	*Rana pipiens*		Special Concern

[a] State Special Concern status applies only to California.
[b] The Bald Eagle has been proposed for delisting as of July 2000.

considered moderately imperiled for all three population and range variables were those potentially susceptible to the cumulative effects of small population size, declining population, and range contraction. Nine species were considered highly imperiled because of population size (Sierra Nevada population presumed extirpated or estimated to consist of ≤ 100 individuals; Appendix L; Table 5-53). Twenty-six species were considered highly imperiled because of population decline (those with known declines in the Sierra Nevada since approximately 1900; Appendix L; Table 5-53). Thirteen species were considered highly imperiled because of range contractions (those with suspected range contractions of ≥ 50 percent since historic times; Appendix L; Table 5-53). Finally, nine additional species were identified as focal because they were considered moderately imperiled for all three population and range variables (estimated Sierra Nevada population size of 100 to 1,000 individuals, suspected population decline in the Sierra Nevada, and estimated range contraction of < 50 percent; Appendix L; Table 5-53).

Potentially Vulnerable Terrestrial Vertebrates—Terrestrial vertebrate species were determined to be potentially vulnerable to future imperilment if they possessed life history characteristics that might increase their vulnerability to disturbance or if they were dependent on old forests.

The vulnerability of species was assessed based on habitat specificity, mobility, and home range size. Data were obtained from the SASI database (USDA 1999b; Appendix L). Mobility reflects the ability of individuals of a species to move in response to daily and seasonal needs, reproductive needs, and/or habitat disturbance; it is considered a habitat-related variable because it represents the ability to access habitat. Mobility was characterized as low, moderate, or high. Home range size was characterized as large, moderate, or small, based on the average area occupied by a species. Habitat specificity was estimated by determining by the proportion of all California Wildlife Habitat Relationships (CWHR) (CDFG 1998a) vegetation type-structural/canopy cover classes (n = 563) suitable for each species. Habitat specificity information was not available for the grizzly bear, which was therefore eliminated from this analysis. Species were put into three groups based on the distribution of habitat specificity for species in the basin: high (< 30 percent of habitats suitable), moderate (30 to 60 percent of habitats suitable), and low (> 60 percent of habitats suitable). Each of the three variables' groups corresponded to high vulnerability, moderate vulnerability, and low vulnerability (Appendix L).

Analysis of vulnerability based on life history characteristics was conducted separately for species dependent upon aquatic habitats ("aquatic species") and all remaining species, characterized as terrestrial habitat associates ("upland species"). Information on dependence on aquatic habitat was obtained from Zeiner et al. (1988, 1990a, 1990b), as summarized in the SASI database (USDA 1999b; Appendix L). All species noted as "aquatic" or "semi-aquatic" (n = 51) were considered aquatic species because the two classifications both represented a reliance on aquatic habitats; we considered all other species upland species (n = 178).

All species that were habitat specialists or that were moderate habitat specialists and had low mobility and/or large home range were considered focal. We considered all aquatic species to be habitat specialists (based on their dependence), but included as focal only those species with either low mobility or large home range (27 species; Table 5-54). For upland species, we included as focal all species with high habitat specificity (39 species; Table 5-55a) because these species represented extreme habitat specialization. In addition, we included as focal those species with moderate habitat specificity and one of the following combinations of features: low mobility and large home range, low mobility and moderate home range, or moderate mobility and large home range (18 species; Table 5-55b).

Information on dependence on old-forest habitat was obtained from the SASI database (USDA 1999b), which adopted Graber's (1996) classification, with a few modifications (Appendix L). Sixteen species listed as dependent on old-forest habitat were included. We listed the species dependent on old forests in order of decreasing

Table 5-53—Focal terrestrial vertebrate species of the Lake Tahoe basin potentially imperiled due to small population size, known population declines, suspected range contraction, or cumulative effects of population and range characteristics in the Sierra Nevada. Data were obtained from the Sierran All Species Information database (USDA 1999b; Appendix L).

Common name	Scientific name	Small pop.[a]	Pop. decl.[b]	Range contrct.[c]	Cumul. effects[d]
Birds:					
American Robin	*Turdus migratorius*		1		
American White Pelican	*Pelecanus erythrorhynchos*		1		
Band-tailed Pigeon	*Columba fasciata*		1		
Barrow's Goldeneye	*Bucephala islandica*	1	1	1	
Belted Kingfisher	*Ceryle alcyon*		1		
Brown-headed Cowbird	*Molothrus ater*		1		
Chipping Sparrow	*Spizella passerina*		1		
Common Snipe	*Gallinago gallinago*				X
Forster's Tern	*Sterna forsteri*		1		
Greater Scaup	*Aythya marila*	2			
House Finch	*Carpodacus mexicanus*		1		
Lesser Goldfinch	*Carduelis psaltria*		1		
Lewis's Woodpecker	*Melanerpes lewis*				X
Northern Shoveler	*Anas clypeata*	2			
Olive-sided Flycatcher	*Contopus cooperi*		1		
Peregrine Falcon	*Falco peregrinus*	2			
Pied-billed Grebe	*Podilymbus podiceps*				X
Red-breasted Sapsucker	*Sphyrapicus ruber*		1		
Steller's Jay	*Cyanocitta stelleri*		1		
Swainson's Thrush	*Catharus ustulatus*		1	2	
Western Scrub Jay	*Aphelocoma coerulescens*		1		
Western Wood-pewee	*Contopus sordidulus*		1		
White-crowned Sparrow	*Zonotrichia leucophrys*		1	2	
Willow Flycatcher	*Empidonax traillii*			1	
Wood Duck	*Aix sponsa*	2			
Mammals:					
Badger	*Taxidea taxus*				X
Beaver	*Castor canadensis*			2	
Black bear	*Ursus americanus*				X
Fisher	*Martes pennanti*			3	
Fringed myotis	*Myotis thysanodes*				X
Grizzly bear	*Ursus arctos*	1	1	1	
Mink	*Mustela vison*				X
Mountain sheep	*Ovis canadensis californiana*		1	1	
Muskrat	*Ondatra zibethicus*			2	
Nuttall's Cottontail	*Sylvilagus nuttallii*				X
River otter	*Lutra canadensis*				X
Sierra Nevada red fox	*Vulpes vulpes necator*	1	1		
White-tailed hare	*Lepus townsendii*		1	2	
Wolverine	*Gulo gulo*	1	1	2	
Amphibians:					
Mountain yellow-legged frog	*Rana muscosa*		1	1	
Northern leopard frog	*Rana pipiens*	2		1	
Pacific treefrog	*Hyla regilla*		1		
Western toad	*Bufo boreas*		1		
Reptiles:					
Western terrestrial garter snake	*Thamnophis elegans*		1		

[a] 1 = potentially extirpated, 2 = estimated Sierra Nevada population of 1-100 individuals.
[b] 1 = species with known population declines.
[c] 1 = estimated Sierra Nevada range contraction of 90-100 percent, 2 = estimated range contraction of 50-89 percent, 3 = estimated range contraction of ≥ 50 percent..
[d] X = species not included in any of the above categories but considered moderately imperiled for each category.

Table 5-54—Potentially vulnerable terrestrial vertebrates of the Lake Tahoe basin. Species in this table are dependent on aquatic habitats and have low mobility or a large home range. Aquatic dependence was obtained from USDA (1999b). Also given are the CWHR habitat types[a] (Mayer and Laudenslayer 1988) occurring in the basin that are used by each species. "Mob" is a species' mobility—its ability to move in response to seasonal or reproductive needs (USDA 1999b; Appendix L); L = low, M = moderate. "Rng" is a species' home range (USDA 1999b; Appendix L); M = moderate, L = large. Also given are the CWHR habitat types (Mayer and Laudenslayer 1988) occurring in the basin that are used by each species.

Common name	Scientific name	Mob	Rng	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Birds:																					
Wood Duck	*Aix sponsa*	H	L			X	X		X			X			X		X	X	X	X	
Northern Pintail	*Anas acuta*	H	L															X	X	X	X
Mallard	*Anas platyrhynchos*	H	L														X	X	X	X	X
Great Blue Heron	*Ardea herodias*	H	L			X		X							X	X	X	X	X	X	X
Canvasback	*Aythya valisineria*	H	L															X	X	X	
Canada Goose	*Branta canadensis*	H	L															X	X	X	X
Common Goldeneye	*Bucephala clangula*	H	L																X	X	
Belted Kingfisher	*Ceryle alcyon*	H	L														X	X	X	X	X
Tundra Swan	*Cygnus columbianus*	H	L															X	X	X	X
California Gull	*Larus californicus*	H	L															X	X	X	X
Ring-billed Gull	*Larus delawarensis*	H	L															X	X	X	X
Hooded Merganser	*Lophodytes cucullatus*	H	L															X	X	X	
Common Merganser	*Mergus merganser*	H	L														X	X	X	X	X
Black-crowned Night Heron	*Nycticorax nycticorax*	H	L					X			X						X	X	X	X	X
Osprey	*Pandion haliaetus*	H	L			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
American White Pelican	*Pelecanus erythrorhynchos*	H	L																X	X	
Mammals:																					
River otter	*Lutra canadensis*	M	L														X	X	X	X	X
Mink	*Mustela vison*	M	L		X												X	X	X	X	
Muskrat	*Ondatra zibethicus*	L	M		X												X	X	X	X	X
Water shrew	*Sorex palustris*	L	S		X	X	X		X			X	X		X	X	X		X	X	X
Amphibians:																					
Long-toed salamander	*Ambystoma macrodactylum*	L	L				X		X			X			X	X	X	X	X		X
Western toad	*Bufo boreas*	L	L			X	X		X	X	X	X		X	X	X	X	X	X	X	X
Pacific treefrog	*Hyla regilla*	L	S	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bullfrog	*Rana catesbeiana*	L	S								X				X	X	X	X	X	X	X
Mountain yellow-legged frog	*Rana muscosa*	L	S		X		X		X			X	X		X	X	X	X	X	X	X
Northern leopard frog	*Rana pipiens*	L	S												X	X	X	X	X	X	X
Reptiles:																					
Western aquatic garter snake	*Thamnophis couchii*	L	S		X		X				X				X	X	X	X	X	X	X

[a] ADS = alpine dwarf scrub; ASP = aspen; EPN = Eastside pine; JPN = Jeffrey pine; JUN = juniper; LPN = lodegepole pine; LSG = low sage; MCH = Montane chapparral; RFR = red fir; SCN = subalpine conifer; SGB = sagebrush; SMC = Sierran mixed conifer; WFR = white fire; FEW = fresh emergent wetland; LAC = lacustrine; RIV = riverine; WTM = wet meadow; MRI = montane riparian.

Table 5-55a—Potentially vulnerable terrestrial vertebrates of the Lake Tahoe basin. Species in this table use terrestrial and riparian habitat types and are habitat specialists, using fewer than 30 percent of CWHR habitat type/seral stage combinations (CDFG 1998a). "Habspec" is the proportion of habitat

type/seral stage combinations used (USDA 1999b; Appendix L). Also given are the CWHR habitat types[a] (Mayer and Laudenslayer 1988) in the basin used by each species (CDFG 1998a).

Common name	Scientific name	Habspec	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Birds:																				
Red-winged Blackbird	*Agelaius phoeniceus*	0.111														X	X			X
American Pipit	*Anthus rubescens*	0.115	X						X				X				X	X	X	X
Canyon Wren	*Catherpes mexicanus*	0.159								X						X				
Marsh Wren	*Cistothorus palustris*	0.063														X	X			X
Rock Dove	*Columba livia*	0.028																		
American Crow	*Corvus brachyrhynchos*	0.296												X	X	X		X	X	
Pileated Woodpecker	*Dryocopus pileatus*	0.195			X	X		X			X			X	X	X				
Hammond's Flycatcher	*Empidonax hammondii*	0.207		X	X	X					X			X	X	X				
Willow Flycatcher	*Empidonax traillii*	0.090														X				X
Horned Lark	*Eremophila alpestris*	0.119	X						X				X							X
Rosy Finch	*Leucosticte arctoa*	0.078	X						X			X	X							X
Red Crossbill	*Loxia curvirostra*	0.275			X	X		X			X	X		X	X	X				
Lincoln's Sparrow	*Melospiza lincolnii*	0.250		X	X	X		X			X			X	X	X	X			X
MacGillivray's Warbler	*Oporornis tolmiei*	0.223			X			X		X	X			X		X				X
House Sparrow	*Passer domesticus*	0.122																		
Savannah Sparrow	*Passerculus sandwichensis*	0.158					X		X	X			X							X
Black-billed Magpie	*Pica pica*	0.117					X						X			X				X
Black-backed Woodpecker	*Picoides arcticus*	0.065						X			X	X		X						
Pine Grosbeak	*Pinicola enucleator*	0.136						X			X	X				X				X
Green-tailed Towhee	*Pipilo chlorurus*	0.298		X	X	X	X	X	X		X		X	X	X	X				
Bank Swallow	*Riparia riparia*	0.287							X	X			X			X	X	X	X	X
Pygmy Nuthatch	*Sitta pygmaea*	0.259			X	X		X						X	X					
Williamson's Sapsucker	*Sphyrapicus thyroideus*	0.159		X	X	X		X			X			X	X	X				
Winter Wren	*Troglodytes troglodytes*	0.246			X	X					X			X	X	X				
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	0.053															X	X		X
Mammals:																				
Snowshoe hare	*Lepus americanus*	0.122		X		X		X			X	X		X	X	X				
White-tailed hare	*Lepus townsendii*	0.154	X		X	X	X	X	X		X	X	X							X
Fisher	*Martes pennanti*	0.223		X	X	X		X			X	X		X	X	X				
Pika	*Ochotona princeps*	0.298	X	X	X	X		X	X		X	X	X	X	X	X				X
Mountain sheep	*Ovis canadensis californiana*	0.060																		

Table 5-55a—*(continued)*

Common name	Scientific name	Habspec	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Dusky shrew	*Sorex monticolus*	0.252	X			X		X			X	X		X	X	X	X			X
Trowbridge's shrew	*Sorex trowbridgii*	0.291								X	X			X	X	X				
Belding's Ground Squirrel	*Spermophilus beldingi*	0.241	X	X	X	X		X	X	X	X	X	X	X	X	X				X
Nuttall's Cottontail	*Sylvilagus nuttallii*	0.088	X				X					X	X			X				
Least chipmunk	*Tamias minimus*	0.108	X			X	X		X				X							
Long-eared chipmunk	*Tamias quadrimaculatus*	0.111								X				X	X					
Lodgepole chipmunk	*Tamias speciosus*	0.124				X		X			X	X		X	X					
Douglas' Squirrel	*Tamiasciurus douglasii*	0.266		X	X	X		X			X	X		X	X	X				
Reptiles:																				
Sagebrush lizard	*Sceloporus graciosus*	0.284			X	X	X	X	X	X			X	X	X					

[a] ADS = alpine dwarf scrub; ASP = aspen; EPN = Eastside pine; JPN = Jeffrey pine; JUN = juniper; LPN = lodegepole pine; LSG = low sage; MCH = Montane chapparral; RFR = red fir; SCN = subalpine conifer; SGB = sagebrush; SMC = Sierran mixed conifer; WFR = white fire; FEW = fresh emergent wetland; LAC = lacustrine; RIV = riverine; WTM = wet meadow; MRI = montane riparian.

Table 5-55b—Potentially vulnerable terrestrial vertebrates of the Lake Tahoe basin. Species in this table use terrestrial and riparian habitats, are moderate habitat specialists, using 30 to 60 percent of CWHR habitat type/seral stage combinations (CDFG 1998a), and have either low mobility and large home range, low mobility and moderate home range, or moderate mobility and large home range. "Habspec" is the proportion of habitat type/seral stage combinations used (USDA 1999b; Appendix L). "Mob" is a species' mobility—its ability to move in response to seasonal or reproductive needs (USDA 1999b; Appendix L); L = low, M = moderate. "Rng" is a species' home range (USDA 1999b; Appendix L); M = moderate, L = large. Also given are the CWHR habitat types[a] (Mayer and Laudenslayer 1988) in the basin used by each species (CDFG 1998a).

Common name	Scientific name	Habspec	Mob	Rng	ADS	ASP	EPN	JPN	JUN	LPN	LSG	MCH	RFR	SCN	SGB	SMC	WFR	MRI	FEW	LAC	RIV	WTM
Mammals:																						
Northern flying squirrel	*Glaucomys sabrinus*	0.341	L	M		X	X	X		X			X	X		X	X	X				
Wolverine	*Gulo gulo*	0.369	M	L	X	X		X		X			X	X		X	X	X				X
Yellow-bellied marmot	*Marmota flaviventris*	0.385	L	M	X	X	X	X		X	X		X	X	X	X	X	X				X
Marten	*Martes americana*	0.369	M	L		X	X	X		X			X	X		X	X	X				X
Long-tailed vole	*Microtus longicaudus*	0.515	L	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X
Desert woodrat	*Neotoma lepida*	0.477	L	M							X	X			X							
Brush mouse	*Peromyscus boylii*	0.586	L	M	X		X	X	X		X	X		X	X	X	X	X				
Canyon mouse	*Peromyscus crinitus*	0.337	L	M	X		X		X		X	X		X	X							
Pinyon mouse	*Peromyscus truei*	0.550	L	M	X		X		X		X	X			X	X	X	X				X
Heather vole	*Phenacomys intermedius*	0.328	L	M	X		X	X		X			X	X		X	X	X				X
Broad-footed mole	*Scapanus latimanus*	0.332	L	M		X	X	X		X			X			X	X	X				X
Western gray squirrel	*Sciurus griseus*	0.513	L	M		X	X	X				X				X	X	X				
Vagrant shrew	*Sorex vagrans*	0.468	L	M	X	X		X		X		X	X	X		X	X	X	X			X
Yellow-pine chipmunk	*Tamias amoenus*	0.595	L	M		X	X	X	X	X	X	X	X	X	X	X	X	X				
Badger	*Taxidea taxus*	0.474	M	L	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X
Mountain pocket gopher	*Thomomys monticola*	0.314	L	M	X		X	X		X	X	X	X	X	X	X	X					X
Sierra Nevada red fox	*Vulpes vulpes necator*	0.424	M	L	X	X	X	X		X		X	X	X		X	X	X				X
Western jumping mouse	*Zapus princeps*	0.380	L	M	X	X	X	X		X			X	X	X	X	X	X				X

[a] ADS = alpine dwarf scrub; ASP = aspen; EPN = Eastside pine; JPN = Jeffrey pine; JUN = juniper; LPN = lodegepole pine; LSG = low sage; MCH = Montane chapparral; RFR = red fir; SCN = subalpine conifer; SGB = sagebrush; SMC = Sierran mixed conifer; WFR = white fire; FEW = fresh emergent wetland; LAC = lacustrine; RIV = riverine; WTM = wet meadow; MRI = montane riparian.

habitat specificity (USDA 1999b) (Table 5-56).

Endemic Terrestrial Vertebrates—No vertebrates are endemic to the Lake Tahoe basin, but the long-eared chipmunk (*Tamias quadrimaculatus*) is endemic to the Sierra Nevada (Graber 1996) and was considered a focal species.

Exotic Species—Seven exotic, undomesticated, terrestrial vertebrate species are currently found in the basin (Table 5-57). Five species are known exotics to the Sierra Nevada (Graber 1996) and therefore the Lake Tahoe basin. It is questionable if beavers are native to the basin; Orr (1949) does not discuss them, implying that they were not present in the basin during his surveys. We treat beavers as exotic. We assume that the California quail has been introduced to the basin, as suggested by Orr and Moffitt (1971). The northern leopard frog has been treated as exotic to the basin by some authors and native by others (Jennings and Hayes 1994); here, we simply note it as a possible exotic. Despite Graber's (1996) identification of the muskrat (*Ondatra zibethicus*) as exotic to the Sierra Nevada, Grinnell (1933) identified the species as native to Lake Tahoe; it is considered native here.

Domesticated Species—We identified six domesticated terrestrial vertebrates that may have significant impacts on the natural environment (Table 5-58). Pets, such as dogs (*Canis familiaris*) and cats (*Felis domesticus*), have been shown to harass and prey on native wildlife species (Frankel and Soule 1981; Graber 1996; Patronek 1998; Anon. 1997; Atkinson 1989). Pack animals, such as horses (*Equus* sp.), mules (*Equus* sp.), and llamas (*Lama glama*), may disturb the soil and trample native vegetation (Ratliff 1985; Cole and Landres 1995), as well as disperse seeds of nonnative grasses and herbs through their feces. Finally, grazing and possible trampling by cattle (*Bos* sp.) can greatly alter native vegetation and destroy habitat for native animals (Ratliff 1985; Atkinson 1989).

Native Ecological Pests—A small number of vertebrate species have the potential to become native ecological pests in the basin should their populations increase unchecked: brown-headed cowbird (a nest parasite; Brittingham and Temple 1983), house wren (*Troglodytes aedon*) (an aggressive

Table 5-56—Old-forest dependent terrestrial vertebrates of the Lake Tahoe basin (Graber 1996, as modified by USDA 1999b), listed in order of decreasing habitat specificity (USDA 1999b) (Appendix L).

Common name	Scientific name	Habitat specificity
Pileated Woodpecker	*Dryocopus pileatus*	0.195
Fisher	*Martes pennanti*	0.223
Winter Wren	*Troglodytes troglodytes*	0.246
Pygmy Nuthatch	*Sitta pygmaea*	0.259
Red Crossbill	*Loxia curvirostra*	0.275
Spotted Owl	*Strix occidentalis*	0.307
Northern flying squirrel	*Glaucomys sabrinus*	0.341
Cassin's Finch	*Carpodacus cassinii*	0.344
White-headed Woodpecker	*Picoides albolarvatus*	0.365
Marten	*Martes americana*	0.369
Brown Creeper	*Certhia americana*	0.378
Red-breasted Nuthatch	*Sitta canadensis*	0.408
Purple Finch	*Carpodacus purpureus*	0.428
Hermit Warbler	*Dendroica occidentalis*	0.507
Evening Grosbeak	*Coccothraustes vespertinus*	0.618
Northern Goshawk	*Accipiter gentilis*	0.674

Table 5-57—Exotic terrestrial vertebrates of the Lake Tahoe basin.

Common name	Scientific name
Birds:	
California Quail	*Callipepla californica*
Rock Dove	*Columba livia*
Wild Turkey	*Meleagris gallopavo*
House Sparrow	*Passer domesticus*
European Starling	*Sturnus vulgaris*
Mammals:	
Beaver	*Castor canadensis*
Amphibians:	
Bullfrog	*Rana catesbeiana*

Table 5-58—Terrestrial vertebrate species of the Lake Tahoe basin that are domesticated and are considered to have significant impacts on the natural environment.

Common name	Scientific name
Cow	*Bos* sp.
Domestic dog	*Canis familiaris*
Horse	*Equus* sp.
Mule	*Equus* sp.
Domestic cat	*Felis domesticus*
Llama	*Lama glama*

competitor for nesting cavities; Ehrlich et al. 1988), Steller's jay (*Cyanocitta stelleri*) (a nest predator; Ehrlich et al. 1988), coyote (a generalist predator; Ahlborn 1990b), and common raven (a nest predator; Ehrlich et al. 1988). Of these, the brown-headed cowbird is the only species that we determined is likely to attain problematic densities in the near future.

The reproductive strategy of the brown-headed cowbird may negatively affect many passerine species in the Lake Tahoe basin. Brown-headed cowbirds are generalist parasites, meaning that they lay their eggs in the nests of other species and allow the host species to hatch and rear the cowbird's young (Brittingham and Temple 1983; Ehrlich et al. 1988). Cowbird eggs usually hatch one day prior to those of the host brood; they develop rapidly and are larger than host chicks. Cowbird chicks are thus able to consume a larger share of the food provided by the parents, at the expense of the host brood. Brown-headed cowbirds are native to North America but have expanded their original range (prior to 1800) from the plains and prairies west of the Mississippi River to include most of North America (Brittingham and Temple 1983; Ehrlich et al. 1988). Ehrlich et al. (1988) considered the range expansion and population increase of the brown-headed cowbird to be a major threat to the continued survival of several parasitized species, mainly songbirds. Records indicate that brown-headed cowbirds have only recently (since 1960) expanded their range into the Lake Tahoe basin. Recent surveys by Manley and Schlesinger (in preparation) detected the brown-headed cowbird at over 75 percent of 80 lotic riparian areas and 28 percent of 88 lentic riparian areas in the basin.

Cultural Criteria—We used four criteria to identify culturally important vertebrate species:

harvest status, watchable status, human conflict, and management agency emphasis.

Harvested Terrestrial Vertebrates—Although many of the basin's terrestrial vertebrates are designated game species in California (CDFG 1998b) and Nevada (NDOW 1998), only a handful are actually harvested in the basin. Hunting activities are greatly restricted in the basin because of the high density of people. We identified two mammals and two birds that are the most commonly hunted animals in the basin (Bezzone 1999) (Table 5-59).

Table 5-59—Terrestrial vertebrate species that are occasionally hunted in the Lake Tahoe basin.

Common Name	Scientific Name
Birds:	
Blue Grouse	*Dendragapus obscurus*
Mountain Quail	*Oreortyx pictus*
Mammals:	
Mule deer	*Odocoileus hemionus*
Black bear	*Ursus americanus*

Watchable Terrestrial Vertebrates—Generally speaking, the most popular watchable wildlife species are large-bodied mammals and birds. We identified five birds and five mammals that are commonly viewed by the public, three of which have been extirpated from the Tahoe basin (Table 5-60).

Human Conflict Terrestrial Vertebrates—We identified 10 terrestrial vertebrates as human conflict species (Table 5-61). The most frequent complaints to the El Dorado County Animal Control office involved coyotes, black bears, Canada geese (*Branta canadensis*), raccoons (*Procyon lotor*), and three species of squirrel (Cecchettini 1999). Raccoons and bears frequently turn over garbage cans, bears and coyotes are seen as potentially dangerous to children and pets, squirrels get into houses, and geese leave their waste on structures and lawns. We assumed that only the most common squirrels that inhabit urban environments have conflicts with humans. We identified three additional species, two gulls and the rock dove, that inhabit urban environments and leave waste on human structures. Finally, we considered beavers potential nuisance animals because the dams they create reconfigure stream channels in a manner often undesirable to residents.

Table 5-60—Terrestrial vertebrate species of the Lake Tahoe basin that are commonly viewed by the public for pleasure. The Peregrine Falcon, mountain sheep, and grizzly bear are considered extirpated from the basin.

Common Name	Scientific Name
Birds:	
Mallard	*Anas platyrhynchos*
Canada Goose	*Branta canadensis*
Peregrine Falcon	*Falco peregrinus*
Bald Eagle	*Haliaeetus leucocephalus*
Osprey	*Pandion haliaetus*
Mammals:	
Coyote	*Canis latrans*
Mule deer	*Odocoileus hemionus*
Mountain sheep	*Ovis canadensis californiana*
Black bear	*Ursus americanus*
Grizzly bear	*Ursus arctos*

Management Agency Emphasis Terrestrial Vertebrates—We identified 15 terrestrial vertebrates as focal based on their listing by the TRPA or USFS as special interest or sensitive species (Table 5-62). TRPA's list of special interest species (TRPA 1982) contains seven terrestrial vertebrates. USFS's list of sensitive species contains ten terrestrial vertebrates that regularly occur in the basin (USDA 1998b). The Townsend's big-eared bat (*Corynorhinus townsendii*) and great gray owl (*Strix nebulosa*) have not been recorded in the Tahoe basin and were therefore not considered focal, despite their listing as sensitive for the Lake Tahoe Basin Management Unit.

Summary—One hundred forty-five terrestrial vertebrate species were identified as focal in the Lake Tahoe basin (Appendix N): 83 birds, 53 mammals, six amphibians, and three reptiles. One hundred fifteen species were focal based on ecological criteria only, six species were focal based on cultural criteria only, and 24 species were focal based on both ecological and cultural criteria.

Table 5-61—Terrestrial vertebrate species of the Lake Tahoe basin with some level of conflict with humans.

Common Name	Scientific Name	Conflict(s)
Birds:		
Canada Goose	*Branta canadensis*	Property damage from waste
Rock Dove	*Columba livia*	Property damage from waste
California Gull	*Larus californicus*	Property damage from waste
Ring-billed Gull	*Larus delawarensis*	Property damage from waste
Mammals:		
Coyote	*Canis latrans*	Perceived as a threat
Beaver	*Castor canadensis*	Channel alteration
Raccoon	*Procyon lotor*	Trash disturbance
Western gray squirrel	*Sciurus griseus*	Unwanted entry into homes
California ground squirrel	*Spermophilus beecheyi*	Unwanted entry into homes
Douglas squirrel	*Tamiasciurus douglasii*	Unwanted entry into homes
Black bear	*Ursus americanus*	Trash disturbance; perceived as a threat

Table 5-62—Terrestrial vertebrates identified as sensitive or of special interest by the two primary management and regulatory agencies in the Lake Tahoe basin (TRPA 1982; USDA 1998). No records of occurrence exist in the basin for the Great Gray Owl (*Strix nebulosa*) and Townsend's big-eared bat (*Corynorhinus townsendii*), which are listed as sensitive for the Lake Tahoe Basin Management Unit.

Common Name	Scientific Name	TRPA Special Interest	USDA Forest Service Sensitive
Birds:			
Northern Goshawk	*Accipiter gentilis*	X	X
Golden Eagle	*Aquila chrysaetos*	X	
Willow Flycatcher	*Empidonax traillii*		X
Peregrine Falcon	*Falco peregrinus*	X	
Bald Eagle	*Haliaeetus leucocephalus*	X	
Osprey	*Pandion haliaetus*	X	
Spotted Owl	*Strix occidentalis*		X
Mammals:			
Pallid bat	*Antrozous pallidus*		X
Wolverine	*Gulo gulo*		X
Marten	*Martes americana*		X
Fisher	*Martes pennanti*		X
Mule deer	*Odocoileus hemionus*	X	
Mountain sheep	*Ovis canadensis californiana*		X
Sierra Nevada red fox	*Vulpes vulpes necator*		X
Amphibians:			
Mountain yellow-legged frog	*Rana muscosa*		X
Northern leopard frog	*Rana pipiens*		X

Focal Fish Species

Ecological Criteria—We used three ecological criteria to identify ecologically important focal species: potential imperilment, endemism, and exotic status. The specific analyses are described below.

Potentially Imperiled Fish—Fish species were determined to be potentially imperiled in the Sierra Nevada based on their designation as endangered, threatened, or of special concern by federal and state governments and based on population trends. Two fish species in the Lake Tahoe basin are listed by federal or state agencies (Table 5-63). The Lahontan cutthroat trout is federally listed as threatened, and the Lahontan Lake tui chub (*Gila bicolor pectinifer*) is a California state species of special concern.

Data were not available at the time of this assessment to facilitate detailed consideration of population characteristics to identify imperiled species. However, qualitative observations indicate that populations of the mountain whitefish in the basin may have declined (Reiner 1999). Moyle et al. (1996) provide no evidence of this for the Sierra Nevada as a whole, but we include mountain whitefish as a focal species in the hope that additional effort will confirm or deny suspected declines in the basin.

Exotic Fish—Sixteen of the 20 fish species that were introduced to the basin have extant populations and are considered exotic species (Table 5-63). Exotic trout species are suspected to be responsible for the decline of native amphibian populations throughout the Sierra Nevada, including the Lake Tahoe basin (Hayes and Jennings 1986; Bradford 1989; Drost and Fellers 1996).

Cultural Criteria—We used three criteria to identify culturally important focal fish species: harvest status, watchable status, and management agency emphasis. Nine cultural focal species were identified (Table 5-63). Eight focal fish species are commonly harvested in the Lake Tahoe basin (Bezzone 1999), one of which, the Kokanee salmon, is also considered a watchable wildlife species because its fall spawning run is viewed by many and celebrated with an annual festival. One focal species, the Lahontan Lake tui chub, is a USDA Forest Service sensitive species (USDA 1998b).

Summary—Nineteen fish species were identified as focal (Appendix N). The four species not identified as focal were small-bodied native species. The sizable recreational fishery in the basin is founded almost entirely on large-bodied exotic fish species.

Focal Invertebrate Species

Given the scarcity of information on invertebrates in the basin, our criteria for the identification of focal species were restricted to a limited set of ecological and cultural factors (Table 5-44).

Ecological Criteria—We used three criteria to identify ecologically important focal invertebrates: potential imperilment, endemism, or exotic status. The specific analyses are described below.

Potentially Imperiled Invertebrates—Two criteria were considered in identifying potentially imperiled invertebrates: listed species and species whose populations have apparently declined. No species of invertebrates occurring in the basin are designated as threatened or endangered by the federal or state governments. Two federally recognized species of special concern, the Mono checkerspot (*Euphydryas editha monoensis*) and Carson Valley silverspot butterfly (*Speyeria nokomis carsonensis*), may occur in the Lake Tahoe basin and were considered focal. One additional focal species, the Lake Tahoe benthic stonefly (*Capnia lacustra*), also is a federal species of special concern and is one of the few biota endemic to the basin.

The Lake Tahoe benthic stonefly is associated with deep-water plant beds and was noted in Lake Tahoe in the early 1960s (Frantz and Cordone 1996). However, more recent surveys have failed to detect this species. Declines in the Lake Tahoe benthic stonefly may be due to the introduction of opossum shrimp between 1963 and 1965 by the California Department of Fish and Game (Frantz and Cordone 1996). The Lake Tahoe benthic stonefly was designated a focal species in recognition of its possible decline (Table 5-64).

Endemic Invertebrates—Frantz and Cordone (1996) noted 10 species of benthic macroinvertebrates endemic to Lake Tahoe; all were considered focal (Table 5-64).

Table 5-63—Focal fish species of the Lake Tahoe basin, with applicable reasons for inclusion as focal species designated with an "X" in the appropriate columns. "Listed" refers to federal or state threatened, endangered, or special concern species. "Exotic" applies to fish species not native to the basin. "Watchable" applies to species viewed by the public for pleasure.

Common Name	Scientific Name	Listed	Population Decline	Exotic	Harvested	Watchable	USFS Sensitive
Goldfish	*Carassius auratus*			X			
Carp	*Cyprinus carpio*			X			
Mosquito fish	*Gambusia affinis*			X			
Lahontan Lake tui chub	*Gila bicolor pectinifer*	X					X
Brown bullhead	*Ictalurus nebulosis*			X			
Bluegill	*Lepomis macrochirus*			X			
Smallmouth bass	*Micropterus dolomieui*			X	X		
Largemouth bass	*Micropterus salmoides*			X	X		
Golden shiner	*Notemigonus crysoleucas*			X			
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*	X					
Rainbow trout	*Oncorhynchus mykiss*			X	X		
Kokanee salmon	*Oncorhynchus nerka kennerlyi*			X	X	X	
White crappie	*Pomoxis annularis*			X			
Black crappie	*Pomoxis nigromaculatus*			X			
Mountain whitefish	*Prosopium williamsoni*		X				
Golden trout	*Oncorhynchus aquabonita*			X	X		
German brown trout	*Salmo trutta*			X	X		
Brook trout	*Salvelinus fontinalis*			X	X		
Mackinaw (lake) trout	*Salvelinus namaycush*			X	X		

Table 5-64—Focal invertebrate taxa for the Lake Tahoe basin.

		Ecological Criteria				Cultural Criteria	
Common Name	**Scientific Name**	**Listed**	**Population Changes**	**Endemic**	**Exotic**	**Watchable**	**Harvest**
Terrestrial:							
Mono checkerspot	*Euphadryas deitha monoensis*	X					
Moths and butterflies	*Lepidoptera*					X	
Carson Valley silverspot butterfly	*Speyeria nokomis*	X					
Aquatic:							
Aquatic macroinvertebrate	*Candona tahoensis*			X			
Aquatic macroinvertebrate	*Capnia lacustra*	X	X	X			
Aquatic macroinvertebrate	*Dendrocoelopsis hymanae*			X			
Opossum shrimp	*Mysis relicta*				X		
Crayfish	*Pacifastacus leniusculus*				X		X
Aquatic macroinvertebrate	*Phagocata tahoena*			X			
Aquatic macroinvertebrate	*Rhyacodrilus brevidentus*			X			
Aquatic macroinvertebrate	*Spirosperma beetoni*			X			
Aquatic macroinvertebrate	*Stygobromus lacicolus*			X			
Aquatic macroinvertebrate	*Stygobromus tahoensis*			X			
Aquatic macroinvertebrate	*Utacapnia tahoensis*			X			
Aquatic macroinvertebrate	*Varichaetadrilus minutus*			X			

Exotic Invertebrates—Two species of invertebrates are known to be introduced to the basin and were considered exotics. Opossum shrimp were introduced to the basin between 1963 and 1965 by the California Department of Fish and Game (Cordone 1999). Crayfish (*Pacifastacus leniusculus*) also were introduced into the basin (Erman 1996). Both of these species were considered focal invertebrates (Table 5-64).

Cultural Criteria—We used three cultural criteria to identify culturally important invertebrates: harvest status, watchable status, and management agency emphasis (Table 5-64). Few invertebrates (outside of marine ecosystems) are held in high regard by people as culturally valuable based on their beauty or grandeur. More typically the mention of spiders, flies, or millipedes will evoke responses of indifference or disgust. However, a few taxa are held in high regard by people. The crayfish is of local interest as a harvest species (see Chapter 4). We identified butterflies and moths (Lepidoptera) as watchable species. No invertebrates have been identified as emphasis species by TRPA or the USFS.

Summary—Fourteen species and one order of invertebrates were identified as focal (Table 5-64). Thirteen species were focal based on ecological criteria alone, one order was focal based on cultural criteria alone, and one species was focal because of both ecological and cultural criteria.

Focal Fungi

Ecological Criteria—We used three ecological criteria to identify ecologically important fungi: potential imperilment, potential vulnerability, and endemism.

No federally or state-listed species of fungi or lichens are known or suspected to occur in the Lake Tahoe basin. However, qualitative observations indicate that one genus of lichen, *Bryoria*, may have declined in frequency and abundance in the basin (Hanson 1999). *Bryoria* is a fruticose lichen and may be particularly susceptible to the negative effects of poor air quality in the basin. We included *Bryoria* as a focal taxon with the hope that additional effort will confirm or deny suspected declines in the basin.

Eight rare species of lichen have been identified in the Sierra Nevada (Shevock 1996). With the exception of *Hydrothyria venosa*, an aquatic lichen, all of these species may occur in the basin (Hale and Cole 1988), although their occurrence has not been confirmed. Thus, seven rare lichens were considered focal fungi species in the Lake Tahoe basin (Table 5-65).

No fungi or lichens are currently recognized as endemic to the Lake Tahoe basin or the Sierra Nevada.

Cultural Criteria—Two cultural criteria were considered to identify focal fungi: harvest status and agency emphasis. No formal record (e.g., special use permits) of mushroom harvesting exist for the Lake Tahoe basin. However, individuals are known to collect mushrooms for personal consumption in the Lake Tahoe basin area (Allessio 1999). Thirteen species and one genus of commonly harvested fungi are known to occur in the basin and are suspected to be harvested at some level (Foster 1993; Taylor 1999) (Table 5-65). They were all considered focal. No fungi are currently designated as agency emphasis species.

Summary—Twenty species and two genera were identified as focal fungi for the Lake Tahoe basin (Table 5-65). Seven species and one genus were considered focal based solely on ecological criteria, and the remaining 13 species and one genus were considered focal, based solely on cultural criteria.

Summary of all Focal Species

Our analysis showed that many taxa are of concern and interest in the Lake Tahoe basin. Two hundred seventy-four focal taxa were identified: 57 vascular plants, 16 nonvascular plants, 83 birds, 53 mammals, six amphibians, three reptiles, 19 fish, 15 invertebrates, and 22 fungi and lichens. The identification of focal species has enabled us to highlight species of greatest interest and concern in the basin. We suggest that these species should receive special consideration in monitoring, management, conservation, and research. They represent a diversity of concerns and interests, and each species may require unique consideration. We

Table 5-65—Focal fungi in the Lake Tahoe basin.

Common Name	Scientific Name	Population Decline	Rare	Harvested
Coccora	*Amanita calyptrata*			X
Honey mushroom	*Armillariella mellea*			X
King bolete	*Boletus edulis*			X
Lichen	*Bryoria spp.*	X		
Giant puffball	*Calvatia gigantea*			X
Sierra puffball	*Calvatia sculpta*			X
Chantrelle	*Cantharellus cibarius*			X
Shaggy mane	*Coprinus comatus*			X
Lichen	*Dermatocarpon moulinsii*		X	
Lichen	*Dimelaena oreina*		X	
Lichen	*Hypogymnia metaphysodes*		X	
Delicious milk cap	*Lactarius deliciosus*			X
Morels	*Morchella spp.*			X
Oyster mushroom	*Pleurotus ostreatus*			X
Chicken of the woods	*Polyporus sulphureus*			X
Yellow coral mushroom	*Ramaria rasilispora*			X
Lichen	*Rhizoplaca glaucophana*		X	
Shrimp russula	*Russula xerampelina*			X
Cauliflower mushroom	*Sparassis crispa*			X
Lichen	*Thisoplaca marginalis*		X	
Lichen	*Umblicaria torrefacta*		X	
Lichen	*Waynea stoechadiana*		X	

address appropriate and recommended actions regarding the conservation, management, and monitoring of focal species later in this issue.

What is the status of our knowledge about select focal species of greatest interest to local agencies and organizations ?

The amount of available information about the basin's focal species varies widely. Some species are well-studied and much published literature is available, while others have not been the focus of much research. Furthermore, some species have been monitored in the basin for years, while the status of others in the basin is unknown. Species accounts can highlight the existing information and data gaps about a species. Species accounts are compilations of the state of knowledge regarding a species, including its distribution, ecology, life history, and responses to human activities. They are intended to assist in planning and the development of conservation, monitoring, and research activities. Accounts have been compiled for other efforts that address some of the focal species (e.g., Zeiner et al. 1988, 1990a, 1990b; Hickman 1993), but they are directed at a scale much larger than the basin, thereby decreasing their usefulness to local managers. Few species accounts specific to the basin exist, so we developed accounts for a few species of greatest interest to managers to provide some examples of how information could be compiled in a useful format for every focal species and also provide managers with a compendium of readily available information on some focal species (Appendix O).

Envirograms (Andrewartha and Birch 1984) are useful for identifying a full range of primary environmental factors influencing species populations. Envirograms distinguish five categories of environmental factors: resources, which includes components (food, water, cover temperature) necessary to support individuals and populations; predators, which includes species that eat or parasitize the focal species; mates, which include resources, habitat configurations, and population sizes necessary to facilitate mate location and reproduction; malentities, which include competitors, disease, and detrimental affectors; and subsidies, which are beneficial affectors. Habitat in

this context includes any of these primary environmental factors. Environmental factors are displayed in a hierarchical manner, with the factors that act directly on the species being located in "the centrum" and factors acting indirectly on the species through the centrum being located in succeeding tiers of "the web" (Table 5-66). Links between the factors and the species and among the factors are typically indicated by drawing lines between them in an envirogram figure.

Apart from their use in displaying important environmental factors, envirograms can provide a strong foundation for quantifying interactions between species and environmental factors based on published literature and field data. Such an exercise can allow managers to predict the responses of species to management actions more accurately. We provide a few envirograms as examples of the utility of this approach (Appendix O).

Select Focal Species

Ideally, species accounts and envirograms would be developed for every focal species, but we did not have the resources to accomplish this. Therefore, we selected a subset of the focal species on which to concentrate our efforts. We wanted these "select focal species" to represent a range of interests (including land managers, regulatory agencies, and interest groups in the basin), to represent several taxonomic groups, and to represent species likely to be affected by proposed management in the basin.

To identify the set of select focal species to take to the next step of development, we queried the following agencies and organizations, asking them to choose 20 vertebrate and 10 plant species of greatest interest: USFWS, California Department of Fish and Game, Nevada Division of Wildlife, California State Parks and Recreation, USDA Forest Service, California Tahoe Conservancy, California State Lands Commission, and the League to Save Lake Tahoe. Individuals from these agencies and organizations providing responses are listed in Appendix P.

Respondents chose a wide variety of both vertebrate and plant species, but some species were clearly of greater concern than others to most respondents (tables 5-67 and 5-69). The specific selection processes and select species are described below.

Select Focal Animals—We created a weighted ranking system to determine the top 10 vertebrate species of interest to agencies. We asked respondents to note whether their vertebrate selections were of highest priority (top 10 species) or of secondary priority (next 10 species). We counted the number of agencies that selected a given species as first and second priority. We doubled the count of agencies choosing the species as first priority (giving them twice the weight) and then summed the counts. We selected the 10 species with the highest summed count (Table 5-67) as the top 10 species of interest to agencies.

The additional 10 vertebrate and one invertebrate species were selected by team consensus to balance the array of taxonomic groups represented and to represent species likely to respond significantly to management in the basin (Table 5-68). We selected the long-toed salamander and western aquatic garter snake (*Thamnophis couchii*) because their association with aquatic habitats makes them vulnerable to changes in management of

Table 5-66—Elements of an envirogram (Andrewartha and Birch 1984) and their general configuration.

Web			Centrum	
3	**2**	**1**		
Resources, predators, mates, malentities, and subsidies directly affecting Web 2	Resources, predators, mates, malentities, and subsidies directly affecting Web 1	Resources, predators, mates, malentities, and subsidies directly affecting the centrum	Resources, predators, mates, malentities, and subsidies directly affecting the species	**Species**

Table 5-67—The top 10 selections by questionnaire respondents of focal vertebrate species of the Lake Tahoe basin. We used a weighted ranking system in which those species designated as "first priority" (A) by respondents received twice the weight of species designated as "second priority" (B). Responses represent the opinions of individual biologists at the agencies and organizations noted and do not necessarily reflect the opinions of others at those agencies and organizations. CDFG = California Department of Fish and Game; CSP&R = California State Parks and Recreation; CTC = California Tahoe Conservancy; League = League to Save Lake Tahoe; NDOW = Nevada Division of Wildlife; TRPA = Tahoe Regional Planning Agency; USFS = USDA Forest Service, Lake Tahoe Basin Management Unit; USFWS = US Fish and Wildlife Service.

Common Name	Scientific Name	CDFG	CSP&R	CTC	League	NDOW	TRPA	USFS	USFWS	1st Priority Count	2nd Priority Count	Wtd Total[a]
Marten	*Martes americana*	A	B	A	A	A	A	A	A	7	1	15
Northern Goshawk	*Accipter gentilis*	A	A	A	A	A	A	A	B	7	1	15
Bald Eagle	*Haliaeetus leucocephalus*	A	A	B	A	A	A	B	A	6	2	14
Willow Flycatcher	*Empidonax traillii*	A	A	-	B	A	A	A	A	6	1	13
Mountain yellow-legged frog	*Rana muscosa*	A	-	B	A	B	A	A	A	5	2	12
Osprey	*Pandion haliaetus*	A	-	B	B	A	A	B	B	3	4	10
Spotted Owl	*Strix occidentalis*	A	A	-	A	A	B	B	-	4	2	10
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*	A	B	-	A	-	B	B	A	3	3	9
Pileated Woodpecker	*Dryocopus pileatus*	-	A	-	-	A	A	A	-	4	0	8
Northern flying squirrel	*Glaucomys sabrinus*	A	B	-	-	A	A	-	-	3	1	7

[a] Weighted total = $\sum$(1st priority count * 2) + $\sum$(2nd priority count)

Table 5-68—Select focal animal species for the watershed assessment in the Lake Tahoe basin.

Common Name	Scientific Name	Comments
Birds:		
Northern Goshawk	*Accipter gentilis*	High agency interest
Yellow Warbler	*Dendroica petechia*	Riparian associate, common cowbird host
Pileated Woodpecker	*Dryocopus pileatus*	High agency interest
Willow Flycatcher	*Empidonax traillii*	High agency interest
Bald Eagle	*Haliaeetus leucocephalus*	High agency interest
Brown-headed Cowbird	*Molothrus ater*	Indicator of change and potential ecological pest
Osprey	*Pandion haliaetus*	High agency interest
Spotted Owl	*Strix occidentalis*	High agency interest
Mammals:		
Pallid bat	*Antrozous pallidus*	Forest-associated bat
Coyote	*Canis latrans*	Top carnivore
Northern flying squirrel	*Glaucomys sabrinus*	High agency interest
Marten	*Martes americana*	High agency interest
Douglas' squirrel	*Tamiasciurus douglasii*	Forest-associated squirrel, important prey item
Black bear	*Ursus americana*	Upper level, large-bodied predator
Amphibians:		
Long-toed salamander	*Ambystoma macrodactylum*	Status unknown, aquatic
Mountain yellow-legged frog	*Rana muscosa*	High agency interest
Reptiles:		
Western aquatic garter snake	*Thamnophis couchii*	Aquatic reptile
Fish:		
Smallmouth bass	*Micropterus dolomieui*	Exotic deep water predator
Lahontan cutthroat trout	*Oncorhynchus clarkii henshawi*	High agency interest
Rainbow trout	*Oncorhynchus mykiss*	Exotic predator of native frogs and fishes
Invertebrates:		
Lake Tahoe benthic stonefly	*Capnia lacustra*	Endemic species; status unknown

aquatic habitat in the basin and because both species are poorly studied in the basin. We selected the rainbow trout and smallmouth bass (*Micropterus dolomieui*) because they are both nonnative predators of native aquatic animals and they represent different habitat associations. The black bear and coyote are both large-bodied upper-level predators that are highly visible to residents and visitors. The Douglas' squirrel (*Tamiasciurus douglasii*) is a forest-dwelling small mammal that is a prey item year-round for raptors and mammals and is also highly dependent on the cone crops of conifers (Sullivan and Sullivan 1982). The squirrel is thus likely to exhibit a response to forest management activities. The brown-headed cowbird is an indicator of ecological change, responding favorably to the clearing of land and representing a potential threat to many open-nesting songbirds (Ehrlich et al. 1988). The yellow warbler (*Dendroica petechia*) is a small-bodied riparian-associated bird known to be negatively affected by cowbirds (Ehrlich et al. 1988; Dunn and Garrett 1997). We chose the pallid bat (*Antrozous pallidus*) because of its association with forests and likelihood of being affected by prescribed burning (Rahn 1999). Finally, we selected a single invertebrate, the Lake Tahoe benthic stonefly, because it is one of the few species endemic to the Lake Tahoe basin and its population status is unknown.

Select Focal Vascular Plants—A simpler method was used to identify select focal plants compared to that for vertebrates. Agency experts were provided a list of focal plant species and were asked to identify the 10 focal species of greatest interest. Fourteen species were selected by two or more of the nine agency representatives queried (Table 5-69). We added one harvest species (sugar pine) to round out the list, for a total of 15 select focal plant species (Table 5-70). Sugar pine was added because it is a harvest species that is becoming increasingly rare because of the spread of a fatal blister-rust (Urie 1999).

Species Accounts for Select Focal Species

We developed species accounts for 10 plants, 20 vertebrates, and one invertebrate. We addressed a range of topics in each species account (Table 5-71): population status, ecology, habitat relationships, effects of human activities, and conservation. Ideally, species accounts would be accompanied by distribution maps and a database of sightings in the basin, but we were not able to compile this information for this assessment. We prepared envirograms for five select focal species: sugar pine, Northern Goshawk, northern flying squirrel, long-toed salamander, and Lake Tahoe benthic stonefly. The full set of species accounts and envirograms for select focal species is in Appendix R.

What data gaps were revealed in the process of assessing species and populations?

Our assessment of species and populations in the Lake Tahoe basin was limited by data gaps, poor data, and time. Only the data gaps are addressed here. In this assessment, we relied most heavily on information on the species composition of the basin; however, more comprehensive data on distribution, relative abundance, and life history characteristics of the basin's species would have strengthened the assessment. In general, data are lacking on the occurrence, distribution, population levels, habitat use (for animals), and response to disturbance of most species within the basin. For example, for terrestrial vertebrates, the group for which we had the best information, we were forced to use estimates of population size, population trend, and degree of range change for populations in the Sierra Nevada instead of information specific to populations in the Lake Tahoe basin. Additionally, basic life history information is not easily accessible for most nonvertebrate organisms or is not presently compiled in a usable format. These are common data gaps often faced by biologists when evaluating species for federal or state listing or evaluating potential responses of species to management actions; the basin is not unusual in this regard. Specific limitations imposed on the assessment by these data gaps are described below for each taxonomic group.

Vascular Plants—Despite some significant efforts invested in the inventory of vascular plants by many agencies and researchers in the Lake Tahoe basin, comprehensive plant inventories have not been conducted, leaving large gaps in our knowledge

Table 5-69—The 14 vascular plant species of greatest interest to local agencies in the Lake Tahoe basin. Responses were solicited by a questionnaire, represent the opinions of individual biologists at the agencies and organizations noted, and do not necessarily reflect the opinions of others at those agencies and organizations. CDFG = California Department of Fish and Game; CSLC = California State Lands Commission; CSP&R = California State Parks and Recreation; CTC = California Tahoe Conservancy; League = League to Save Lake Tahoe; TRPA = Tahoe Regional Planning Agency; USFS (El Dorado)= USDA Forest Service, El Dorado National Forest; USFS (LTBMU) = USDA Forest Service, Lake Tahoe Basin Management Unit; USFWS = US Fish and Wildlife Service.

Common name	Scientific name	CDFG	CSLC	CSP&R	CTC	League	TRPA	USFS (El Dorado)	USFS (LTBMU)	USFWS	Total
Lake Tahoe draba	*Draba asterophora* var. *asterophora*	X	X	X	X	X	X		X	X	8
Tahoe yellow cress	*Rorippa subumbellata*	X	X		X	X	X	X	X	X	8
Bullthistle	*Cirsium vulgare*	X		X		X		X			4
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	X				X	X		X		4
Tall whitetop	*Lepidium latifolium*			X	X		X	X			4
Austin's milkvetch	*Astragalus austiniae*		X		X					X	3
Epilobium	*Epilobium howellii*				X	X			X		3
Eurasian watermilfoil	*Myriophyllum spicatum*				X	X	X				3
Long-petaled lewisia	*Lewisia longipetala*	X					X		X		3
Mariposa sedge	*Carex mariposana*		X			X				X	3
Mountain bentgrass	*Agrostis variabilis*	X	X					X			3
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*			X			X		X		3
Galena Creek rockcress	*Arabis rigidissima*	X	X				X				3
Water bulrush	*Scirpus subterminalis*	X	X								2

Table 5-70—Select focal vascular plant species in the Lake Tahoe basin.

Common Name	Scientific Name	Comments
Mountain bentgrass	*Agrostis humilis*	High agency interest
Galena Creek rockcress	*Arabis rigidissima* var. *demota*	High agency interest
Austin's milkvetch	*Astragalus austiniae*	High agency interest
Mariposa sedge	*Carex mariposana*	High agency interest
Bullthistle	*Cirsium vulgare*	High agency interest
Lake Tahoe draba	*Draba asterophora* var. *asterophora*	High agency interest
Cup Lake draba	*Draba asterophora* var. *macrocarpa*	High agency interest
Epilobium	*Epilobium howellii*	High agency interest
Torrey buckwheat	*Eriogonum umbellatum* var. *torreyanum*	High agency interest
Tall whitetop	*Lepidium latifolium*	High agency interest
Long-petaled lewisia	*Lewisia longipetala*	High agency interest
Eurasian watermilfoil	*Myriophyllum spicatum*	High agency interest
Sugar pine	*Pinus lambertiana*	Uncommon, harvested, threatened by disease
Tahoe yellow cress	*Rorippa subumbellata*	High agency interest
Water bulrush	*Scirpus subterminalis*	High agency interest

Table 5-71—General outline for species accounts developed for select focal species.

Population status
Distribution in California, Nevada, and the Lake Tahoe basin
Ecology
Population biology/demographics
Life history
Reproductive behavior
Foraging (behavior/needs)
Dispersal behavior
Home range (size/characteristics/use)
Interactions with other species
Research needs
Habitat relationships
Specialist/generalist?
Habitat types used
Successional stages used
Response to natural disturbance
Effects of human activities (historic/current/anticipated)
Impacts on habitat
Impacts on individuals
Impacts on populations
Current management
Management objectives
Conservation
Current conservation
Conservation objectives
Potential conservation efforts

of the species composition of the basin and the distribution of rare plants. Approximately one-quarter of the plant species list is composed of species whose occurrence has not been documented. Uncertainties about plant occurrence in the basin resulted in our creating a plant species list that most likely overestimates the richness of plant species in the basin. Shevock (1996) stated that large portions of the Sierra Nevada remain unsurveyed, and certainly this is true of much of the basin. High elevation species are particularly poorly inventoried. Studies by Smith (1973, 1983) represent the only attempt at a floristic treatment of the basin; they were the earliest and most comprehensive surveys of plants of the basin and neighboring areas. Surveys by Manley and Schlesinger (in preparation) were designed to answer questions about riparian biodiversity patterns rather than to describe the basin's flora, but identified 145 additional plants at 80 sites in the basin. This suggests that additional survey efforts would be highly successful in confirming additional plant species as occurring in the basin.

Nonvascular Plants—Nonvascular plants are possibly the least studied group of organisms addressed here (Shevock 1996). Shevock (1996) highlighted the poor state of knowledge for mosses in the Sierra Nevada. Distributional information for these taxa is typically general (e.g., "western US"), perhaps indicating broad ranges for these species but more likely suggesting incomplete knowledge of species' distributions. These gaps in data make assessments of species potentially occurring in a specific area, such as the basin, especially difficult. The only confirmed records of bryophytes in the basin come from Manley (unpublished data); this is a very short list. The list of potential species we compiled is short also, reflecting the lack of available distributional information on nonvascular plants. Perhaps when the bryophyte flora for California referenced by Shevock (1996) is published, a more definitive list of nonvascular plants in the basin can be derived.

Vertebrates—Some groups of vertebrates are better studied than others; birds have received the most attention, followed by fish, mammals, amphibians, and reptiles. Information on the basin's birds is relatively easy to obtain; the Lake Tahoe basin bird list (Eastern Sierra Interpretive Association ca. 1993) and Orr and Moffitt (1971) provide lists of the basin's bird species, while recent studies, such as Keane and Morrison (1994) and Manley and Schlesinger (in preparation), provide more recent data. Fish also have been well-studied, in part because of the basin's significant sport fisheries. Our information on mammals came primarily from two volumes (Orr 1949; Hall 1995) describing observations mostly over 50 years old, a survey of riparian areas throughout the basin (Manley and Schlesinger in preparation), and two site-specific bat surveys (Pierson 1998; Tatum 1998a, 1998b). Though we can describe the basin's mammal species composition with some confidence, systematic surveys for all mammal species, particularly bats and mid-sized carnivores, would greatly enhance our understanding of the composition, distribution, and population sizes of the basin's mammals. Amphibians and reptiles are more poorly studied than the other vertebrate groups in the basin, reflecting the historical lack of interest in these groups. Only recently have systematic surveys of amphibians been conducted in the basin (Manley and Schlesinger, in preparation; Lehr 1999; Leyse 1999); we are only beginning to understand patterns of amphibian occurrence and occurrences of sensitive amphibian species around Lake Tahoe. Reptiles are the taxonomic group for which there is the greatest discrepancy between the potential species occurrence (CDFG 1998a) and actual records in the basin. Further surveys for herpetofauna in the basin are much needed.

Invertebrates—Over half of the described species on Earth are insects, and many undescribed species are most likely insects (Noss and Cooperrider 1994), yet we know very little about their distributions. Kimsey (1996) and Erman (1996) point out the poor state of knowledge in the Sierra Nevada for terrestrial insects and aquatic invertebrates, respectively. Distributional information for these groups is typically very general (e.g., "western US"), as it is for nonvascular plants, perhaps indicating broad ranges for these species but more likely suggesting incomplete knowledge of species' distributions. In the basin, we were able to confirm the occurrence of many lepidopteran species, but only because they have been relatively

well studied. Some studies, such as Manley and Schlesinger (in preparation) have identified additional invertebrate taxa, but the list is far from complete. Kimsey (1996) notes that the status of insect taxa is poorly understood in California except for a few particularly well-studied locations (mainly research and teaching stations), which are still studied at certain times of year only. In the basin, a number of small-scale surveys have been conducted that have addressed some taxa at varying levels of specificity. Invertebrates are particularly troublesome because of the difficulty of identifying genera and species; most are identified to family only. In some cases, invertebrate sampling is conducted during assessments of water quality; for this purpose it is often unnecessary to key aquatic invertebrates below the family level (Mangum 1997). These constraints make it difficult to inventory species and to detect changes in species composition, especially in light of the limited funding and time available for invertebrate studies. However, identification of invertebrates to species is important for understanding the invertebrate fauna; one species is not interchangeable for another in terms of its environmental requirements and its function in ecosystems (Erman 1996).

Fungi—Because fungi are often harvested for food, they are somewhat better known than nonvascular plants. However, fungi are typically under-studied by both managers and researchers. The small number of state-listed and federally listed fungi more likely reflects the lack of information on the state of fungal populations than it does viable populations of all fungal species. The Sierra Nevada Ecosystem Project (SNEP 1996) did not address fungi, apart from a brief treatment of the lichens (Shevock 1996). Only Ryan (1990) and Manley and Schlesinger (in preparation) have surveyed fungal and lichen taxa in the basin, and neither approaches a comprehensive survey. Fungi are an extremely important group of organisms to ecosystem function, as they play a vital role in decomposition and nitrogen fixation and represent food sources for humans and other animals, such as tree squirrels (Alexopolous et al. 1996). Fungi warrant some inventory effort and study in the basin.

What monitoring, conservation, and research activities are most appropriate for the focal species identified?

Focal species represent a wide range of concerns about and interests in species and populations in the basin and appropriate conservation, monitoring, and research activities will vary among focal species. In general, the greater the concern and interest associated with a species, the more support there will be for increased investment. The large number of focal species precluded detailed discussions of conservation and monitoring in relation to each species. Instead, we rated the relative level of concern and interest (i.e., importance) of the criteria for focal species selection (Table 5-72). Species associated with multiple criteria were treated in relation to the criterion with the highest level of importance. Potentially imperiled species received a relative importance of 1, the highest level of importance for monitoring and conserving focal species. The three remaining ecological criteria, along with agency emphasis species, received a relative importance of 2, the next highest level of importance. The remaining cultural criteria received a relative importance of 3, the most modest level of importance. We used these rankings to guide our identification of appropriate monitoring and conservation activities. It is important to note that all focal species are of high concern or interest and that actions taken on behalf of every species will benefit the basin's biological diversity. These rankings are simply intended to help identify appropriate levels of investment. Considerations and recommendations for inventory, conservation, monitoring, and research regarding focal species by criterion, as well as some species-specific recommendations, are discussed below.

Prerequisite Inventory Data

The first step in the conservation and monitoring of any species is to obtain an accurate inventory of its distribution and abundance. Earlier, we discussed data gaps encountered in the identification of focal species. Inventory data are

Table 5-72—Relative level of concern and interest in focal species associated with specific criteria. The relative importance of species associated with each criterion is indicated, with 1 representing the highest level of concern and interest and 3 representing the lowest.

Criteria	Importance
Ecological criteria:	
Potentially imperiled	1
Potentially vulnerable	2
Endemic	2
Exotic, domestic, native pest	2
Cultural criteria:	
Agency emphasis	2
Harvested	3
Watchable	3
Human conflict	3

emphasized here as fundamental information necessary to design meaningful and effective conservation efforts. The thoroughness of the inventory needed will depend on the type of conservation and monitoring activities proposed. Systematic surveys of plant species in the basin would greatly improve our understanding of the composition, distribution, and population sizes of plants in the basin. Surveys to confirm potentially occurring focal species (e.g., subalpine fireweed [*Epilobium howellii*], the Mono checkerspot butterfly) and surveys for Forest Service sensitive vertebrates not currently known to occur (e.g., great gray owls and Townsend's big-eared bats) would be especially helpful. Finally, obtaining a more thorough inventory of species occurrence and distribution in the basin for the lesser known taxa (i.e., nonvascular plants, fungi, invertebrates, herbaceous plants, and bats) would provide a more balanced and comprehensive depiction of biological diversity in the basin and a stronger foundation for conservation efforts.

Conservation

The integrity of the basin's biological diversity would best be maintained and enhanced if conservation measures were developed, adopted, and implemented for biological diversity in the basin. We discuss three types of conservation actions: awareness and education, measures to protect biological integrity, and restoration options. Awareness and education can be achieved in a variety of ways, including concerns highlighted in such publications as this assessment and in workshops, research symposia, campfire talks, web sites, newspaper and radio media, school programs, and the public's involvement in monitoring and conservation efforts. Measures to protect biological integrity entail implementing actions intended to safeguard or mitigate impacts to focal species. Such measures may include disturbance buffer zones around nest sites, maintenance of movement corridors, or relocation of populations. Restoration for focal species can involve specific measures to improve the quality or quantity of habitat (including control of exotic species) or to reintroduce populations of focal species. The more intensive conservation actions also include actions at lower levels; for example, restoration activities are often most effective when accompanied by protective measures and education. Increasing levels of concern about the persistence of a species will merit increasing levels of investment in conservation, from awareness (the lowest level) to highly intensive conservation measures such as guarding all individuals in the wild (e.g., elephants in parts of Africa), to restoration options such as augmenting the population through captive breeding (e.g., California Condor [*Gymnogyps californianus*]) (Figure 5-38). Conservation of biological diversity will be most successful if all three types of conservation actions are employed. Below, we discuss some options for conservation actions.

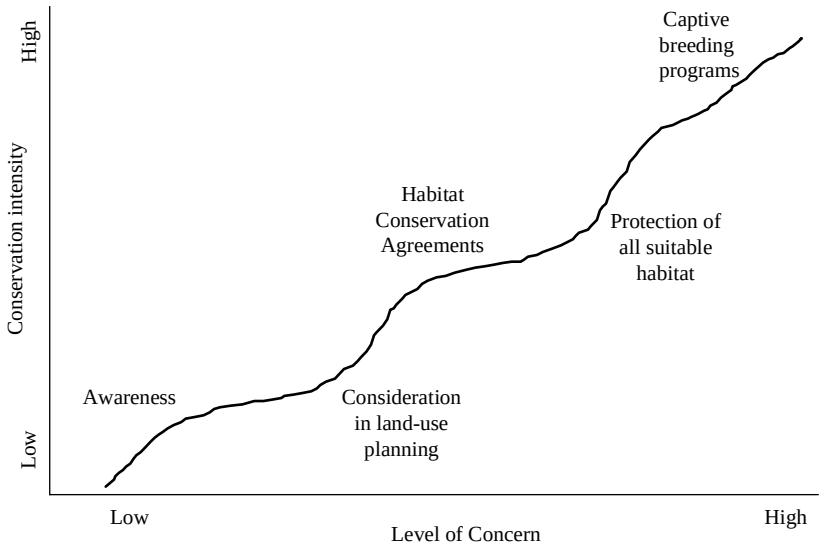


Figure 5-38—Relationship between the level of concern for a species or population and intensity of conservation actions.

We identified opportunities for conservation actions that seemed appropriate for each focal species (Appendix Q). The number of focal species precluded detailed discussion of the actions suggested for each species. Instead, we provide a summary of conservation opportunities identified across all species. Awareness and education measures were appropriate for the most species (n = 127), followed by measures to protect biological integrity (124 species), and finally restoration (21 species) (Table 5-73). Many of the conservation measures, such as habitat protection, could benefit multiple species; only a few species warrant species-specific conservation plans (e.g., bald eagle). Population restoration opportunities included potential reintroductions of one bird (peregrine falcon), one mammal (mountain sheep), two amphibians (mountain yellow-legged frog and northern leopard frog), and one fish (Lahontan cutthroat trout). We also identified the restoration of habitat for native species through the control and/or eradication of 12 exotic species as an opportunity to protect biological diversity. Our treatment of threats and conservation actions is incomplete, but it should serve as a starting point for developing awareness and education programs, measures to protect biological integrity, and restoration of biological diversity in the basin.

Monitoring

Monitoring designed to describe the status of and change in populations and associated habitats of focal species would provide a wealth of information about their potential persistence in the basin and potential threats to their persistence. Developing a monitoring scheme entails identifying attributes to describe populations and habitats and designing and implementing data collection and analysis. Monitoring attributes can consist of direct measures and indirect measures that serve as indicators. Ideally, indicators provide a strong signal about conditions through relatively few attributes. Habitat quantity or quality is often considered a potential indicator of population status. However, it is an indirect indicator and should not be relied on unless local validation efforts can quantify the error

Table 5-73—Summary of conservation actions recommended for focal species.

Type of Conservation Action	Total Number of Species	Number of Species by Taxonomic Group
Awareness/education	127	4 vascular plants 16 nonvascular plants 57 terrestrial vertebrates 16 fish 12 invertebrates 22 fungi and lichens
Measures to protect populations and habitats	124	43 vascular plants 77 terrestrial vertebrates 1 fish 3 invertebrates
Restoration: habitat or environmental features	16	10 vascular plants 5 terrestrial vertebrates 1 fish
Restoration: populations	5	4 terrestrial vertebrates 1 fish

associated with tracking habitat as an indirect measure of population status for individual species in the basin.

The development of a sound monitoring strategy requires careful evaluation of potential attributes (both direct and indirect measures), questions the attributes would address, and design options that accommodate data collection requirements. Here, we simply address options for population attributes that would be appropriate measures of population conditions relative to the level of concern for each species. First we define the range of types of monitoring data and then discuss the appropriate match with each focal species.

General Condition Monitoring—Focal species were identified to prioritize management and conservation efforts based on species specific interests and concerns. Monitoring these species will not necessarily be informative about the status of biological diversity in the basin or general trends in species populations. The identification of focal species that serve as indicators of ecosystem conditions is one approach that would complement the set of focal species currently identified for monitoring. The other approach is to implement a monitoring scheme that tracks trends in many species which together serve to provide information on the general trends of species populations. The ability to accomplish multi-species monitoring is in the process of being developed for species throughout the Sierra Nevada (Manor 1999; USDA 1999c), and preliminary results suggest that some method of general condition monitoring is a powerful approach to addressing trends in biological diversity, particularly in a geographic area as small and well-defined as the Lake Tahoe basin.

Types of Monitoring Data—We identified seven types of monitoring data to aid in differentiating monitoring needs among species groups and individual species: presence, frequency of occurrence, relative abundance, population size, territory occupancy, reproductive success, and population demography (Table 5-74). The higher the level of concern, the greater the investment in monitoring that is appropriate. Monitoring the presence and relative abundance of a species would be commensurate with a low level of concern or with uncertainty about the presence of a species in

Table 5-74—Types of monitoring data for focal species in the Lake Tahoe basin, in increasing order of intensity (adapted from USDA 1999c).

Type of Data	Description
Presence	An assessment of whether a species occurs in the basin. Some species' presence in the basin must be established before conservation actions can be addressed. Presence monitoring is also appropriate for species with a very small portion of their range in the basin.
Frequency of occurrence	An accounting of the proportion of survey sites occupied by a species. Can provide both status and change data. Changes in the number of sites occupied by a species provides a crude measure of trend. Analysis of occupied sites also can provide data on habitat relationships.
Relative abundance	An index of abundance that can allow comparison of abundance among survey sites, and therefore among habitat types, but cannot yield density estimates. Typically, it is based on a count of individuals.
Territory occupancy	Proportion of all known territories that are inhabited by breeding individuals. Also can provide strong information about habitat relationships. Data can include shifts in individuals occupying territories over time.
Population size	Typically an estimate of the number of individuals in the population based on a sample. For animals, mark-recapture techniques are commonly used. For rare species, it may be an actual census of individuals.
Reproductive success	Can be measured in a variety of ways, depending on the species and sampling method. For instance, reproductive success of birds may be determined using the number of eggs laid and young fledged to calculate number of young produced per adult or per egg laid. For plants, can include measures of seed viability and germination rates.
Population demography	Estimation of important population parameters, such as birth rates, mortality, and age structure, that can suggest causes of observed population trends. Most informative for long-lived species. Can enable detection of population trends that less sensitive measures (abundance of individuals, frequency of occurrence) would not detect as quickly.

the basin, whereas monitoring trends in abundance and distribution within the basin would be commensurate with a higher level of concern (Figure 5-39). Monitoring reproductive success or obtaining detailed demographic data would be commensurate with the very highest level of concern. Intensive monitoring would be most effective if accompanied by monitoring at lower levels of investment; for instance, detailed demographic data would be bolstered by estimates of population size.

Population Monitoring—We identified the type of monitoring most appropriate for each focal species (Appendix P). We identified the target data, indicating the type of data we recommended should be collected for each species, and the nontarget data, indicating additional data that would be beneficial to acquire if not requiring excessive additional effort. Designation of data as nontarget is intended to alert those designing and implementing monitoring efforts that these additional data would be helpful if feasible to obtain.

The appropriate types of monitoring data identified for each focal species are summarized in Table 5-75. Data on relative abundance were identified as target for most focal species (114 species), particularly terrestrial vertebrates. Data on frequency of occurrence were identified as target next most frequently (82 species). This type of

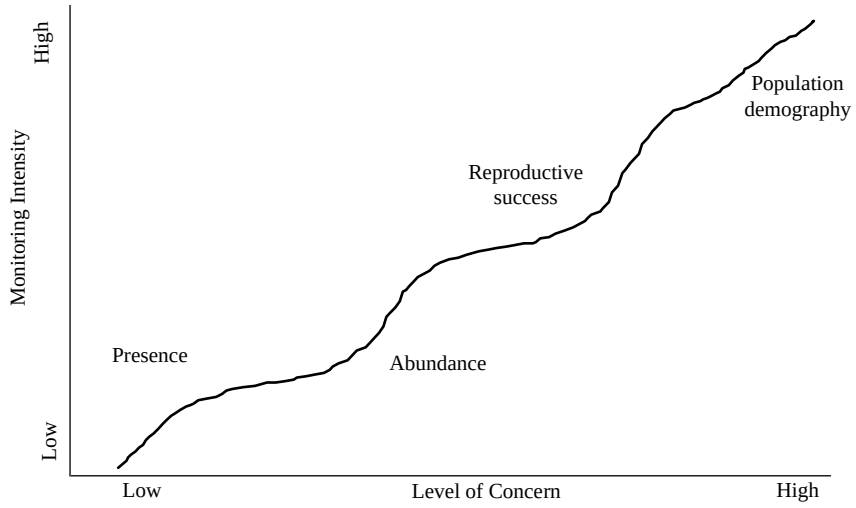


Figure 5-39—Relationship between the level of concern for a species or population and associated intensity of monitoring actions.

Table 5-75—Summary of recommended types of target monitoring data for focal species.

Type of Monitoring Data	Total Number of Species	Number of Species by Taxonomic Group
Presence/absence	67	27 vascular plants 16 nonvascular plants 17 terrestrial vertebrates 7 lichens
Frequency of occurrence	82	19 vascular plants 24 terrestrial vertebrates 11 fish 13 invertebrates 15 fungi and lichens
Relative abundance	114	5 vascular plants 99 terrestrial vertebrates 8 fish 2 invertebrates
Population size	11	6 vascular plants 5 terrestrial vertebrates
Population demography	2	2 fish

monitoring was generally identified for species known to occur in the basin and possessing one or more of the following characteristics: the level of concern was moderate, information on population size in the basin was lacking, or the feasibility of collecting relative abundance data was low. Presence/absence monitoring was identified third most frequently (67 species). Species for which presence/absence monitoring was identified were those with a high level of concern outside the basin but that have not been confirmed to occur in the basin. Monitoring population size was identified next most frequently (11 species), for five raptors and five vascular plants with small populations in the basin, as well as for one noxious weed. Finally, we identified population demographic (age class distribution) monitoring for two species of fish with a high level of concern. Monitoring relative abundance or territory density were not identified as target data for any species but were identified as nontarget data for many species.

We recognize that monitoring efforts are underway for many individual species in the basin, although many of them are restricted to specific areas. We identified monitoring needs at a baseline level for the entire basin, understanding that for some species this level of monitoring would not directly meet the needs or desires of individual agencies or interest groups. Our objective was to identify the basic level of data required to assess the status and population changes of each focal species in the basin, considering current information gaps and the ultimate need to improve our knowledge of the condition and trends of biological integrity in the basin.

Research Opportunities

Our list of research opportunities is intended to highlight key information that would significantly further our understanding of biological integrity and diversity in the basin. Enumerating all research opportunities relating to species and populations in the Lake Tahoe basin would not be possible. The following is a short list of research opportunities:

1. We need to understand the effects of human disturbance on focal species (particularly bald eagle, northern goshawk, and marten).
2. We need to understand the effects of land use practices (grazing, prescribed fire, mechanical thinning) on focal species (especially spotted owl, northern goshawk, willow flycatcher, and amphibians).
3. We need to assess the impacts of brown-headed cowbird parasitism on the reproductive success of the basin's nesting passerines (particularly willow flycatcher and yellow warbler).
4. We need to assess the impacts of exotic fish and bullfrogs on native fish, amphibians, and invertebrates.
5. We need to evaluate parameters likely to influence the success of potential reintroduction of extirpated species and species in imminent danger of extirpation (e.g., mountain yellow-legged frog and Lahontan cutthroat trout).
6. Management of biological diversity in the basin would be informed by research directed at understanding the effects of topographic barriers created by the mountain ranges surrounding the basin on the populations of less mobile species, including testing hypotheses on the potential impact of reduced immigration and emigration rates on the probability of persistence for some species in the basin.

Species and Populations: Conclusions

Our assessment of species and populations in the Lake Tahoe basin exposed the following key findings:

- Biological diversity in the basin has been diminished because of losses of several native species and the establishment of many exotic species. Species extirpations were probably influenced by larger-scale declines, fire suppression, and the basin's topographic isolation. Species additions resulted from direct introductions, fire suppression, an increased level of settlement, increased abundance of large trees, and the basin's topographic isolation.

- Some basic information on the basin's species composition is lacking, especially regarding nonvascular plants, invertebrates, and fungi.
- A multitude of species are of concern and interest in the basin. Many species were of concern for ecological reasons, including extirpated species, listed species, species with population declines, species whose life history characteristics make them vulnerable to future declines, endemic species, and exotic species. Cultural interest species included harvested species, watchable wildlife species, human conflict species, and management agency emphasis species. Most species were of concern for ecological reasons. Because of the differing levels of concern for and interest in focal species, appropriate conservation, monitoring, and research efforts will vary widely among species.
- Many vertebrate species were potentially imperiled because of population declines and range contractions. Although these declines have occurred at larger geographic scales than the basin, attention paid to these species at smaller scales is critical in supporting larger-scale populations.
- Several exotic and ecological pest species occurring in the basin may, in the absence of control, cause future ecological damage, primarily through predation on and competition with native species. In some cases, significant damage may have already occurred. Exotics of particular concern include beavers, trout, bass, bullfrogs, tall whitetop, Scotch thistle, Eurasian watermilfoil, opossum shrimp, and crayfish. Further, several domesticated species, such as dogs, cats, and cows, may negatively affect native species through predation and harassment and may damage local ecosystems through overgrazing and trampling.

Concluding Remarks

This assessment of biological integrity in the Lake Tahoe basin considered a wide array of topics of concern to the public, land managers, and scientists. We addressed three major facets of biological integrity: community structure and composition, the fire regime, and species composition and population characteristics. Most of the issues included historical perspectives, which informed our interpretations of the current status of biological integrity and which may inform future decisions about the desired future condition of biological integrity in the basin.

We were unable to address some topics of equal importance to biological integrity in the basin. For example, a more thorough treatment of terrestrial vegetation types would contribute greatly to improving our understanding of community diversity and landscape dynamics. Similarly, additional Ecologically Significant Areas could be identified by considering some additional criteria (e.g., representativeness) that we were unable to address in the time available. An extended discussion of physical processes in the basin that shape biological diversity and integrity would enrich considerations for conservation and restoration. Finally, our conservation, monitoring, and research recommendations represent a starting point in the process of developing an integrated conservation strategy for biological integrity that addresses management, monitoring, and research.

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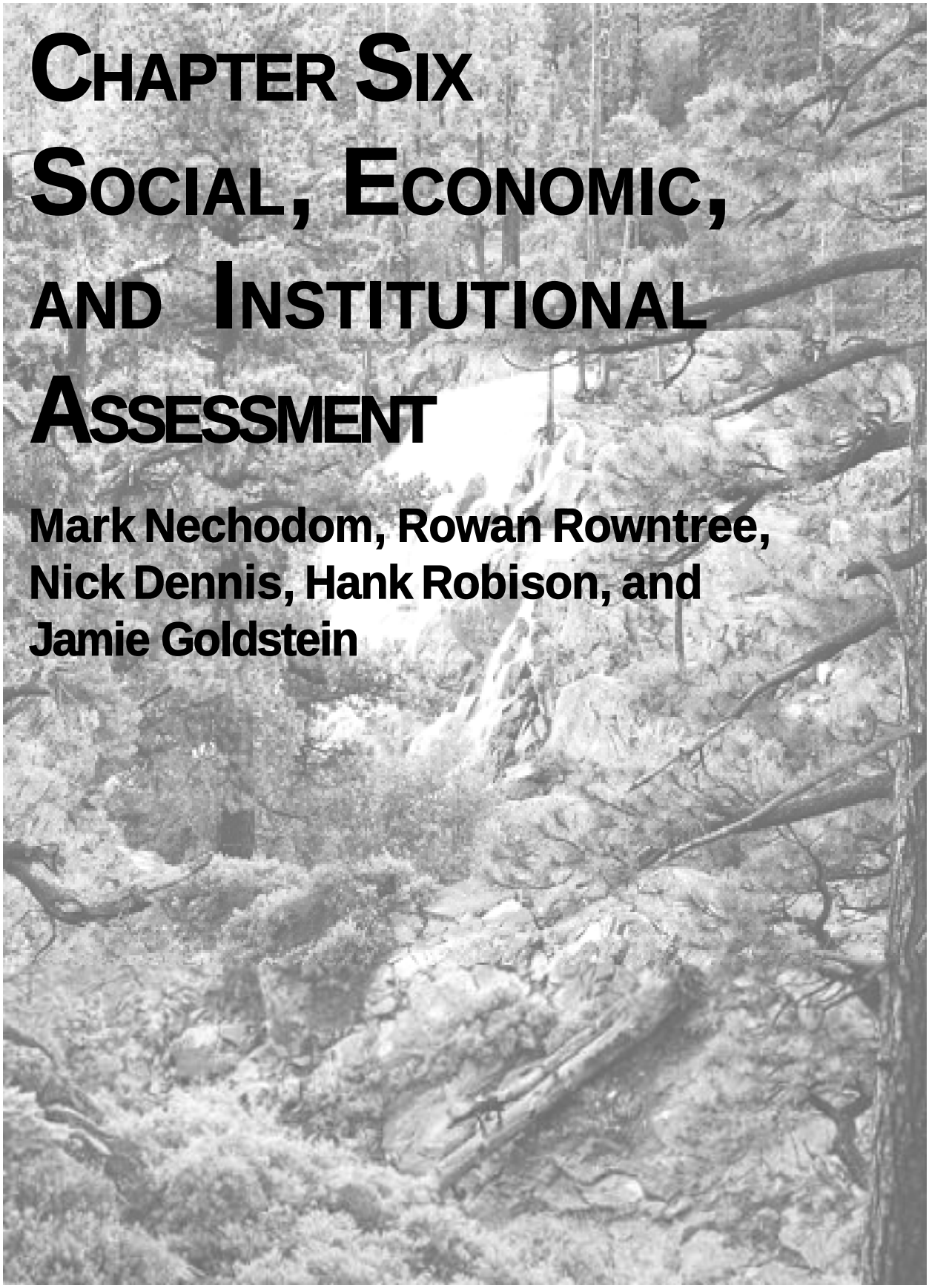
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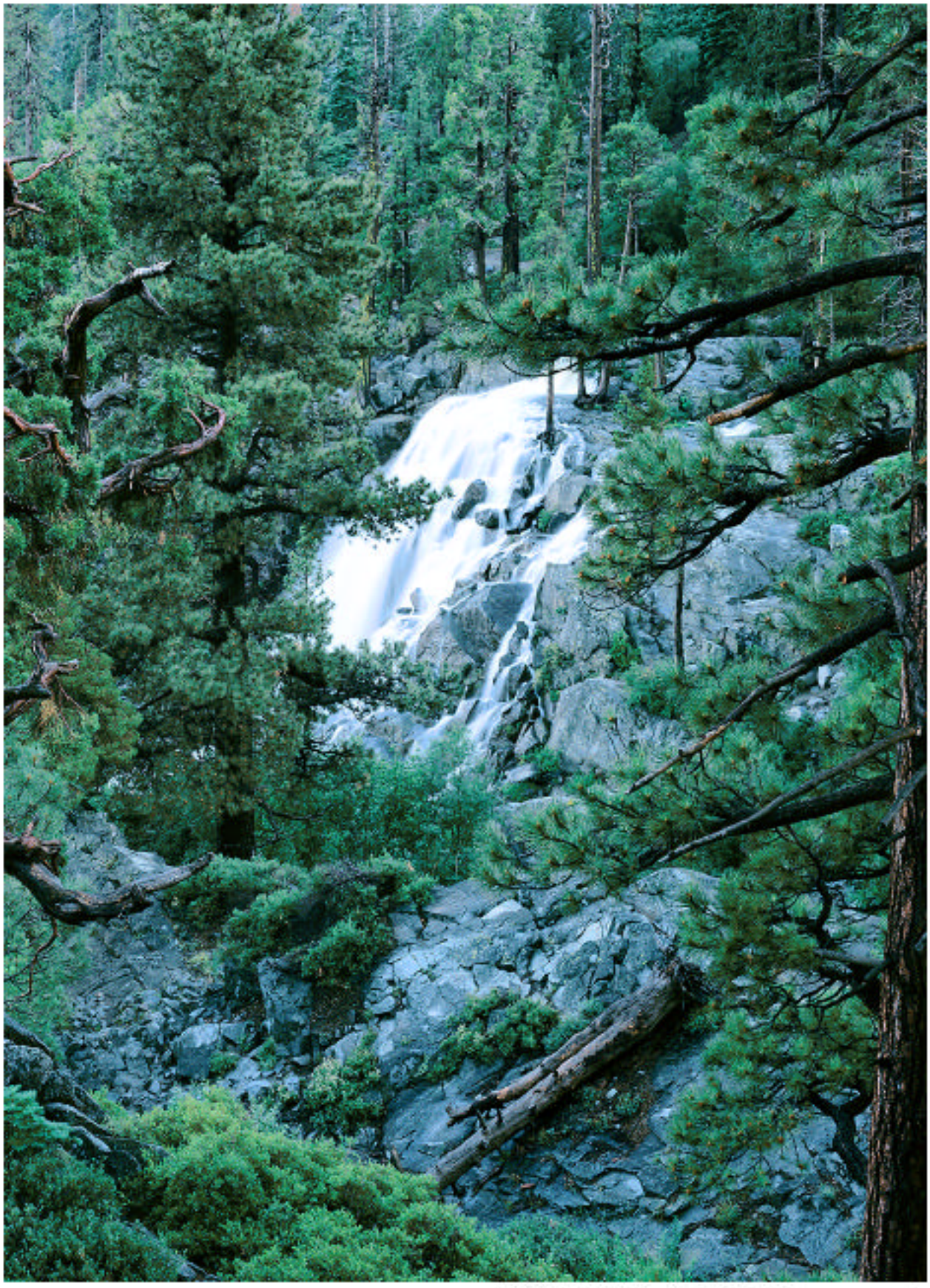
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Chapter Six
Social, Economic, and Institutional Assessment

Mark Nechodom, Rowan Rowntree, Nick Dennis, Hank Robison, and Jamie Goldstein

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CHAPTER SIX

SOCIAL, ECONOMIC, AND INSTITUTIONAL ASSESSMENT

Mark Nechodom, Rowan Rowntree, Nick Dennis, Hank Robison, and Jamie Goldstein

The Lake Tahoe basin lies in the political jurisdictions of Eldorado and Placer counties in California and in Washoe and Douglas counties in Nevada. A small portion of the basin's east shore lies in the Carson City Rural Area, but is largely devoid of development and economic activity. One incorporated municipality (South Lake Tahoe) occupies the southwestern portion of the basin, but several distinctive communities are dotted around the lake's perimeter. Recent population growth has been relatively slow compared to the surrounding area, due in large part to the stringent regulatory environment that determines the locations and types of development. Current population stands at approximately 55,000 permanent residents. A highly transient labor population, combined with unknown numbers of part-time residents, makes it difficult to establish precisely how many people actually live in the Tahoe basin.

Since the early part of the twentieth century the economy has been geared primarily toward recreation and tourism. During the period of rapid development in the 1950s and 1960s, permanent resident populations were projected to reach upwards of 180,000 by 1980 (California Department of Water Resources 1957), nearly four times the population in 1999. An aggressive public land acquisition program, combined with strict constraints on development, has made those early projections seem out of proportion by current standards.

Estimates of the number of people who visit the basin annually have ranged from 2.6 million to 23 million visitor days (Strategic Marketing Group 1994, 1999; Elliott-Fisk et al. 1996).[1] Visitation figures used in planning and marketing decisions tend to vary widely due to differences in the methodologies used (Ribaudo 1999b); however, it is clear that the seasonal influx of visitors and part-time residents has a marked impact on the economy and may have some important impacts on social dynamics in the basin.

Relatively little comprehensive or integrated social and economic analysis has been done in the basin to date. Nearly all the recent economic studies conducted in the basin have been focused either on a specific sector, such as the skiing or gaming industries, or on a particular geographic region of the basin, such as the Tahoe City-Truckee "resort triangle" (R/UDAT 1989). The broad and inconsistent range of socioeconomic data that does exist has been gathered in a piecemeal fashion, funded by the private sector or by public agencies whose missions are to support tourism and recreation (see, for example, RRC 1989, EDS 1990; NLTRA 1995; RRC Associates and Vasey Engineering 1996; and SEDD 1998). Despite the efforts of TRPA and others to foster development of an economic and social agenda for the basin and region, no comprehensive social and economic monitoring program exists. Moreover, there is no apparent consensus about what kinds of indicators should be monitored, even if such monitoring efforts were to be instituted in the basin (Teshara 1998; Ross 1999; SEI Working Group 1999).

There are many gaps in the social and economic information necessary to make well-

[1] The USDA Forest Service uses a standard recreation visitor day (RVD) as a metric, defined as a person recreating for 12 hours, or 12 persons recreating for one hour. Using this measurement, they have recorded up to 3 million RVDs of usage on USFS land alone (see section on recreation trends below).

grounded decisions about facilities, infrastructure, and resource management in the Lake Tahoe basin. This portion of the watershed assessment does not attempt to fill in those gaps; rather, the task is to identify the gaps and to suggest, in some cases, where further research appears to be needed or better methods need to be developed.

The socioeconomic and institutional assessment focuses on the following issue areas:

1. *Issue 1:* The need to determine appropriate indicators and geographic scales for measuring social well-being and economic health as they relate to environmental quality;
2. *Issue 2:* The need to understand patterns of recreation and tourism as they affect environmental quality, social well-being, and economic health;
3. *Issue 3:* The need to understand how land use trends affect the Lake Tahoe basin's environment and socioeconomic dynamics; and
4. *Issue 4:* The need to determine appropriate institutional and organizational aspects of adaptive management in the Tahoe basin context.

Each of these issues is developed by addressing a series of subsequent topic areas, which were identified interactively by the assessment team and a working group that met several times in early 1999. The working group provided essential guidance in formulating issues, read and commented extensively on drafts of portions of this chapter, and helped to identify sources of data.

The socioeconomic and institutional assessment is itself a part of a larger process, one which will transcend the watershed assessment. Decades of negotiation and struggle have resulted in a highly complex and sophisticated set of laws, rules, and procedures to protect the unique environmental qualities of the Tahoe basin's environment. Key social and political dynamics have been an integral part of crafting this complex network of formal and informal authorities, resulting in an intimate weave of scientific information, public processes, and social relations rarely found in a regional community.

Against this backdrop, the political community has produced a suite of proposed projects and land acquisitions under the umbrella of the Environmental Improvement Program (EIP), designed to address the pressing impacts of development and human activities that threaten the health of Lake Tahoe (TRPA 1998). The cost of the EIP is slated to exceed $900 million, approximately a third of which is to be generated by the local economy. And yet the information base on which the social and economic impacts of generating the local share of the EIP might be evaluated is relatively thin. Perhaps more importantly, measurements of the social and economic benefits of spending $900 million, including multiplier effects and positive impacts on recreational opportunities, are complex and difficult to define.

Employment and Income

One of the key concerns raised by the working group focused on the impacts of regulations on employment and business opportunities. In another section, a modeling approach is described in which the basin is broken down into five community regions. Briefly, the community regions are identified by their central economic and social units: Tahoe City, Kings Beach, Incline Village, Stateline, and South Lake Tahoe (the boundaries are discussed in greater detail in the following section). These community regions allow the economy to be analyzed in more accessible units. As well, the models enable a scale of analysis that shows commuting and trade patterns throughout the basin and between the basin and the broader regional economies surrounding it. The community-region models are discussed in greater detail below. However, aggregate figures referencing the basin's economy as a whole are presented here. Note that the data presented below on earnings and employment are the results of the first and second phases of a three-step process. The first phase involved compiling employment and earnings data from standard sources, such as the US Bureau of

Economic Analysis and the state employment services. The second phase involved local experts verifying data. The final phase will involve applying and adapting the models to support policy development and decisions (Robison, forthcoming).

In 1998, an estimated 47,922 people were employed in the basin; their wages totaled $1.14 billion. About three quarters of those jobs fell into visitor services and amenity categories, and the workers earned nearly $1 billion in 1998 (Table 6-1). By far the largest employment sectors are lodging, eating and drinking establishments, and amusement and recreation providers (some of these categories may seem awkward, but the data are organized in categories that conform to nationwide standards). Together these major industries make up over half the employment (51.8 percent) and approximately 44 percent of the total earnings in the Tahoe basin. There is no question that the basin's economy is focused primarily on recreation and tourism.

It is useful to compare these employment figures to those in the four surrounding counties. The population of the surrounding counties has been growing rapidly over the past decade, at a rate of 2.7 percent per year between 1990 and 1998. Most of this growth has been concentrated on the west slope of the Sierra Nevada between Auburn and Placerville in the foothills and in Sacramento in the valley to the west. In contrast, Tahoe basin population grew at an average annual rate of 0.4 percent over the same period. Table 6-2 shows a comparison of basin and surrounding counties' population in 1990 and 1998.

Employment figures for 1998 show higher basin-to-county ratios in numbers of jobs[2] (12 percent) compared to population (7.6 percent), suggesting a net commuting of workers into the basin. Table 6-3 shows that basin jobs account for an average of 23.4 percent of the total number of jobs in the four-county region. This figure can be deceptive, however, because there is wide variation in the shares of basin jobs across all four counties. For example, over half of the jobs in Douglas County are in the basin, while less than five percent of the jobs in Washoe County are in the basin. Similarly, South Lake Tahoe (including Meyers and other unincorporated basin communities) has more than a quarter of the jobs in Eldorado County, while the basin portion of Placer County accounts for fewer than one in ten Placer County jobs.

These figures also suggest that there may be significant environmental impacts associated with employment in the basin. The fiscal impacts of employment on public infrastructure are difficult to quantify and may be more precisely determined after the subbasin economic models are developed further. However, TRPA's transportation studies have demonstrated the links among patterns of employment, commuting (i.e., vehicle miles traveled, or VMTs), and associated environmental impacts. The 1992 Short Range Transit Study (TRPA 1992) concluded that 24 percent of total basin employees live outside the basin. More specifically, the 28 percent of employees who commute to the Stateline-Zephyr Cove area come from the Carson City-Gardnerville-Minden Valley area, commuting over US Highway 50 and State Route (SR) 207 (Kingsbury Grade). Another 17 percent of commuters come from the same area destined for jobs in South Lake Tahoe (Leigh, Scott & Cleary, Inc. 1993). Similarly, on the north shore, while about nine percent of basin residents commute *to* jobs outside the basin (TRPA 1997), approximately 10 percent of basin employees commute *from* outside the basin (Leigh, Scott & Cleary, Inc. 1997).

It is difficult, even under ideal circumstances, to calculate the full flow of capital and wages in a region. The figures shown in the economic models reflect wages earned and property transferred within the Tahoe basin but do not account well for the impact of income earned or transferred from outside the basin. For example, wages may be reported by place of work because the

[2] "Jobs" include both full and part time, and refer to the annual average of monthly employment. Thus, a person who holds two part-time jobs for the full year will appear as two jobs, while two persons employed for six months each will appear in the table as one job.

Table 6-1—Economic profile of the Lake Tahoe basin: jobs and earnings.

Standard Industry Code (SIC) category	Jobs	%	Earnings	%
			($1,000)	
Agriculture & agricultural services	649	1	8,618	1
Mining, sand and gravel	1	0	14	0
Construction	3,198	7	108,413	9
Food processing	8	0	249	0
Wood products	68	0	2,873	0
Misc. manufacturing	384	1	10,345	1
Transportation	789	2	20,942	2
Publishing and communications	352	1	11,973	1
Public utilities	228	0	16,575	1
Trade	4,410	9	96,283	8
Motels, eating and drinking	19,046	40	433,062	38
Finance, insurance, and real estate	3,943	8	80,815	7
Amusement and recreation	5,684	12	76,571	7
Consumer services	1,440	3	39,957	3
Business services	2,130	4	75,951	7
Medical, educational and social services	2,743	6	77,602	7
Federal government	314	1	9,906	1
State and local government	2,534	5	77,463	7
TOTAL	**47,922**	**100%**	**$1,147,612**	**100%**

Source: US Bureau of Economic Analysis; IMPLAN; Economic Modeling Specialists, Inc.

Table 6-2—Comparison of total county population with basin population.

	1990	1998	% change per year
Four counties' population	581,095	720,268	2.7%
Basin's population	52,591	54,407	0.4%
Basin-to-county ratio	9.1%	7.6%	- - -

Source: 1990 Census; California Department of Finance; Nevada Department of Employment, Rehabilitation and Training; Authors' calculations.

Table 6-3—Comparison of employment in the basin to surrounding counties in 1998.

County	Total Jobs	Basin Jobs	% Basin Jobs in County
Placer	111,115	8,113	7.3%
El Dorado	59,613	15,869	26.6%
Douglas	26,453	14,558	55.0%
Washoe	202,347	9,382	4.6%
Totals	**399,528**	**47,922**	**12.0%**
		Average basin-to-county ratio	23.4%

Sources: IMPLAN; Economic Modeling Specialists, Inc.; Authors' calculations

earnings data come from employers, but this does not account for wages earned by commuters outside the study area. When income data is combined with commuting data, it is possible to calculate the amount of income that accrues to residents in contrast to the income of nonresidents or "incommuters."

Table 6-4 shows an analysis of property and labor income, broken out by sources. While $1.14 billion is earned by wage-earning employees in the basin, many of those jobs are held by nonresidents or incommuters, whose earnings account for about 42 percent of total basin wages. [illegible]s, earnings by full-time basin residents accou[illegible]or about 90 percent of the basin's net inside income. Of the income generated in the basin, almost all of it goes to workers in the basin itself; however, when basin jobs are eliminated from the calculations, approximately 60 percent of all income comes from outside the basin in the form of jobs (outcommuters), property income, transfer payments, and part-time residence income. Property income and transfer payments[3] account for approximately a third of the total income in the basin (32 percent). Earnings by incommuters are almost precisely offset by earnings by outcommuters.

[illegible]mating the Impacts of Part-time Residents their Incomes on the Basin Economy

Communities in the Tahoe basin include large numbers of part-time residents (PTRs), who are likely to have a substantial economic influence on local spending patterns and an impact on the demand for local services. Few studies have attempted to identify the numbers of PTRs, due in large part to the difficulty of gathering and analyzing appropriate data. PTRs in the basin can be divided into two very different groups. A high income group occupies the many recreational homes and condominiums that line the shoreline and occupy other amenity-rich parts of the basin. This assessment refers to this portion of PTRs as "nonworking PTRs[illegible]n contrast, the second group of PTRs includes[illegible]wer income wage earners, consisting primarily of seasonal (in some cases, migrant) workers, referred to here as "working PTRs."

Tracking PTR jobs and income, particularly those of nonworking PTRs, is an important ingredient for understanding the functioning of community region economies in the basin. During periods of basin residency, PTRs patronize local businesses for the usual purposes of household operation and personal lifestyle maintenance. [illegible] money they spend, particularly that spent [illegible]y relatively affluent nonworking PTRs, can amount to a significant share of local business income and thus plays an important part in local economies.

[illegible] proportion of total residents in each commun[illegible]region who are PTRs was estimated based on the average proportion of utility bills that are mailed to nonbasin addresses from utility districts serving the Tahoe basin [illegible]quette 1999; Loding 1999; Roenspie 1999; G[illegible]afson 1999a; Forsythe 1999; England 1999). These data were used in conjunction with data on housing vacancy rates reported in a recent housing needs assessment for the basin (TRPA 1997a). Vacancy rates, as defined by the US Census Bureau, refer to housing units for which no occupants qualify as permanent residents (i.e., people who reside locally at least six months of the year). Based on this definition and on the character of part-time residency in the basin, vacancy rates bear a close relationship to the share of housing units occupied by PTRs. The proportion of PTRs in each community region, expressed as a percentage of full-time residents (FTRs), is shown in Table 6-5. These results show that part-time residency is generally more predominant in communities on the California side of the basin than on the Nevada side. A fuller explanation of the methodology used to calculate the numbers and incomes of PTRs is in tables 6-5 and 6-6.

The community region models provide an accounting mechanism to translate resident incomes into total consumer expenditures and in turn to translate these into community region expenditures. This accounting procedure is usually applied only to PTR incomes in economic models. However, PTRs in the basin make a significant contribution to the

[3] Property Income is defined as income from the ownership of privately held equities and real estate; transfer payments are payments (typically from the government) not associated with current production and for which no services are currently rendered (such as retirement, annuities, etc.).

Table 6-4—Property and earnings income analysis from inside and outside the Lake Tahoe basin.

	Earnings X $1,000	% of Subtotal	% of Total
Labor Income by Place of Work	$1,147,612		
Less Incommuting Income	-$479,113	42.0	
Labor Income by Place of Residence	$668,499	89.5	
Property Income	$78,529	10.5	
Total Inside Income	**$747,028**	**100%**	**41.3%**
Property Income	$307,112	28.9	
Transfer Payments	$197,849	18.6	
Outcommuting Income	$460,610	43.3	
Income of Non-working Part-Time Residents	*$96,979*	*9.1*	
Total Outside Income	**$1,062,551**	**100%**	**58.7%**
Total Residents' Income	**$1,809,579**		**100.0%**

Source: Economic Modeling Specialists, Inc.

Table 6-5—Methodology for estimating part-time residents in the Lake Tahoe basin. This table shows the steps in estimating the total number of PTRs (working plus nonworking) by each community region. The first column shows community region populations assembled from estimates for 1990, as reported in Table 6-8 (population figures for each community in the greater Tahoe Basin, Doak and Kusel 1996). Column 2 shows these estimates projected to 1998, assuming the declining basin population trend exhibited in Figure 6-1. Column 3 displays a set of semi-subjective estimates of total PTRs in each community region, expressed as a percentage of FTRs.

In column 5, the fraction of nonworking PTRs is estimated by community region. These are subjective estimates conditioned by interviews and expert knowledge from each community region. Kings Beach, for example, is generally recognized as a location for basin-working PTRs, while Incline Village is known locally as a location for high proportions of nonworking PTRs. The percentages in column 5 reflect a breakdown between working and nonworking PTRs. Column 6 shows the total of the PTRs (column 4) and the nonworking PTRs (column 5) and thus shows estimates of nonworking PTRs by community region. Column 7 adds FTRs (column 2) to total PTRs (column 4) and thus provides an estimate of what might be termed "peak-season populations"; that is, populations when FTRs and PTRs are both present in the community regions. The three final columns are computed as a reasonableness check. They show the mix of peak-season residents according to the percentage of FTRs, working PTRs, and nonworking PTRs.

Community Region	FTRs 1990	FTRs 1998	PTR as % of FTR	PTR Total	Non-working PTR (%)	Non-working PTR Total	Peak Season All Residents	Peak Season FTR (%)	Peak Season Working PTR (%)	Peak Season Non-working PTR (%)
Tahoe City	6,679	7,153	75%	5,365	50%	2,682	12,044	55%	22%	22%
Kings Beach	2,365	2,533	100%	2,533	20%	507	4,898	48%	41%	10%
Incline Village	7,856	8,414	25%	2,103	95%	1,998	9,959	79%	1%	20%
Stateline	5,630	6,030	30%	1,809	90%	1,628	7,439	76%	2%	22%
South Lake Tahoe	28,823	30,870	75%	23,152	30%	6,946	51,975	55%	31%	13%
Totals	**51,353**	**55,000**		**34,962**		**13,761**	**86,315**			

Source: Economic Modeling Specialists, Inc.; Authors' calculations

FTR = Full time resident
PTR = Part time resident

Table 6-6—Nonworking part-time resident incomes in the Lake Tahoe basin. This table illustrates how PTR incomes are derived. Column 1 shows total nonworking PTRs by community region and is the same as Table 6-5, column 6. Column 2 estimates the number of PTR families, based on average family size estimates in 1998 of 3.24 members per family (US Census Bureau 1999a). The model assumes that the average annual family income of PTRs is $137,000, the lower limit of annual incomes (in 1997) of the top five percent of all US family incomes (US Census Bureau 1999b). Column 4 estimates the total income of PTRs while they are residing in the basin. These estimates are based on the assumption that the average PTR family spends two months per year in the Lake Tahoe basin. The figures in column 4 appear as nonworking PTR income in the community region economic models.

	Non-working PTR Total	Non-working PTR Families*	Total Non-working PTR Family Incomes ($1,000)	Basin Portion of Non-working PTR Family Incomes** ($1,000)
Tahoe City	2,682	828	$113,427	$ 18,904
Kings Beach	507	156	21,421	3,570
Incline Village	1,998	617	84,496	14,083
Stateline	1,628	502	68,841	11,473
South Lake Tahoe	6,946	2,144	293,693	48,949
Totals	**13,761**	**4,247**	**581,878**	**96,979**

Source: Economic Modeling Specialists, Inc.

FTR = Full time resident
PTR = part time resident
* Assumes 3.24 persons per family
** Assumes 2 months' residency in the basin

region's economy, thereby justifying application of this accounting procedure.

As discussed above, nonworking PTR incomes are likely an important aspect of the community region economies. Accordingly, the assessment team constructed community region economic models with an account for nonworking PTR incomes. The account includes an estimate of nonworking PTR incomes for the average period PTRs spend in the Lake Tahoe basin, which is assumed to be two months. This assumption, in addition to the assumptions made about average levels of income among nonworking PTRs, probably underestimates the actual contributions of PTRs to the basin economy. Table 6-5 shows the assumptions made and the procedures used for deriving the nonworking PTR income estimates that appear in the community region model summary, shown in Table 6-4.

An estimated $97 million in income accrues to nonworking PTRs' each year during their basin residency. Income earned by working PTRs represents an unknown share of the labor income component of the basin's inside income, as shown in Table 6-4. Further development of the community region models will enable a more accurate portrayal of the roles that nonworking and working PTR incomes play in the economy of the basin.

Population and Demography

The population of the basin has remained relatively constant over the last decade, reaching an estimated 55,000 in 1998. Early population projections now seem astronomical from a current perspective. In 1960, the Eldorado County general plan anticipated a city of 200,000 along the south shore (Griffenhagen-Kroeger, Inc. 1960). A 1961 study of the feasibility of regional government in the basin assumed a population by 1980 of 418,000 (Wilsey, Ham and Blair, Inc. 1961), but those high estimates were revised three years later down to 313,000 (Wilsey, Ham and Blair, Inc. 1964). Seasonal variation notwithstanding, the permanent resident population has grown since the 1960s from just under 20,000. The per-year growth rate, however, has declined dramatically over the past three decades, from a high of seven percent from 1965 to

1970 to less than one percent projected between 1995 and 2000 (Figure 6-1). About two thirds (67.6 percent) of the basin's population is concentrated on the south shore, including Eldorado and Douglas counties and the city of South Lake Tahoe (Table 6-7, Figure 6-2). However, 81 percent of the total jobs in the basin (26.4 percent in Douglas County, 54.6 percent in Eldorado County) are on the south shore, suggesting again a significant amount of incommuting. Transportation and commuting patterns have been well established by earlier studies on both the north and south shores (Leigh, Scott & Cleary, Inc. 1993, 1997; TRPA 1997). Figures reflecting the geographic distribution of jobs by sector are presented in the section describing the community-regions model.

The social and cultural composition of the Tahoe basin is thought to be changing as both visitor bases and labor force populations change in California, Nevada, and nationwide. During the assessment process, community leaders often raised a concern that services and infrastructure in the community may not adequately reflect preferences and customs representative of ethnic minorities. Standard census figures are used to present what little is documented on the basin's ethnic and racial picture.

Table 6-8 shows the geographic distribution of the basin's population broken out by percentages of race/ethnicity represented in each county. Clearly, non-Hispanic whites predominate in numbers throughout the basin, comprising almost 90 percent of the total population. Note that "Hispanic" is not a race category recognized by the US Census Bureau; however, Hispanics are an important ethnic group and, using figures extrapolated from the 1990 census, represent 14.1 percent of the total population in the basin.

A significant proportion of Hispanics and Asian/Pacific Islanders are thought to be employed

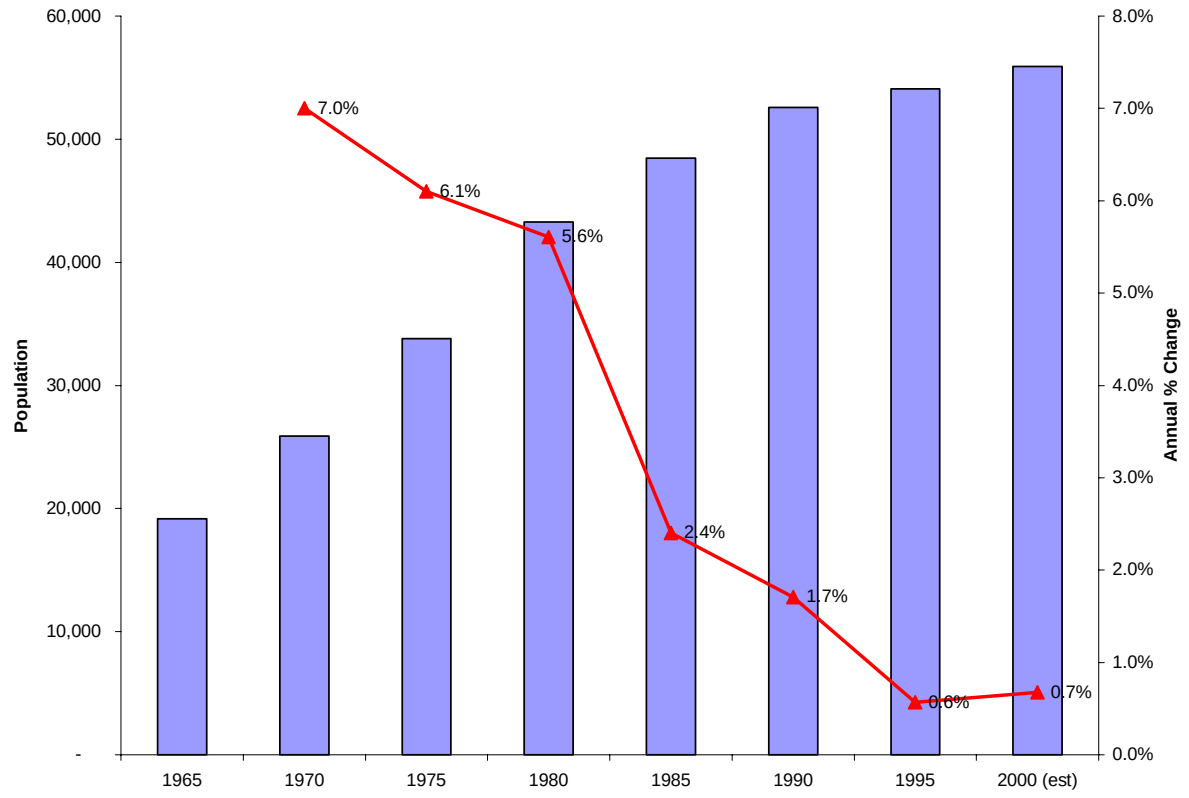


Figure 6-1—Basin historical population trend, 1965 to 2000.

Table 6-7—Population of basin, 1990, 1995, and 2000.

Population	1990 Census	1995 TRPA Projections	2000 TRPA Projections
El Dorado/CSLT	29,652	30,343	31,326
Placer	9,257	9,473	9,835
Washoe	7,567	7,959	8,270
Douglas	6,115	6,308	6,480
Totals	**52,591**	**54,083**	**55,911**

Sources: US Census Bureau; University of Nevada Bureau of Business and Economic Research; TRPA Transportation Model and Affordable Housing

Table 6-8—Geographic distribution of population by ethnicity/race.

	El Dorado	Placer	Washoe	Douglas	Basin
White	86.0%	89.7%	94.4%	88.3%	**89.6%**
Black	0.9%	0.4%	0.3%	0.6%	**0.6%**
American Indian	1.2%	0.8%	0.4%	1.2%	**0.9%**
Asian/Pacific Islander	6.5%	0.7%	1.4%	5.1%	**3.4%**
Other	5.4%	8.4%	3.5%	4.8%	**5.5%**
Hispanic*	*18.6%*	*16.8%*	*9.0%*	*11.8%*	***14.1%***

Sources: US Census Bureau; University of Nevada Bureau of Business and Economic Research; Authors' calculations; TRPA 1997a

* The US Census considers "Hispanic" an ethnic category and not a race. Hispanics are distributed throughout the five races above.

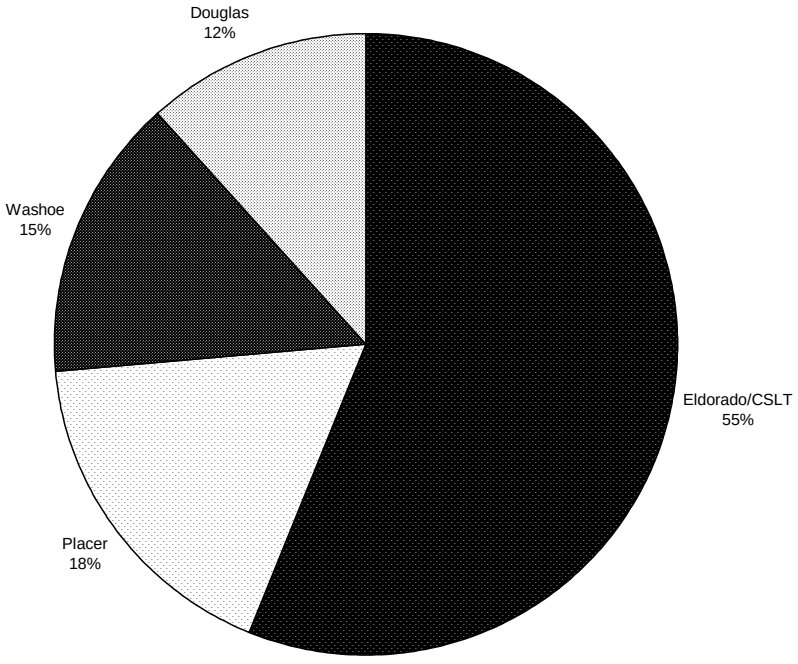


Figure 6-2—Distribution of basin population.

in the service sector, particularly working in hotels, casinos, and restaurants in the basin. However, no data are collected that permit a basinwide analysis of jobs in each industry by ethnicity or race.

Housing

Social equity concerns have been expressed about concentrations of inadequate or substandard housing and the degree to which occupation of substandard housing correlates to race or ethnicity. Because the data on distribution of owner-occupied and rental housing are not correlated to race or ethnicity, no analysis is possible to determine whether this presents a problem of social equity.

Housing data from the US Census Bureau is correlated to income by census tract. A recent study by TRPA analyzes the availability of affordable housing using 1990 census data. Under the Housing Subelement of the Land Use Element of the Regional Plan, Policy #1 states that "Local governments will be encouraged to assume their fair share of the responsibility to provide lower and very low income housing" (TRPA 1986). While "fair share" is a fundamental concept in the basin's regional plan, clearly defining what it means for the availability of affordable housing had not been undertaken prior to the study. The study was initiated because of growing concerns among the basin's jurisdictions that providing their "fair share" of affordable housing may not be feasible under the development restrictions imposed by the regional plan.

Using employment and census data to determine low and very low household incomes,[4] the study correlates those income categories to the commuting patterns integrated into the TRPA transportation planning model. Each jurisdiction was analyzed for its employment opportunities and the availability of affordable housing. The standard definition of affordability from the US Department of Housing and Urban Development is used by the study, applied to rental and owner-occupied housing. Rental housing is considered affordable when it does not place a cost burden of more than 30 percent of a household's gross monthly income on the renter. Owner-occupied housing is considered affordable when the total cost of the home does not exceed 2.5 times a household's annual income.[5] Median income is calculated for each of the five basin jurisdictions (Eldorado County is distinguished from the city of South Lake Tahoe) to accommodate geographic variation in the basin.

The figures shown in the tables are adapted from the TRPA study in order to present some of the data on which the study's conclusions are based. Note that Eldorado County and the city of South Lake Tahoe are merged in order to correspond more closely with other data presented in this section.

Median incomes were developed for each of the jurisdictions using US Census data and projection techniques developed by the University of Nevada's Bureau of Business and Economic Research (TRPA 1997; Bonnenfant 1999). Table 6-9 presents per capita income, median household income, and average household income, for each of the four counties. As one might expect, there is significant regional variation. When compared to the regional distribution of jobs by sector (showing places of employment as distinct from places of households), a typical pattern becomes apparent. Where there are higher paying jobs, housing costs tend to be higher, shifting lower cost housing to more affordable regions.

The affordable housing study concluded that "(t)he region appears to have enough affordable housing stock, however the displacement of the low income households into non-affordable situations results in an ineffective use of this housing stock" (TRPA 1997a). After analyzing the suitable sites and the expected construction allocations for each jurisdiction, the study finds that sufficient opportunities exist within the basin itself to provide for affordable housing needs. The solution proposed is not so much concentrated in building new units as it is in reinvesting in existing stock. The report

[4] "Low" and "very low" income are defined by the US Census and US Bureau of Labor Statistics. Low income is household income at 51 to 80 percent of the median income in the region of concern. Very low income is household income below 50 percent of median income.

[5] "Cost burden" is defined in the report as "the total financial impact of the housing unit on the inhabitants, including rent (or mortgage), utilities and any applicable "taxes" (TRPA 1997: 1.1).

Table 6-9—Per capita, median household, and average household income.

	El Dorado	Placer	Washoe	Douglas	Basin Averages
Per capita income	$ 15,750	$ 19,237	$ 27,278	$ 29,537	$ 22,951
Median household income	33,752	36,604	49,835	46,525	41,679
Average household income	40,437	46,606	65,650	67,719	55,103

Sources: TRPA 1997a; Authors' calculations

concludes by urging local governments to make "rehabilitation of sub-standard housing and promoting more opportunities for home ownership" a higher priority (TRPA 1997a).

Socioeconomic Well-being and Community Capacity

The term "social capital" has evolved from a rather specific application in sociology (Coleman 1990; Putnam 1993) to a broad rubric for the human aspects of a region's resources and sources of wealth (Sierra Business Council 1997). The Sierra Nevada Wealth Index is a series of social, economic, and biophysical indicators compiled in 1996 to measure the relative health of the entire Sierra Nevada range. This study developed a composite of fifteen social indicators, including population, age distributions, voter participation and volunteerism, access to health care, educational achievement, and crime.

This assessment effort recognizes that the basin's community has worked for some time to develop a series of indicators appropriate to its own priorities and conditions. The Sierra Business Council is updating the wealth index and is exploring adapting the index to the basin. A discussion of potentially useful indicators identified by the socioeconomic working group follows this section.

Two additional measures bear mention in this brief overview of the basin's socioeconomic dynamics. In their work with the Sierra Nevada Ecosystem Project (SNEP), Doak and Kusel (1996) developed two categories for evaluating socioeconomic dynamics in the Sierra Nevada. The first, socioeconomic status, results in a numerical score combining coefficients of several measures, including housing tenure, poverty, education, employment, and households receiving public assistance (Doak and Kusel 1996). The second category is community capacity, a measure developed by Kusel by focusing on forest-dependent communities. Community capacity refers to "the collective ability of residents in a community to respond . . . to external and internal stresses; to create and take advantage of opportunities; and to meet the needs of residents, diversely defined. It also refers to the ability of a community to adapt to and respond to a variety of different circumstances" (Kusel 1996: 369).

Kusel links the exercise of community capacity analysis to the interaction of physical, social, and human capital. The capacity of a community to respond to change depends on its ability to use the skills, education, and experience of its individual members (human capital), to tap into networks of exchange and reciprocity (social capital) (Putnam, Leonardi, and Nanetti 1993: 164), and to use the physical and fiscal resources at its disposal to achieve collective ends.

Doak and Kusel found that in order to measure socioeconomic well-being and community capacity new spatial units of analysis had to be developed. County level data were too gross to be useful, while smaller units of analysis (such as census tracts and "places"[6]) needed to be grouped into more socially and economically meaningful units. Their social assessment approach to the Sierra Nevada required establishing a statistically viable unit of analysis based on census data and local knowledge and correcting the data through a public

[6] Places are formally defined by the US Bureau of Census as incorporated areas or unincorporated population centers identified by name and known as census-designated places (CDPs). Doak and Kusel find CDPs inadequate for several reasons, including identification and sense of place among local residents.

involvement process closely akin to the community indicator efforts discussed later in this chapter. Their "community aggregation" metric allowed them to identify 180 distinct aggregations in the Sierra Nevada, sixteen of which make up the Greater Lake Tahoe basin region.

Five of the sixteen aggregations in the Greater Lake Tahoe basin identified in SNEP lie outside the definition of the basin assumed for this analysis (i.e., TRPA regional boundaries). However, the remaining eleven aggregations are presented in tables 6-10, 6-11, and 6-12, with the socioeconomic and capacity scores assigned them by Doak and Kusel's analysis. Further interpretation of the socioeconomic score would require an examination of each of the indicators (discussed above) and their relative weight in determining the numerical outcome.

Similarly, community capacity scores are composites of indicators derived from local expert knowledge (Table 6-10). Each capacity score represents the culmination of a seven-step process in which knowledgeable members of each aggregation or community collectively rank a number of indicators and develop a composite score on which they can agree. The usefulness of the capacity score is in its ability to capture a qualitative, but disciplined, reflection of the community's sense of its own abilities to use social, human, and physical capital to increase collective well-being.

Doak and Kusel include home ownership and tenure in their calculation of socioeconomic score. In the basin, due to high vacancy rates typical of resort communities, this factor will drive the score down slightly. Vacancy rates in the basin run as high as 52 percent when short-term rental units are included in the stock. Home ownership and tenure (i.e., how long residents in a community have lived there) has an indeterminate effect on overall socioeconomic well-being and community capacity in the basin. Further research would have to be carried out to examine whether vacancy rates and high turnover of the resident population have a measurable effect on capacity or well-being.

Scores can be correlated to population levels to show geographical distributions of socioeconomic well-being in the Tahoe basin. For example, as Table 6-11 indicates, about a fifth of the basin's population resides in areas with socioeconomic scores of five or more, indicating high levels of income, low levels of unemployment, and low levels of families with children receiving public assistance. In contrast, half of the basin's population lives in two areas (South Lake Tahoe and Kings Beach) with socioeconomic scores of less than four (refer to Table 6-10). These scores indicate concentrations of poverty, public assistance needs, and relatively low average levels of education, among other measures. It is interesting to note that of the two aggregations with scores of less than four, Kings Beach also has the lowest capacity score, while South Lake Tahoe carries a capacity score of four. On the one hand, this indicates that participants in the Kings Beach exercise measured the community's capacity to respond to change at a relatively low level and has expressed little confidence in its ability as a community to use a combination of human, social, and physical capital. The South Lake Tahoe participants, on the other hand, evaluated their ability to respond to change at a much higher level, despite demographic and social characteristics that gave them a lower socioeconomic score. Because the method for measuring capacity is based largely on community participation and expert opinion, this score could change, depending on the composition of experts gathered for the rating exercise.[7]

Finally, Doak and Kusel's socioeconomic and capacity scores are useful in illuminating a greater picture of overall social and institutional capacity in the basin (Table 6-12). Pockets of poverty, concentrations of low and very low income jobs and needs for affordable housing underscore areas for further development of social policy in the basin. At the same time, this quantification of socioeconomic status and the disciplined measure of community capacity corroborate other evidence of a highly sophisticated, well-educated and socially

[7] One might hypothesize, for example, that a workshop held in Spanish at the Kings Beach headquarters of La Comunidad Unida, a major Hispanic community service organization on the north shore, would produce different capacity scores.

Table 6-10—Socioeconomic and community capacity scores for the basin.

Doak and Kusel Aggregation	Population 1990 census	Socioeconomic Score (1 to 7)	Capacity Score (1 to 5)
Echo/Upper Truckee	2,425	6	3
Glenbrook	393	7	4
Incline/Crystal Bay/Brockway	7,856	4	5
Kings Beach	2,365	1	2
Montgomery Estates/Tahoe Paradise/Meyers	3,079	5	3
North Tahoe	2,630	5	3
South Lake Tahoe	23,319	2	4
Stateline Kingsbury	3,153	4	4
Tahoe City	2,587	4	3
West Shore	1,462	4	3
Zephyr Cove/Skyland	2,084	6	2
Totals / Averages	**51,353***	**4.36**	**3.27**

Source: Modified from Doak and Kusel 1996

* Total population figure does not match total basin population in other 1990 census calculations in this assessment because of aggregation techniques using different census blocks.

Table 6-11—Socioeconomic score distribution by population (scale = 1-7).

Socioeconomic Score	Population	% of population
< 4	25,684	50.0%
4	15,058	29.3%
> 5	10,611	20.7%

Sources: Doak and Kusel 1996; authors' calculations

Table 6-12—Capacity score distribution by population (scale = 1 to 5).

Capacity Score	Population	% of population
2	4,449	8.7%
3	12,183	23.7%
4,5	34,721	67.6%

Sources: Doak and Kusel 1996; authors' calculations

aware regional community. As is discussed in the institutional assessment below, the relatively high levels of social and human capital in the system likely contribute to a manifest disposition to cooperation and institutional collaboration.

Issue 1: Determining Appropriate Indicators and Geographic Scales for Measuring Social Well-being and Economic Health as They Relate to Environmental Quality

Economic Information and Models to Inform Socioeconomic Decisions

Recent social science contributions to ecosystem assessment work have pointed out critical problems with establishing both the methods and scales at which data are acquired (Bright et al., forthcoming). Many socioeconomic questions in the Lake Tahoe basin require an examination of patterns of income, spending, and employment at the community and subregional scale. However, public economic data is most commonly available to researchers at the county level. As mentioned above, the basin portions of the four counties represent only a small percentage of the total demographic, social, and economic regional picture. Acquiring useful data at the subcounty level requires a substantial investment of time and resources (Bonnenfant 1999; Robison, forthcoming).

While there are many state and federal agencies that gather economic and social data, four are responsible for tracking economic data that are most relevant to the basin's needs: California's Economic Development Department (EDD), Nevada's Department of Employment, Training and Rehabilitation (DETR), the US Bureau of Labor Statistics (BLS), and the US Bureau of Economic Analysis (BEA) (both in the Department of Commerce). Confidentiality rules often require data at the subcounty level to be aggregated or "rolled up." Industry-level data must represent three or more firms in order to mask proprietary information. Further, if any single employer represents 80 percent or more of the employment in a single industry within the unit of analysis, the data must be suppressed or aggregated.

Employment and earnings data are presented by Standard Industry Classification (SIC) codes, which are assigned to each firm by the type of business it represents. Each industry or SIC code is broken down into several subcategories. Employers report once per year during March and in some cases have some discretion in which codes they use to report the kind of business they represent. The data represent only firms that pay into state-maintained unemployment insurance accounts; therefore, sole proprietorships are not tracked in the same data sets.

Until recently, socioeconomic assessments in rural areas in the United States have been conducted on the county and multicounty scale. However, increasing economic diversity at the subcounty level, the growing demand for local services, and a broad range of social and economic needs in rural counties require more sensitive measurements and models. In the Tahoe basin, as well as in the Sierra Nevada region, increasing population, changes in economic behavior, and different social expectations create diversity among local economies that is not meaningfully measured at the county level (Duane 1996; Doak and Kusel 1996; Robison 1997)

In the Tahoe basin, social and economic data is gathered in ways that are either specific to a particular economic sector or driven by a specific problem or issue. The assessment working group's discussions and other interviews indicate an increasing demand for social and economic modeling that will more accurately track the flow of capital, investment, and discretionary spending in the basin, both at the micro scale and the larger regional scale.

The EIP proposes to invest over $900 million in an array of projects and land acquisitions intended to bring the Tahoe basin closer to attainment of the TRPA thresholds. Over $250 million of that investment will come from local sources, with an additional $100 million required over ten years for operation and maintenance. Providing the local share of the EIP will create as yet unknown burdens in the local economy. Public policy will need to determine how that burden will be shouldered equitably. However, the paucity of data at useful scales makes it difficult to show how the economy of the basin actually functions and therefore to anticipate likely outcomes from impacts on the local economy.

In this section we present five community-region models for the Lake Tahoe basin. A community-region model is the most localized of the modeling scales appropriate for the Tahoe basin for tracking and monitoring social and economic indicators. A second scale is across the entire basin region, including Truckee-Donner, the Highway 89 corridor, including Olympic and Squaw valleys and the Reno-Carson and Gardnerville-Minden areas. A third scale of analysis compares economic data across industries and analyzes the basin's economy in comparison to other similar regions (for example, see NLTRA 1995, 1997). Currently, the skiing and gaming industries collect marketing data at the second and third levels. However, a broader based model would track similar data for all recreational and other significant economic activities that affect the generation of revenue and local spending patterns in the basin. At this time no institutional mechanism exists that can coordinate or integrate the three scales of modeling and analysis.

The community-region model recognizes that economic activity tends to be spatially organized in patterns of trade hierarchies. An economically dominant center (a downtown or otherwise commercially developed area) hosts the bulk of the region's goods and services producing activities. In many rural areas in which this model is implemented, a surrounding region of isolated homesteads, neighborhoods, and suburbs relies on the goods and services of the center, and the center relies in varying degrees on the region for its workforce. In some cases the surrounding region includes smaller areas of commercial activity (towns or villages), and each of these exhibits a subcenter-region organization. The operative principle is that the region as a whole, the larger community-region, exhibits a measure of economic cohesion and otherwise functions as a distinct and semi-independent economy. In the Lake Tahoe basin, these modeling assumptions require significant adaptation because a great deal of interaction takes place among different geographic centers.

The strength and direction of trade links within community regions often are described in terms of gravity theory. Accordingly, links are strongest near the commercial center of community regions and become weaker toward the outer edges. At some point, moving outward from the center, the influence of a neighboring community center appears, and shopping and commuting flows begin to go both ways. In this area of overlapping influence, community-region boundaries appear as shaded zones rather than distinct lines (Robison 1997).

A significant share of the data needed to build community region models is provided by sources with zip code level detail. Much of the data collected by the state employment development agencies (e.g., EDD and DETR) can be obtained under the right authorities down to the zip code or even census block level. However, as mentioned above, the display of Tahoe data is subject to confidentiality tests that limit its conveyance and use. The problem to be confronted is that zip code area boundaries are distinct lines; they miss the two-way trade flows that characterize the sometime shaded zone boundaries of community-regions. In implementing the model, one must be mindful of this limitation and make adjustments where needed to reflect its effects on the model's economic outputs.

The basin was divided into community-region models based on the following criteria:

- Commuting patterns;
- Shopping travel patterns;
- Locations of commercial centers; and
- State boundaries.

The most important boundary that divides the basin economically is an imprecise line separating the north and south shore areas. The Tahoe basin's population is concentrated near the southern and northern shores of the lake, with relatively sparse population densities along the east and west shores. The roughly 30-mile distance separating the north and south shores, combined with challenging highway conditions typical of mountain roads (including frequent winter highway closures), severely limits travel between these areas for work and shopping.

Within the north and south shore areas are distinct communities containing commercial centers. The principal commercial centers in the north shore

area are associated with the communities of Incline Village, Nevada, and Tahoe City and Kings Beach, California. South Lake Tahoe, California, and Stateline, Nevada, feature the principal commercial centers in the south shore area. The community regions for which economic models have been developed are defined by these five commercial centers. Each region consists of a node (i.e., the commercial center) surrounded by a developed area, typically including several distinct neighborhoods and villages. The boundaries of each community region are defined by zip code areas, as shown on the maps in figures 6-3 through 6-7.

State lines are political boundaries that may or may not have socioeconomic significance. Land use patterns, for example, are relatively similar on both sides of the California-Nevada boundary in both the south and north shore areas. An important justification for separating the California and Nevada sides of the basin into separate community regions, however, is the prominence of legalized gaming in Nevada. The relative economic importance of casinos and related visitor services in Nevada argued for dividing the community regions of the south and north shores along state lines.

The specific geographic locations of the five community regions are as follows:

Tahoe City—Figure 6-3 shows the zip code areas used to model the Tahoe City community region. From the south, the region begins just south of Meeks Bay and extends north and north-eastward past the main commercial center. The boundary continues beyond Tahoe City to just past Dollar Point. The west and northwest boundary extends up Highway 89 to include Squaw Valley.

Kings Beach-Carnelian Bay—Figure 6-4 shows the zip code areas used to model the Kings Beach-Carnelian Bay community region. It includes Kings Beach, Tahoe Vista, and areas to the southwest to just beyond Carnelian Bay. The northwest boundary extends north over the Tahoe basin hydrologic divide to include the Northstar Ski Resort area.

Incline Village—Figure 6-5 shows the zip code areas used to model the Incline Village community region. The area extends south as far as the Sand Harbor State Park, north to the Mt. Rose Ski Resort, and west to the Nevada-California border.

Stateline—Figure 6-6 shows the zip code areas used to model the Nevada side of the South Lake Tahoe-Stateline community region. It includes the area south and southeast of Tahoe Village, encompassing Edgewood and the Kingsbury Grade and the area north along the shoreline to and including Glenbrook.

South Lake Tahoe—Figure 6-7 shows the zip code areas used to model the California side of the South Lake Tahoe community region. The region includes an area up the western shoreline nearly to Meeks Bay in Placer County. To the southwest, it includes Echo Lake and the US Highway 50 corridor to just beyond Strawberry to take in the economic activities surrounding Sierra-at-Tahoe (formerly Sierra Ski Ranch). Many skiers at this facility combine their activities there with visits to the basin, although the exact proportion of skiers coming from and returning to the Central Valley and Bay Area to the west is unknown at this time.

Limitations of assessment time and resources precluded modeling economic influences in the areas immediately adjacent to the Tahoe basin. Following initial implementation of the community-region models within the formal TRPA boundaries of the basin, models linked to surrounding communities are expected to be deemed appropriate. Several important economic and social influences exist between Truckee-Donner, Reno-Carson, Gardnerville-Minden, and the Tahoe region. A fuller understanding of regional economic dynamics will require implementing at least rudimentary versions of the community region model in those communities.

The five selected community regions clearly have multiple links that must be taken into account

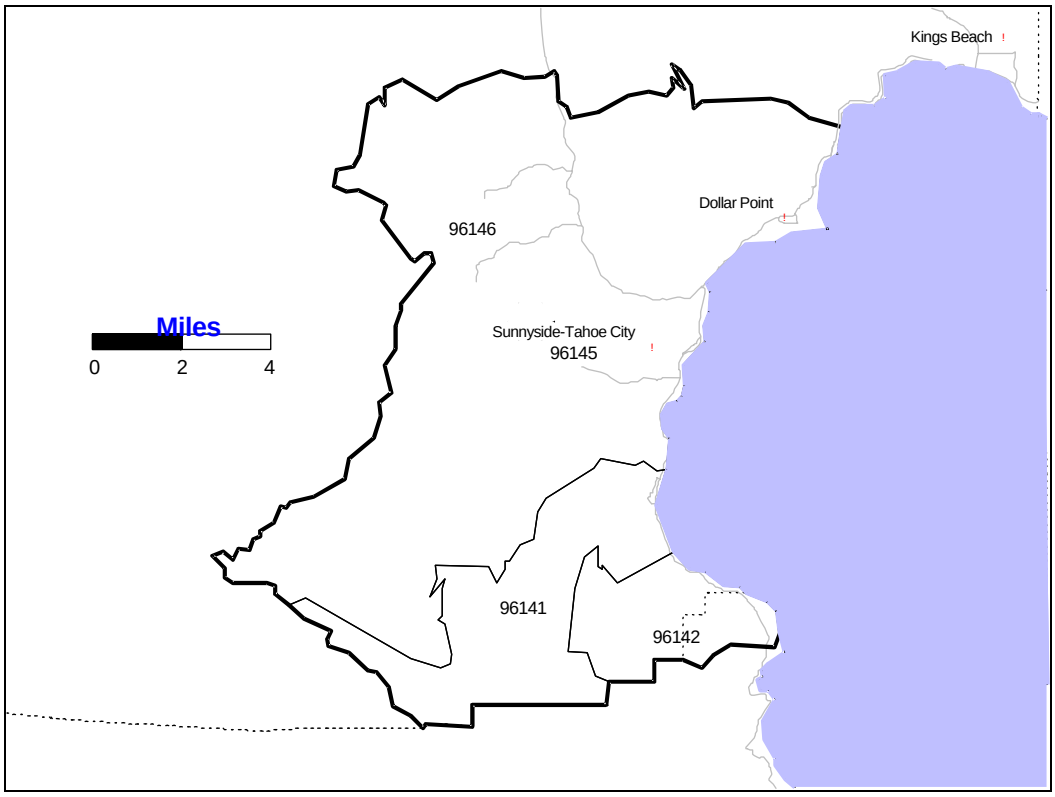


Figure 6-3—Tahoe City community region.

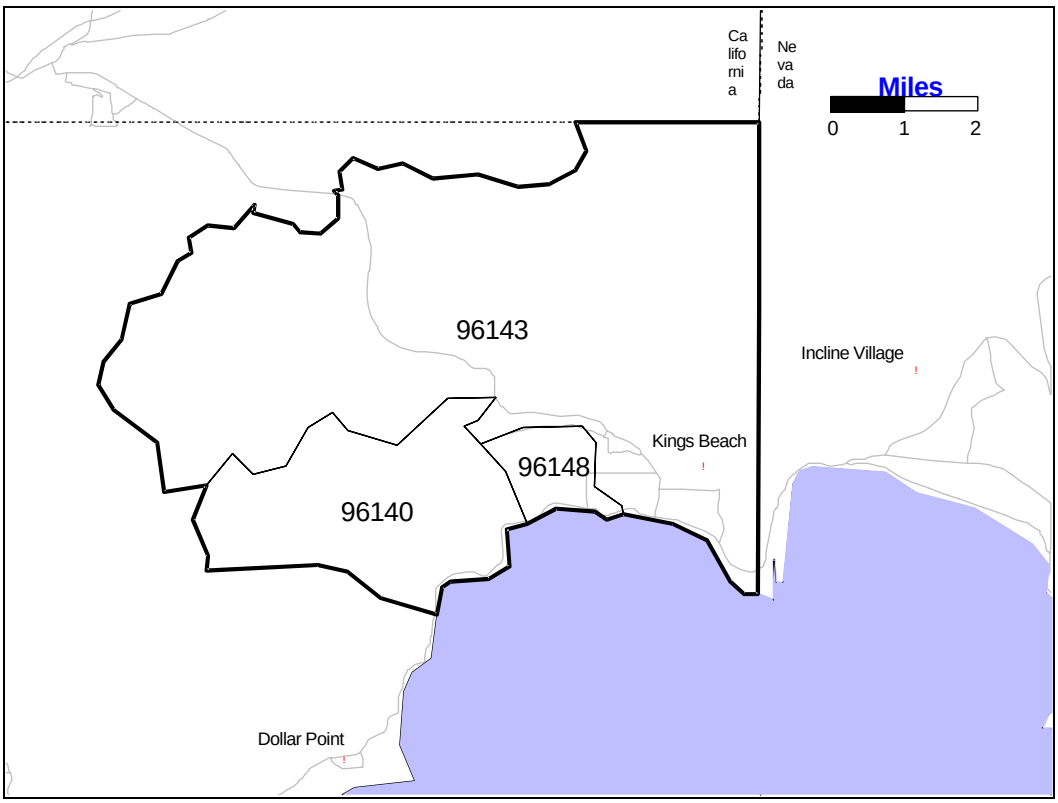


Figure 6-4—Kings Beach community region.

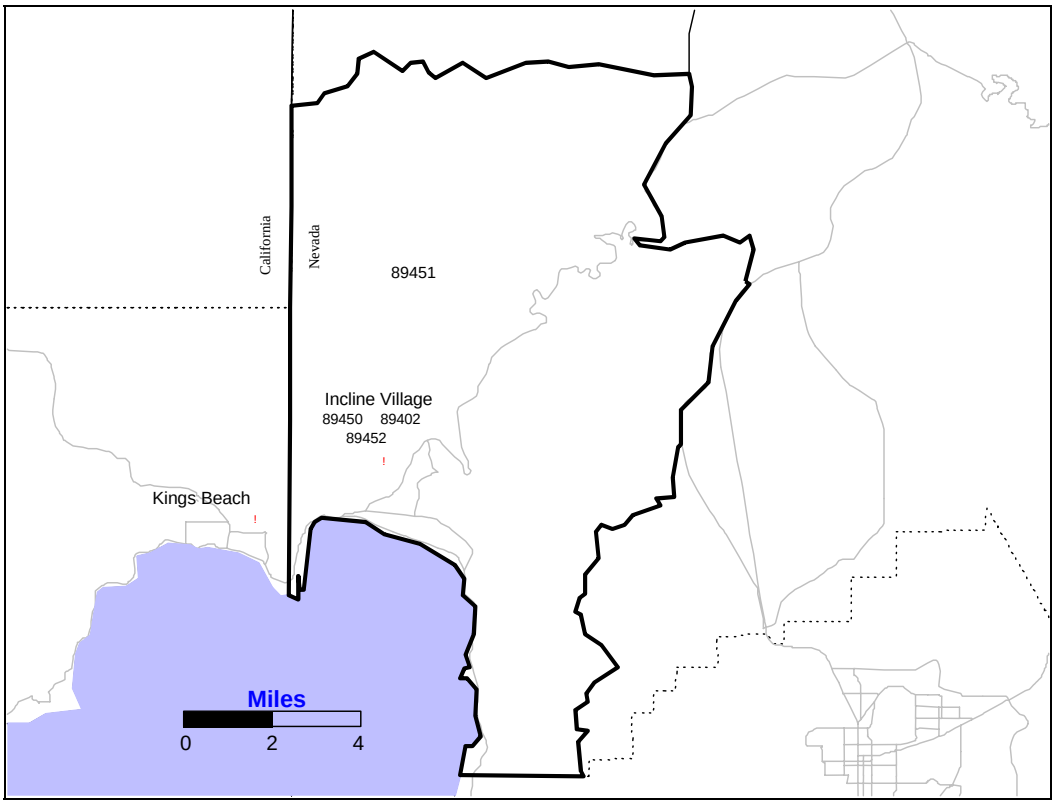


Figure 6-5—Incline Village community region.

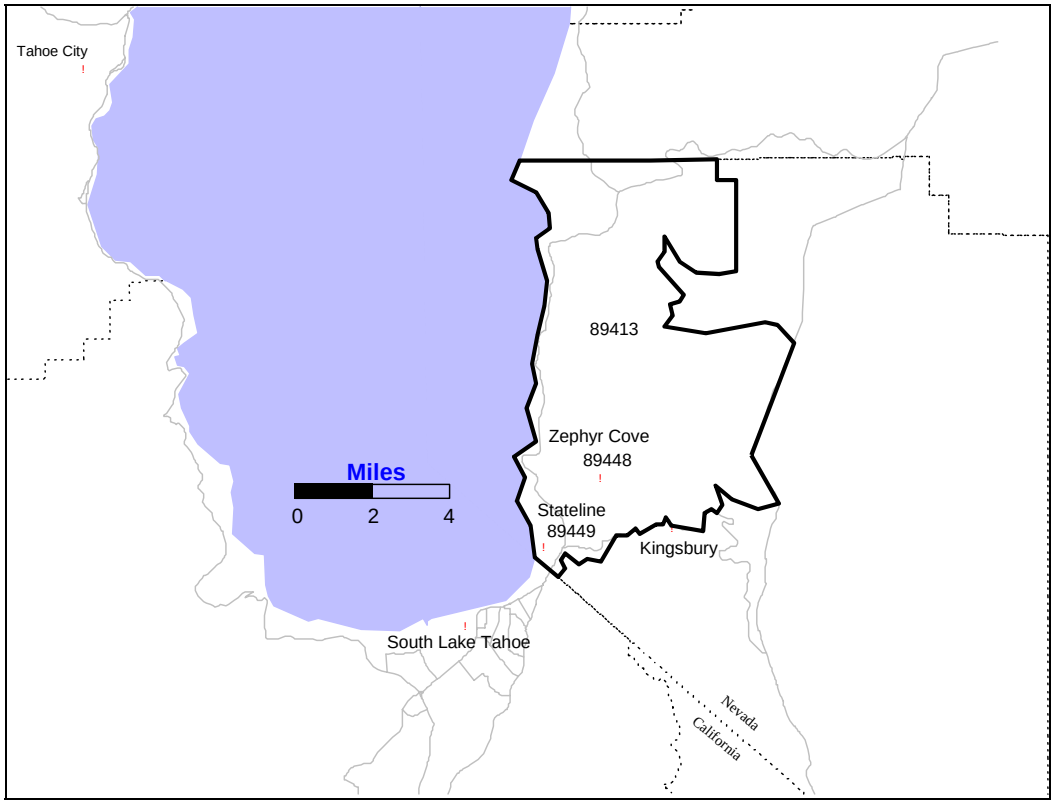


Figure 6-6—Stateline community region.

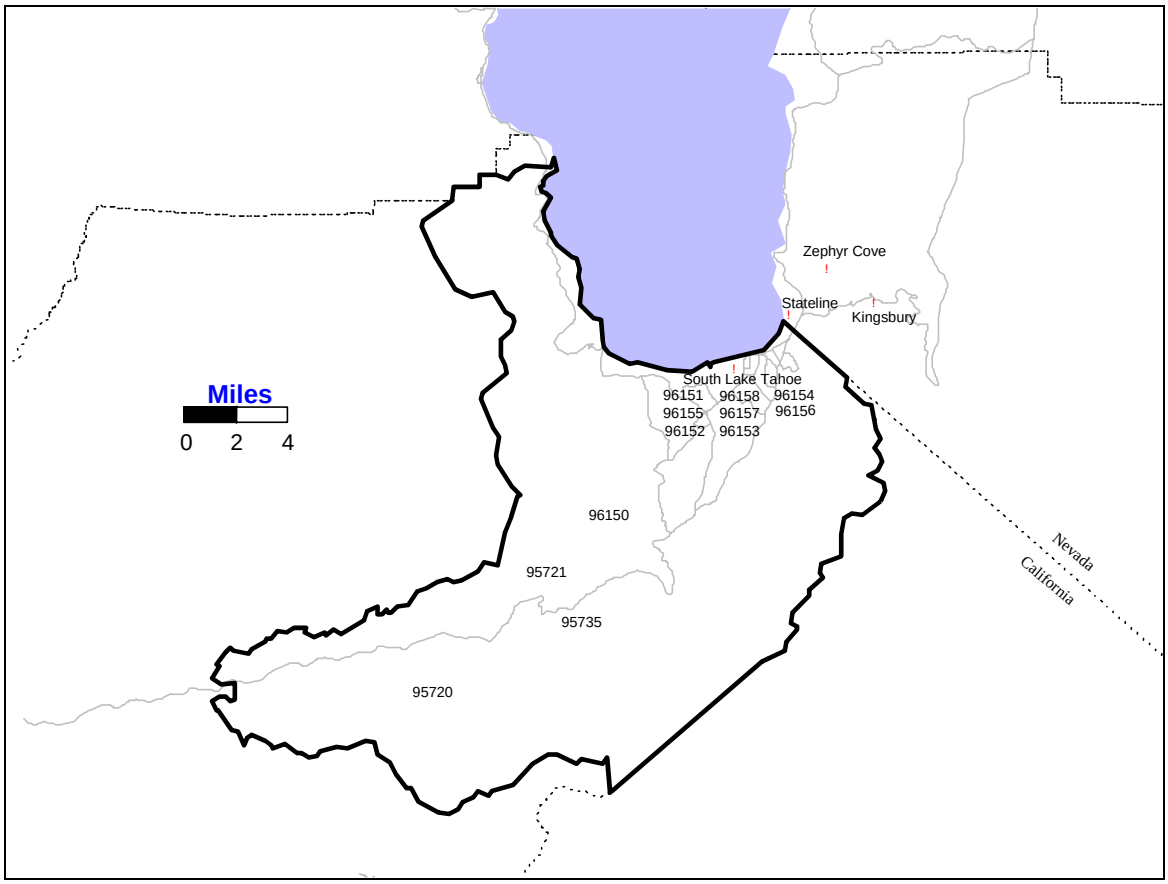


Figure 6-7—South Lake Tahoe community region.

to understand the flow of capital and resources in the entire basin. Most of those links are accommodated in the model. Effectively implementing the models requires extensive local knowledge and expert opinion. Allocating the relative portions of internal and external share of both capture and impacts is a critical phase of the model implementation. This is usually done by presenting the data from such sources as County Business Patterns (compiled by the US Census) to local knowledgeable experts and, through interviews and other interactions, adjusting the relative weight among values, known as the "ground truthing" phase (Robison, forthcoming).

The data presented here have a high confidence level but are necessarily in flux. The modeling effort was developed to continue beyond the completion of the watershed assessment, and the ground truthing phase has not been implemented. However, the assessment team is confident that the data are useful in their current form to describe current (as of 1998) patterns of employment and income in the five community-regions.

The following definitions are important for a clear understanding of the community-region profile data presented in tables 6-13 through 6-17:

- *Residents' Income*—The total before tax income of persons living within the boundaries of the community. It can be thought of as income generated in the community, less the claims of in-commuters and absentee owners (defined as *Residents' Inside Income*), plus the income of out-commuters, income from ownership of property located outside the community, and transfer payments (defined as *Residents' Inside Income*). *Residents' Income* = *Residents' Inside Income* + *Residents' Outside Income.*

Table 6-13—Tahoe City community region economic profile.

Tahoe City	**(x $1,000)**			
Labor Income by Place of Work	$113,628			
Less Incommuting Income	-$43,407			
Labor Income by Place of Residence	$70,221	83.1%		
Property Income	$14,300	16.9%		
Total Inside Income	**$84,520**	**100%**	**47.0%**	
Property Income	$21,334	22.4%		
Transfer Payments	$19,645	20.6%		
Outcommuters Income	$35,380	37.1%		
Income of non-working Part-time Residents	$18,904	19.8%		
Total Outside Income	**$95,264**	**100%**	**53.0%**	
Total Residents' Income	**$179,784**		**100.0%**	

Labor Income and Jobs by Industry	**Jobs**	**%**	**Earnings**	**%**
Agriculture & agricultural services	123	2.2%	$ 1,904	1.7%
Mining, sand and gravel	1	0.0%	$ 14	0.0%
Construction	637	11.4%	$ 21,588	19.0%
Food processing	-	0.0%	-	0.0%
Wood products	49	0.9%	$ 2,380	2.1%
Misc. manufacturing	121	2.2%	$ 2,479	2.2%
Transportation	158	2.8%	$ 4,801	4.2%
Publishing and communications	29	0.5%	$ 1,407	1.2%
Public utilities	5	0.1%	$ 197	0.2%
Trade	609	10.9%	$ 13,396	11.8%
Motels, eating and drinking	1,069	19.2%	$ 14,043	12.4%
Finance, insurance, and real estate	426	7.7%	$ 7,259	6.4%
Amusement and recreation	1,224	22.0%	$ 15,095	13.3%
Consumer services	232	4.2%	$ 4,485	3.9%
Business services	294	5.3%	$ 8,460	7.4%
Medical, educational and social services	195	3.5%	$ 4,950	4.4%
Federal government	30	0.5%	$ 822	0.7%
State and local government	361	6.5%	$ 10,348	9.1%
TOTAL	**5,563**	**100.0%**	**$113,628**	**100.0%**

Source: Economic Modeling Specialists, Inc.

Table 6-14—Kings Beach community region economic profile.

Kings Beach	**(x $1,000)**			
Labor Income by Place of Work	$51,401			
Less Incommuting Income	-$18,382			
Labor Income by Place of Residence	$33,019	86.3%		
Property Income	$5,263	13.7%		
Total Inside Income	**$38,282**	**100%**	**32.2%**	
Property Income	$6,941	8.6%		
Transfer Payments	$13,011	16.1%		
Outcommuters Income	$57,223	70.9%		
Income of non-working Part-Time Residents	$3,570	4.4%		
Total Outside Income	**$80,745**	**100%**	**67.8%**	
Total Residents' Income	**$119,027**		**100.0%**	

Labor Income and Jobs by Industry	**Jobs**	**%**	**Earnings**	**%**
Agriculture & agricultural services	45	1.8%	$ 506	1.0%
Mining, sand and gravel	-	0.0%	-	0.0%
Construction	267	10.5%	$ 9,042	17.6%
Food processing	-	0.0%	-	0.0%
Wood products	-	0.0%	-	0.0%
Misc. manufacturing	19	0.7%	$ 886	1.7%
Transportation	112	4.4%	$ 2,951	5.7%
Publishing and communications	22	0.9%	$ 704	1.4%
Public utilities	1	0.0%	$ 31	0.1%
Trade	211	8.3%	$ 4,495	8.7%
Motels, eating and drinking	838	32.8%	$ 12,366	24.1%
Finance, insurance, and real estate	145	5.7%	$ 2,436	4.7%
Amusement and recreation	428	16.8%	$ 5,325	10.4%
Consumer services	20	0.8%	$ 439	0.9%
Business services	63	2.5%	$ 1,988	3.9%
Medical, educational and social services	145	5.7%	$ 3,562	6.9%
Federal government	21	0.8%	$ 575	1.1%
State and local government	213	8.4%	$ 6,094	11.9%
TOTAL	**2,550**	**100.0%**	**$51,401**	**100.0%**

Source: Economic Modeling Specialists, Inc.

Table 6-15—Incline Village community region economic profile.

Incline Village	**(x $1,000)**			
Labor Income by Place of Work	$258,166			
Less Incommuting Income	-$91,882			
Labor Income by Place of Residence	$166,284	90.5%		
Property Income	$17,388	9.5%		
Total Inside Income	**$183,672**	**100%**	**43.4%**	
Property Income	$109,654	45.8%		
Transfer Payments	$25,654	10.7%		
Outcommuters Income	$89,818	37.5%		
Income of non-working Part-Time Residents	$14,083	5.9%		
Total Outside Income	**$239,209**	**100%**	**56.6%**	
Total Residents' Income	**$422,881**		**100.0%**	

Labor Income and Jobs by Industry	**Jobs**	**%**	**Earnings**	**%**
Agriculture & agricultural services	115	1.2%	$ 1,828	0.7%
Mining, sand and gravel	-	0.0%	-	0.0%
Construction	783	8.3%	$ 26,552	10.3%
Food processing	3	0.0%	$ 147	0.1%
Wood products	7	0.1%	$ 176	0.1%
Misc. manufacturing	56	0.6%	$ 1,983	0.8%
Transportation	161	1.7%	$ 4,687	1.8%
Publishing and communications	60	0.6%	$ 2,276	0.9%
Public utilities	16	0.2%	$ 1,149	0.4%
Trade	732	7.8%	$ 18,758	7.3%
Motels, eating and drinking	3,431	36.6%	$ 77,768	30.1%
Finance, insurance, and real estate	1,233	13.1%	$ 29,040	11.2%
Amusement and recreation	563	6.0%	$ 13,857	5.4%
Consumer services	414	4.4%	$ 15,944	6.2%
Business services	859	9.2%	$ 35,343	13.7%
Medical, educational and social services	462	4.9%	$ 11,452	4.4%
Federal government	44	0.5%	$ 1,907	0.7%
State and local government	444	4.7%	$ 15,299	5.9%
TOTAL	**9,382**	**100.0%**	**$258,166**	**100.0%**

Source: Economic Modeling Specialists, Inc.

Table 6-16—Stateline community region economic profile.

Stateline	**(x $1,000)**			
Labor Income by Place of Work	$394,895			
Less Incommuting Income	-$285,489			
Labor Income by Place of Residence	$109,406	88.6%		
Property Income	$14,101	11.4%		
Total Inside Income	**$123,507**	**100%**	**43.3%**	
Property Income	$92,490	57.1%		
Transfer Payments	$24,707	15.3%		
Outcommuters Income	$33,282	20.6%		
Income of non-working Part-Time Residents	$11,473	7.1%		
Total Outside Income	**$161,952**	**100%**	**56.7%**	
Total Residents' Income	**$285,459**		**100.0%**	

Labor Income and Jobs by Industry	**Jobs**	**%**	**Earnings**	**%**
Agriculture & agricultural services	149	1.0%	$ 1,728	0.4%
Mining, sand and gravel	-	0.0%	-	0.0%
Construction	610	4.2%	$ 20,677	5.2%
Food processing	-	0.0%	-	0.0%
Wood products	-	0.0%	-	0.0%
Misc. manufacturing	115	0.8%	$ 3,545	0.9%
Transportation	86	0.6%	$ 2,191	0.6%
Publishing and communications	24	0.2%	$ 1,199	0.3%
Public utilities	14	0.1%	$ 1,107	0.3%
Trade	451	3.1%	$ 9,791	2.5%
Motels, eating and drinking	10,721	73.6%	$ 284,720	72.1%
Finance, insurance, and real estate	941	6.5%	$ 23,047	5.8%
Amusement and recreation	429	2.9%	$ 11,514	2.9%
Consumer services	272	1.9%	$ 7,846	2.0%
Business services	252	1.7%	$ 13,254	3.4%
Medical, educational and social services	274	1.9%	$ 7,438	1.9%
Federal government	27	0.2%	$ 734	0.2%
State and local government	195	1.3%	$ 6,103	1.5%
TOTAL	**14,558**	**100.0%**	**$394,895**	**100.0%**

Source: Economic Modeling Specialists, Inc.

Table 6-17—South Lake Tahoe community region economic profile.

South Lake Tahoe	(x $1,000)			
Labor Income by Place of Work	$329,522			
Less Incommuting Income	-$39,953			
Labor Income by Place of Residence	$289,569	91.3%		
Property Income	$27,477	8.7%		
Total Inside Income	**$317,046**	**100%**	**39.5%**	
Property Income	$76,692	15.8%		
Transfer Payments	$114,833	23.7%		
Outcommuters Income	$244,907	50.5%		
Income of non-working Part-Time Residents	$48,949	10.1%		
Total Outside Income	**$485,381**	**100%**	**60.5%**	
Total Residents' Income	**$802,427**		**100.0%**	

Labor Income and Jobs by Industry	Jobs	%	Earnings	%
Agriculture & agricultural services	216	1.4%	$ 2,651	0.8%
Mining, sand and gravel	-	0.0%	-	0.0%
Construction	901	5.7%	$ 30,553	9.3%
Food processing	5	0.0%	$ 103	0.0%
Wood products	13	0.1%	$ 317	0.1%
Misc. manufacturing	73	0.5%	$ 1,452	0.4%
Transportation	272	1.7%	$ 6,312	1.9%
Publishing and communications	217	1.4%	$ 6,386	1.9%
Public utilities	192	1.2%	$ 14,091	4.3%
Trade	2,407	15.2%	$ 49,843	15.1%
Motels, eating and drinking	2,988	18.8%	$ 44,166	13.4%
Finance, insurance, and real estate	1,199	7.6%	$ 19,033	5.8%
Amusement and recreation	3,040	19.2%	$ 30,779	9.3%
Consumer services	502	3.2%	$ 11,243	3.4%
Business services	662	4.2%	$ 16,905	5.1%
Medical, educational and social services	1,668	10.5%	$ 50,200	15.2%
Federal government	192	1.2%	$ 5,868	1.8%
State and local government	1,321	8.3%	$ 39,618	12.0%
TOTAL	**15,869**	**100.0%**	**$329,522**	**100.0%**

Source: Economic Modeling Specialists, Inc.

- *Labor Income*—Sometimes called "*earnings*," includes wages, salaries, and proprietors' income.
- *Jobs*—As reported in the tables, jobs are both full-time and part-time and refer to the annual average of monthly employment. Thus, a person who holds two part-time jobs for the full year will appear as two jobs, while two persons employed for six months each will appear in the table as one job.
- *Property Income*—Income from the ownership of privately held equities and real estate. Includes claims on the profit of corporations and any other payments classed as dividends, interest, and rent. Includes private pension income.

  Inside property income is generated on property located within the boundaries of the community. In rural communities this normally includes rental income on real estate and the income of incorporated businesses located in the community. Inside property income excludes claims by nonresident (or absentee) owners. Thus, the property income of a locally owned grocery store or restaurant will be included, while that of a national chain will be excluded.

  Outside property income is generated outside the community but claimed by community residents. It includes claims on outside corporate income, normally paid as dividends, capital gains, and interest payments on corporate stocks and bonds, mutual fund income, and so on. It also includes money market and other bank interest and rental income on real estate located outside the community. Private pension income is included in outside property income.
- *Transfer Payments*—Payments to community residents (normally by the government) that do not result from current production and for which no services are rendered. Examples include Social Security and veteran's payments, public assistance, and unemployment compensation.

Model Validation and Application

The validity of the community region economic models was tested based on an analysis of visitor spending impacts, as projected by the models. Visitor spending accounts for large, although variable and unknown, shares of the economic activity in several highly important sectors of each community region, including hotels and lodging places, amusement and recreation services, and eating and drinking places. The models were validated by estimating the amount of visitor spending in these sectors, as well as in food stores, automotive dealers, and service stations and in miscellaneous retail sectors, which are also relatively dependent on visitor spending. Model validity is indicated by results showing that visitor spending in fact accounts for most of these sectors' sales; conversely, results indicating that visitor spending accounts for either a relatively small portion of these sectors' sales or more than 100 percent of their sales would suggest significant errors in the models.

The validation test required generating independent estimates of numbers of basin visitor days and average daily spending levels by sector. Annual visitation to the south shore area was estimated at 1.8 million visitor days, based on reported rentals of lodging room-nights and estimates of the average number of persons per room and the proportion of visitor days accounted for by day users (Strategic Marketing Group 1999). Annual visitation in the north shore area was estimated at 46 percent of the south shore visitation total (0.8 million visitor days), based on reported room-night rentals in the north shore area relative to that in the south shore area. Within the north and south shore areas, visitor days were allocated among community regions in proportion to the combined number of jobs in the motels and lodging places and amusement and recreation services sectors (as shown in tables 6-13 through 6-17). The resulting allocation of visitation to the community regions is shown in Table 6-18.

Table 6-18—Estimated allocation of visitation to the Lake Tahoe basin community regions.

Community Region	Visitor Days	Percent of Total Visitation
California Region		(%)
Kings Beach	36,400	1
South Lake Tahoe	621,400	24
Tahoe City	382,200	15
Nevada Region		
Incline Village	410,800	16
Stateline	1,149,200	44
Total	**2,600,000**	**100**

Source: Jones and Stokes Associates, Inc.

Spending profiles reflecting average daily spending levels by spending category in the north and south shore areas (Table 6-28) were obtained from recent visitor surveys (RRC Associates 1992; Strategic Marketing Group 1998). These spending categories were modified to conform to the economic sectors contained in the models (Table 6-19). As indicated in Table 6-19, the validation test was based on the assumption that all gaming expenditures in the north and south shore areas are made by visitors to Incline Village and Stateline, respectively. Daily spending levels for visitors to the Nevada regions thus were increased from the area-wide average to absorb all of the area's gaming expenditures, while daily spending levels for California region visitors were correspondingly decreased.

Table 6-20 shows the estimated total annual visitor-related spending in each of six key visitor-serving sectors, based on the annual visitation levels and daily spending levels shown in tables 6-18 and 6-19, respectively. Tables 6-21 through 6-25 show the estimated direct employment impacts that would result from the loss of all basin visitation, using the lower more conservative figure discussed above, of 2.6 million annual visitor days. These tables reveal some of the inaccuracies and questionable assumptions contained in the community region economic models developed for this assessment.

The most obvious and economically important model error revealed in tables 6-21 through 6-25 is the relatively small shares of the community region economies (e.g., as measured by employment effects) accounted for by visitation. A 100 percent loss of the estimated 2.6 million annual visitor days throughout the basin is estimated to reduce overall employment in the community regions from a minimum of six percent in Kings Beach to a maximum of 32 percent in Tahoe City. That these shares are low is readily apparent from results for Stateline, for example, where 69 percent of all jobs are classified within the hotels and lodging places sector, whereas only 25 percent of the jobs would be lost if Stateline visitation (estimated at 1,149,200 annual visitor days) were entirely displaced (Table 6-24).

Two main potential sources of this underestimation of the economic impacts of visitation are that estimates of visitation are too low or that average daily spending is inaccurately measured. However, the estimated average per capita daily spending level of $204 for Stateline would not intuitively appear to be a substantial underestimate; at this rate, for example, a typical family of four would spend $5,712 during a one-week stay. If the spending estimate is not too low, the main source of error would likely be a low estimate of annual visitation. Considering that alternative estimates of basinwide visitation range as high as 23 million visitor days (almost nine times larger than the level assumed for this validation test), underestimating visitation is a plausible source of model error.

One hypothesis explaining the underestimation of basin visitation is that day use exceeds the estimated 12 percent of total

Table 6-19—Estimated allocation of visitor spending to economic sectors.

Region / Spending Category	Average Daily per capita Spending (in $)	Economic Sector Allocation[1]	Retail Margin (in %)	Amount (in $)
California South Shore (without gaming)				
Food & Drink	$32.00	Food Stores (450) - 50%	25%	4.00
		Eating & Drinking (454) - 50%	100%	16.00
Lodging	31.00	Hotels & Lodging (463) - 100%	100%	31.00
Transportation	6.00	Food Stores (450) - 80%	25%	1.20
		Service Stations (451) - 20%	25%	.30
Entertainment	22.00	Amusement & Recreation (488) - 100%	100%	22.00
Other[2]	44.00	Miscellaneous Retail (455) - 25%	25%	2.75
		Amusement & Recreation (488) - 75%	100%	33.00
Total				**110.25**
Nevada South Shore (with gaming)				
Food & Drink	32.00	Food Stores (450) - 50%	25%	4.00
		Eating & Drinking (454) - 50%	100%	16.00
Lodging	31.00	Hotels & Lodging (463) - 100%	100%	31.00
Transportation	6.00	Food Stores (450) - 80%	25%	1.20
		Service Stations (451) - 20%	25%	.30
Entertainment	22.00	Amusement & Recreation (488) - 100%	100%	22.00
Gaming	69.00	Hotels & Lodging (463) - 85%	100%	58.65
		Amusement & Recreation (488) - 15%	100%	10.35
Other[2]	44.00	Miscellaneous Retail (455) - 25%	25%	2.75
		Amusement & Recreation (488) - 75%	100%	33.00
Total				**179.25**
California North Shore (without gaming)				
Food & Drink	43.00	Food Stores (450) - 50%	25%	5.38
		Eating & Drinking (454) - 50%	100%	21.50
Lodging	42.00	Hotels & Lodging (463) - 100%	100%	42.00
Transportation	8.00	Food Stores (450) - 80%	25%	1.60
		Service Stations (451) - 20%	25%	.40
Entertainment	12.00	Amusement & Recreation (488) - 100%	100%	12
Other[2]	66.00	Miscellaneous Retail (455) - 25%	25%	4.12
		Amusement & Recreation (488) - 75%	100%	49.50
Total				**136.50**
Nevada North Shore (with gaming)				
Food & Drink	43.00	Food Stores (450) - 50%	25%	5.38
		Eating & Drinking (454) - 50%	100%	21.50
Lodging	42.00	Hotels & Lodging (463) - 100%	100%	42.00
Transportation	8.00	Food Stores (450) - 80%	25%	1.60
		Service Stations (451) - 20%	25%	.40
Entertainment	12.00	Amusement & Recreation (488) - 100%	100%	12.00
Gaming	38.00	Hotels & Lodging (463) - 85%	100%	32.30
		Amusement & Recreation (488) - 15%	100%	5.70
Other[2]	66.00	Miscellaneous Retail (455) - 25%	25%	4.12
		Amusement & Recreation (488) - 75%	100%	49.50
Total				**174.50**

Source: Jones and Stokes Associates, Inc.

Notes:
[1] 3-digit numbers in parentheses refer to Standard Industry Classification (SIC) codes)
[2] The "Other" category includes spending at local retail establishments (e.g., sundries, souvenirs, etc.)

Table 6-20—Estimated visitor spending by economic sector and community region.

Community Region	Economic Sector	$/Visitor Day	Total Annual Spending ($1,000)
Kings Beach	Food Stores (450)	6.98	254
	Service Stations (451)	.40	14
	Eating & Drinking (454)	21.50	782
	Miscellaneous Retail (455)	4.12	149
	Hotels & Lodging Places (463)	42.00	1,528
	Amusement and Recreation (488)	61.50	2,238
Total		**136.50**	**4,965**
South Lake Tahoe	Food Stores (450)	5.20	3,231
	Service Stations (451)	.30	186
	Eating & Drinking (454)	16.00	9,942
	Miscellaneous Retail (455)	2.75	1,708
	Hotels & Lodging Places (463)	31.00	19,263
	Amusement and Recreation (488)	55.00	34,177
Total		**110.25**	**68,507**
Tahoe City	Food Stores (450)	6.98	2,667
	Service Stations (451)	.40	152
	Eating & Drinking (454)	21.50	8,217
	Miscellaneous Retail (455)	4.12	1,574
	Hotels & Lodging Places (463)	42.00	16,052
	Amusement and Recreation (488)	61.50	23,505
Total		**136.50**	**52,167**
Incline Village	Food Stores (450)	6.98	2,867
	Service Stations (451)	.40	164
	Eating & Drinking (454)	21.50	8,832
	Miscellaneous Retail (455)	4.12	1,692
	Hotels & Lodging Places (463)	74.30	30,522
	Amusement and Recreation (488)	67.20	27,605
Total		**174.50**	**71,682**
Stateline	Food Stores (450)	5.20	5,975
	Service Stations (451)	.30	344
	Eating & Drinking (454)	16.00	18,387
	Miscellaneous Retail (455)	2.75	3,160
	Hotels & Lodging Places (463)	89.65	103,025
	Amusement and Recreation (488)	65.35	75,100
Total		**179.25**	**205,991**

Source: Jones and Stokes Associates, Inc.

Table 6-21—Direct employment impacts related to loss of visitation at Kings Beach, California.

Economic Sector	Sales ($1,000)	Employment (# of Jobs)	Employment Change (# of Jobs)	Change (%)
Food Stores (450)	1,255	27	(6)	-22
Service Stations (451)	1,265	16	0	0
Eating & Drinking (454)	19,111	570	(31)	-5
Miscellaneous Retail (455)	3,182	114	(7)	-6
Hotels & Lodging Places (463)	14,403	267	(28)	-11
Amusement and Recreation (488)	13,085	411	(70)	- 17
Subtotal (all visitor serving sectors)	52,301	1,405	(142)	-10
All Other Sectors	324,546	1,145	(17)	-2
Total	376,847	2,550	(159)	-6

Source: Jones and Stokes Associates, Inc.

Table 6-22—Direct employment impacts related to loss of visitation at South Lake Tahoe, California.

Economic Sector	Sales ($1,000)	Employment (# of Jobs)	Employment Change (# of Jobs)	Change (%)
Food Stores (450)	27,564	600	(89)	-15
Service Stations (451)	13,760	234	(11)	-5
Eating & Drinking (454)	44,799	1,361	(348)	-26
Miscellaneous Retail (455)	18,068	624	(73)	-12
Hotels & Lodging Places (463)	74,202	1,627	(422)	-26
Amusement and Recreation (488)	74,396	2,897	(1,331)	- 46
Subtotal (all visitor serving sectors)	252,789	7,343	(2,274)	-31

Source: Jones and Stokes Associates, Inc.

Table 6-23—Direct employment impacts related to loss of visitation at Tahoe City, California.

Economic Sector	Sales ($1,000)	Employment (# of Jobs)	Employment Change (# of Jobs)	Change (%)
Food Stores (450)	5,503	117	(65)	-56
Service Stations (451)	2,847	35	(4)	-11
Eating & Drinking (454)	31,619	944	(331)	-35
Miscellaneous Retail (455)	5,366	192	(70)	-36
Hotels & Lodging Places (463)	6,735	125	(298)	-238
Amusement and Recreation (488)	38,101	1,196	(738)	- 62
Subtotal (all visitor serving sectors)	90,171	2,609	(1,506)	-58
All Other Sectors	702,947	2,954	(257)	-9
Total	793,118	5,563	(1,763)	-32

Source: Jones and Stokes Associates, Inc.

Table 6-24—Direct employment impacts related to loss of visitation at Incline Village, Nevada.

Economic Sector	Sales ($1,000)	Employment (# of Jobs)	Employment Change (# of Jobs)	Change (%)
Food Stores (450)	10,132	233	(70)	-30
Service Stations (451)	3,111	42	(3)	-7
Eating & Drinking (454)	18,030	495	(253)	-51
Miscellaneous Retail (455)	5,137	160	(58)	-36
Hotels & Lodging Places (463)	189,697	2,936	(472)	-16
Amusement and Recreation (488)	25,943	399	(425)	- 107
Subtotal (all visitor serving sectors)	252,050	4,265	(1,281)	-30
All Other Sectors:	1,228,220	5,117	(275)	-5
Total	1,480,270	9,382	(1,556)	-17

Source: Jones and Stokes Associates, Inc.

Table 6-25—Direct employment impacts related to loss of visitation at Stateline, Nevada.

Economic Sector	Sales ($1,000)	Employment (# of Jobs)	Employment Change (# of Jobs)	Change (%)
Food Stores (450)	1,850	42	(134)	-319
Service Stations (451)	1,829	36	(7)	-19
Eating & Drinking (454)	23,131	674	(535)	-79
Miscellaneous Retail (455)	6,606	217	(104)	-48
Hotels & Lodging Places (463)	736,117	10,047	(1,406)	-14
Amusement and Recreation (488)	26,666	385	(1,085)	- 282
Subtotal (all visitor serving sectors)	796,199	11,401	(3,271)	-29
All Other Sectors:	901,829	3,157	(320)	-10
Total	1,698,028	14,558	(3,591)	-25

Source: Jones and Stokes Associates, Inc.

visitation (see recreation section below). In comparison to overnight visitation, for which relatively reliable data are reported by lodging places, day use is difficult to estimate reliably (Ribaudo 1999b). Although the average daily spending level for day users is probably much lower than for overnight visitors, substantial underestimation of day use would account for at least a portion of the models' underestimation of visitor impacts on the economy.

Another type of model error apparent in tables 6-21 through 6-25 is that the assumed apportioning of spending among visitor-serving sectors (Table 6-19) is inconsistent with the models' classification of employment by sector. This error is indicated by the fact that eliminating visitation is shown as having an unreasonably small employment effect on some sectors (e.g., -14 percent in Stateline hotels and lodging places) and an unreasonably large effect on other sectors (e.g., -323 percent in Stateline food stores). This error is probably attributable primarily to the standard industrial classification (i.e., SIC coding) of major visitor-serving facilities in US Census Bureau employment data. It appears, for

example, that all or nearly all employment in Stateline casino facilities is classified within the hotels and lodging places sector. This classification is inconsistent with the assumed apportioning of spending (Table 6-19), where no food and drink, entertainment, or other spending is allocated to hotels and lodging places, and results in underestimating the effects of visitation on this sector. Conversely, apportioning 50 percent of food and drink spending and 80 percent of transportation spending to food stores probably overstates the effects of visitation on this sector.

A discussion of these errors is included here in order to point out the need for better estimates of basin visitation and related spending, primarily for day users, and also to improve understanding of the classification of major visitor-serving facilities in relation to the allocation of visitor spending among sectors. Improved information on these economic variables must be incorporated into the models before the models can be applied reliably for policy analysis.

A second validation test was conducted by comparing the estimated distribution of visitation based on room-night rentals, as described above, and the distribution based on employment levels in the hospitality sectors—motels and lodging places and amusement and recreation services. As discussed above, based on room-night rentals, the north shore area is estimated to account for 46 percent more visitor days than the south shore area. Based on the hospitality sector employment estimates reported in tables 6-13 through 6-17, the north shore area also accounts for 46 percent more visitor days than the south shore area. The convergence of these independent estimates supports the validity of the estimated distribution of visitation between the north and south shore areas.

Social and Economic Indicators to Measure Links between Socioeconomic Well-being and Environmental Quality

Especially in light of the fiscal implications of the EIP, many interests in the Tahoe basin's community have expressed a need to monitor the social and economic impacts of actions required to move the basin toward threshold attainment (Wallace 1998; Ribaudo 1999; Hasty 1999; TCORP 1999). TRPA's 1996 threshold evaluation report notes that while there are no specific social or economic thresholds, there is a need to "study, on an ongoing basis, the cause and effect relationships related to the Region's economy" (TRPA 1996: 9-1). Under its goals and policies, the regional plan mandates a monitoring program to "allow analysis of possible socioeconomic impacts of the Regional Plan" (TRPA 1986: VII-26). The purpose of monitoring social and economic indicators is to "assist in economic development and diversification within the constraints of the thresholds" (TRPA 1986). Indeed, under Goal #3 of the implementation element, the plan establishes a socioeconomic advisory panel "to help develop a socioeconomic monitoring program, to periodically review and report on the state of the basin's economy and make recommendations to the governing board" (TRPA 1986).

The 1996 threshold evaluation document makes several recommendations to account for the impacts of the regulatory environment on the economy, including the following:

- Allocations of additional residential development should be continued to allow for some residential development opportunities, which would have positive economic benefits in terms of stability, assessed valuation, and—to a limited degree—housing supply and availability.
- TRPA should initiate a study of the local economy to determine key business relationships and the impacts of development guidelines, including environmental mitigation programs, on new business development.
- TRPA should monitor the rate of absorption of commercial allocations by business type and location to establish the need for additional commercial allocations in the future.
- TRPA should develop a model of the local economy to determine significant contributors to local economic growth. This model should estimate total economic activity, economic multiplier rates, and

assess the impact and extent of economic leakage.

- TRPA should study the recreational nature of the local economy to determine how this relates to the commercial needs of the Region (TRPA 1996: 9-17).

Finally, the 1996 evaluation includes an implementation plan and a schedule for each of the elements in the plan. In that schedule, there is a commitment to work with the Tahoe Truckee Economic Coalition (TTREC) to provide data on economic trends in preparation for the 2001 evaluation. One element of the plan is to complete an "[i]ntegrated model of the Tahoe Region economy," to be completed by June 30, 2000 (TRPA 1996).

TRPA and many representatives of the larger community have long recognized the importance of tracking indicators of social and economic impacts beyond the immediately obvious impacts of regulation. However, it appears that neither institutional mechanisms nor social or political demand have been strong enough for TRPA (or any other public agency with regional influence in the basin) to monitor a full suite of socioeconomic indicators and trends.

TTREC was formed in the early 1990s to monitor economic trends and to plan regionally for economic change. While the primary impetus to initiate TTREC came from TRPA, the idea had broad community support (Teshara 1998; Hasty 1999; SEI Working Group 1999b). TTREC articulated the need for regional perspectives on economic trends and development in the basin; however, TTREC has been less successful in fostering a social and economic monitoring and modeling program at a basin-wide scale. Between 1993 and 1996 TTREC sponsored efforts to develop a suite of quality of life indicators for the basin, holding workshops and public meetings to capture the range of perspectives and needs in the community (TTREC 1996).

TTREC's economic indicators project held several workshops and meetings and stimulated public discussion about quality of life in the Tahoe basin's communities. However, a monitoring effort based on the quality of life indicators developed by TTREC and others was not carried forward or institutionalized (Farrell 1998; Hasty 1999; Ross 1999).

As is noted in the institutional assessment, the separation of regulatory authority and political representation creates a structural separation between the articulation of social preferences at the local community level and the expression of social preferences at regional, state, and national scales (R/UDAT 1989: 5, 21 & 25 ; NLTRA 1995: 3). TRPA is designed to compensate for this structural disconnection through a tiered approach to representation of interests. At the local scale, the TRPA-supported community planning process, in which 23 "natural communities" formed citizen advisory committees to develop community plans and plan area statements (PAS), continues in some of the communities. Ideas and recommendations that emerge from the advisory committees are integrated into TRPA's policy process through its Advisory Planning Commission (APC) (Lacey 1998). In general, the community plans reflect a desire to preserve the area's historic characteristics while improving known scenic, parking, transportation, and public facility deficiencies.

The APC is on the second tier, with basin-wide representation. This level of governance is designed to provide a regional focus to planning issues and to allow a greater degree of public involvement in developing regulation and policy. Finally, there is a board of governors, whose membership represents interests at the bi-state and national level. Through this three-tiered approach, TRPA is institutionally positioned to negotiate the "nested hierarchies" of social preferences.

There has been a decades-long evolution in the collective understanding of the purposes of public assets and public resources in the basin. One of the clearest statements of that collective understanding is found in the Goals and Policies of the Tahoe Regional Plan:

> The primary function of the region shall be as a mountain recreation area with outstanding scenic and natural values . . . . The economic health of the Region depends on a viable tourist and recreation-oriented environment. It is

> not the intent of this Regional Plan to encourage other economic development, such as industry or non-service commercial facilities, at the expense of outdoor recreation in the Tahoe Region (TRPA 1986: II-2).

As is pointed out in the SNEP case study of the Lake Tahoe basin (Elliott-Fisk et al. 1996), the relatively rapid acquisition of public lands in the basin over 30 years is a significant indicator of a public vision for Lake Tahoe. Various early efforts to designate the basin as a national park or to give the basin similarly protected status were not successful (TRPA 1976; Schmidt 1979; Fink 1991). However, Lake Tahoe's value as a scenic resource and tourist destination became the primary asset around which public and private investment was to be made (Jackson and Pisani 1973; Strong 1984, 1998). The recreation, tourism and service economy that grew up around that vision is still determined by the basin's fundamental organizing principal, clearly stated in the 1996 threshold evaluation document: the export of a high quality recreational experience (see introduction to TRPA 1996).

The mandate of the regional plan is to achieve a relative balance of costs and benefits in all sectors—social, economic, and environmental—without compromising the unique natural assets of the basin. The TTREC community indicators process identified a mutual dependency: a healthy community in the basin depends on a healthy environment, and the health of the environment depends on the health of the community. The challenge TTREC and others face is how to measure what is meant by "health." Many of the indicators identified in the TTREC process between 1993 and 1996 went beyond economic measurements to social concerns, acknowledging that measurement of a community's health through predominantly econometric means is unsatisfactory.

The creative tension among economic development, community well-being, and environmental quality has been heightened as the suite of EIP projects has been more clearly defined following the Presidential Summit in July 1997. There is substantial concern that the local private and public contribution, totaling about $254 million,[8] will create unfair burdens on certain economic and social sectors. Those social and economic questions are yet to be understood and resolved by future research and policy development efforts.

There are differing perspectives on the relative weight that community well-being should have in the development of public policy in the basin. General agreement exists that purely economic measures of community well-being contribute to a misconstruction of the social and economic questions raised by TTREC and others. At the core of the issue is a two-step argument: investments in community well-being (i.e., investments in sources of social and human capital) result in higher levels of social and economic resiliency (i.e., community capacity) (Doak and Kusel 1996; Kusel 1996; Sierra Business Council 1997). Higher community capacity and socioeconomic scores (Doak and Kusel 1996), measured across the entire community, are likely to indicate a greater willingness to participate in seeking sources of investment for environmental quality (Miller 1998b; Hasty 1999; Ross 1999). This logic has been articulated in other community indicators projects occurring throughout the United States (Tyler, Norris Associates 1997; Redefining Progress 1998; National Association of Regional Councils 1999). Daniel Kemmis and Neal Pierce, both regional writers of national and international stature, have monitored the trend toward what Pierce has called the "new citistate" (Peirce 1993; Kemmis 1995). This trend is characterized by cities, metropolitan regions, and groups of towns that have collectively identified the economic, cultural, and social logic of their regions. The revitalization of regions as coherent political, social, and economic units has accompanied the movement toward environmental justice and livable communities. What these efforts have in common, and what is particularly relevant to the basin, is a commitment to broad-based participatory review of the measurable indicators by which the region or "citistate" will monitor its livability, sustainability, and relative collective health. "Community indicators" is an increasingly common term used to capture both the processes and outcomes of these collective efforts to renegotiate the terms of health, livability, and sustainability. As one national clearinghouse on these processes defines them,

[8] The EIP's cost analysis projects a total of $908 million, including $152.7 million from the private sector and $101 million from local government sources (TRPA 1998).

> "Community Indicators" are a measuring system, designed, developed and researched by the community members themselves. They are like instrument panels, that provide citizens with clear and honest information about past trends and current realities, and assist them in steering their communities on their desired course. They help civic leaders clarify key issues and challenges, or prioritize spending when budgets are tight. (Tyler, Norris Associates 1997: 1).

According to the database maintained by the San Francisco-based nonprofit, Redefining Progress, there are presently nearly 250 community indicator processes underway in cities across the country (Redefining Progress 1999). The database criteria require that entries have an ongoing multi-stakeholder process, actual projects, and an active effort to define appropriate indicators (Frank 1999). An analysis of the database shows approximately ten percent of those projects are currently under development in California alone. A common thread among all of these processes is the development of quantifiable social and economic indicators that more closely match each community's or city's sense of how to measure quality of life, community well-being, and sustainability. Moreover, the process itself often turns out to be as important as the ultimate content and focus of the resulting suite of indicators (Tyler, Norris Associates 1997: 1).

The Tahoe basin's regulatory environment, as expressed in the regional plan, already mandates an approach to economic and social sustainability balanced with conservation of its unique environmental assets (Ross 1999; Hasty 1999). However, the need to quantify and analyze the social and economic impacts of the EIP and the evolving demand to include some understanding of community well-being in the basin's planning and investment strategies are likely to stimulate demand for a regionally focused effort to identify shared indicators of quality of life. There is demand from the private sector to develop an economic model of the basin, echoing the recommendations of both TRPA threshold evaluations (1991 and 1996). The modeling development effort also may trigger support for quality of life indicators that enable the policy community to better monitor social and community well-being.

The assessment's socioeconomic working group reviewed a list of 57 indicators that might be used to monitor social well-being and economic health. Some of the indicators identified have relatively little data to support their measurement in the basin at this time. While the complete list is reproduced in Appendix T (SEI Working Group 1999a, 1999c), the selected indicators can be grouped into the following general categories:

- Recreation, tourism, and visitor-profile information;
- Demographics and social characteristics of part-time and full-time residents;
- Social indicators, including educational achievement, crime, and public assistance;
- Political and social participation and volunteerism;
- New and emerging economic activities;
- Labor and employment;
- Housing;
- Transportation; and
- Redevelopment and community reinvestment.

No formal mandate or process is in place at this time to pursue a suite of social and economic indicators in the basin. However, developing and monitoring social and economic indicators in the basin has challenged planners and policy-makers for some time. The difficulty of the task is closely related to the following issues:

- Indicators themselves are difficult to identify in ways that are both useful to policy-makers and scientifically and methodologically credible. A recent informal survey of community indicator project sponsors found that many indicators initially proposed by a collaborative process

eventually are rejected because their measurement is often infeasible or cost prohibitive (Nechodom 1999; Bonnenfant 1999).

- The identification of indicators requires sufficient public process in order to establish the purpose of the indicators and to explore fully the potential consequences of measuring one particular suite of indicators as opposed to another.
- Community indicator processes are resource-intensive and time-consuming. Many attempts to initiate community indicators processes fail because of lack of sufficient coordination, capacity, and funding. Others find that, despite large investments of volunteer and in-kind labor and resources, the process often outruns any single organization's ability to sustain it to completion (Redefining Progress 1998; Nechodom 1999).
- The process of establishing an appropriate suite of indicators is itself a political process and is likely to be controversial.

Issue 2: Understanding Patterns of Recreation and Tourism as They Affect Environmental Quality, Social Well-being, and Economic Health

Emerging Trends in Tourism and Recreation

In the first third of the twentieth century, the Tahoe basin provided recreation opportunities to an elite group of summer residents and resort guests drawn to the area's natural amenities. In the 1930s, an increasing number of middle class and working people began to enjoy camping in the basin (Strong 1986). Following World War II, tourism expanded rapidly, as motorists from northern California and around the country took advantage of improved highway access to and around the lake. While games of chance attracted primarily summer visitors to the Nevada side of the basin, rapid development of downhill ski resorts following the 1960 Winter Olympics at Squaw Valley established the basis for a year-round tourist destination. A seasonally bimodal pattern of visitation, with peaks in summer and winter, developed and has persisted through today. Hotels, marinas, trails, and campgrounds were developed to accommodate the recreation needs of a growing and increasingly mobile, wealthy, and suburban population of visitors.

Quantitative Trend Analysis—Emerging trends in tourism can be identified by analyzing various types of quantitative and qualitative data. Users of the information often prefer quantitative data on recreation use levels and patterns and on demographics over qualitative data, primarily because of the relative objectivity of quantitative data. Visitor and user censuses and surveys have been conducted in the basin to establish baseline levels and trends for basin tourism and recreation. (Censuses involve collecting information on an entire population of interest; surveys usually involve collecting information on a sample of the population.) Not all quantitative data on recreation are census- or survey-based, however. The USDA Forest Service, for example, estimates annual participation in selected recreation activities based on various methods, including occasional counts of people and vehicles. As a result of using these diverse methods, the reliability of the estimates is variable. The total number of visitor days spent in the basin is a highly contentious recreation datum (Lacey 1999). An estimate of 23 million annual visitor days was reported in a recent case study (Elliott-Fisk et al. 1997). This estimate is based on a broadly inclusive definition of visitation and undoubtedly overstates actual visitation, as usually defined. For example, it includes seasonal residents among visitors and assumes that each seasonal resident accounts for 90 visitor days each year. It also includes people who make incidental stops while traveling through the basin, predominantly on the south shore via Highway 50 (Lacey 1999).

A much more conservative recent estimate of the basin's annual visitation level is 2.6 million visitor days (Strategic Marketing Group 1999), which includes 1.8 million visitor days in the south shore area and 0.8 million in the north shore area. This estimate for the south shore area was based on the reported number of room-nights rented annually over a three-year period, multiplied by the average number of persons per room, which had been

estimated in a previous study. Based on another study, day users were estimated to account for approximately 12 percent of total visitation on the south shore, which is in addition to the number resulting from the room-night analysis. The north shore visitation estimate was based on the relative number of rented room-nights reported for the north shore area. The 2.6 million total visitor-day estimate probably understates the true total, as usually defined, because it excludes, among other things, campground use. As indicated by the large discrepancy between these two estimates, however, the annual level of visitation actually occurring in the basin is a highly imprecise statistic.

Qualitative data on tourism trends usually take the form of professional judgment and expert opinion. Local professional recreation managers and experienced local providers of tourism and recreation services are usually the most authoritative sources of professional judgment and expert opinion on tourism trends.

Quantitative trend analysis requires compiling time-series data; that is, measurements or estimates of variables of interest consistently made over time. The best time-series data on tourism in the basin have been on skier days, gaming revenues, Tahoe-bound airport arrivals, and lodging nights purchased, all of which have been compiled for recreation and tourism industry associations. Consistent data on these variables cover at least the past eight years. As shown in Table 6-26, total alpine skier days at resorts in and adjacent to the basin generally have increased during the 1990s, although skier days have declined in a few recent years. Gaming revenues (expressed in constant 1998 dollars) generally have declined during this decade. The number of Reno-Tahoe International Airport arrivals bound for the basin has increased dramatically since 1991, as has the proportion of arrivals who are visitors. These air-passenger trends indicate the growth of the basin as a tourist destination for long-distance visitors.

Total hotel lodging nights purchased in the South Lake Tahoe area have fluctuated in the 1.0 million to 1.1 million range since 1990, achieving their maximum in 1994 (Table 6-27). The average room occupancy rate at South Shore casinos declined in 1991, but since then the rate has been relatively stable. During the 1990s, the average hotel room occupancy rate in the Incline Village/Crystal Bay area fluctuated in the 60 percent to 69 percent range, achieving a maximum in 1995, while the average occupancy rate for condominiums and vacation homes in this area fluctuated in the 23 percent to 32 percent range, peaking in 1993.

The most comprehensive statistically reliable sources of data on tourism in the basin are the quarterly visitor surveys conducted for the Lake Tahoe Visitors Authority (for the South Lake Tahoe area) and the North Lake Tahoe Resort Association (for the northern portion of the basin). Although these surveys do not provide estimates of total visitation, they provide substantial information on group type (e.g., family or other) and size, regions of origin, length and frequency of stay, activities, choice of lodging type, and spending patterns. Some of the problems that limit the identification and interpretation of tourism trends based on these survey results, however, include the small number of years in which surveys have been conducted, changes over time in the wording of survey questions leading to the incomparability of data on selected variables for various years, and declining reliability of results due to reduced survey sample sizes (Ribaudo 1999b).

In some cases, year-to-year variations in the data for several variables, combined with the above data limitations, suggest that what might appear to be a trend may merely represent aberrations or normal fluctuations. Examples of such questionable patterns include the proportion of South Lake Tahoe visitors who are day users, who stay in hotels or casinos, who participate in gaming or alpine skiing, and who live in California or the San Francisco Bay Area (Strategic Marketing Group 1997 and 1998; RRC Associates 1992; Rosall, Remmen, and Cares, Inc. 1990). The data source that provides estimates of total recreation use in the largest portion of the

Table 6-26—Skier days, gaming revenues, and air passenger arrivals and visitors for the Lake Tahoe basin.

Year	Skier Days[a]	Gaming Revenues[b]	Tahoe Basin-bound Air Passenger Arrivals[c]	Percent of Airport Arrivals Who Are Visitors
1990		489	--	--
1991		455	66,054	64.4
1992		438	104,969	77.1
1993		433	89,287	82.2
1994	2,500	436	127,148	81.6
1995	2,900	402	132,138	84.8
1996	2,700	375	115,985	89.0
1997	2,600	338	188,667	89.2
1998	3,200	348	--	--

Sources: California Ski Industry Association 1990-1998, Nevada State Gaming Control Board 1990-1998, Airport Authority for Washoe County 1991-1997.

Notes:
[a] In thousands. Each ski year includes the November-December period from the previous year.
[b] In millions of 1998 dollars.
[c] For Reno-Tahoe International Airport.

Table 6-27—Lodging room nights and occupancy rates for the Lake Tahoe basin.

Year	South Shore Hotel Nights	South Shore Casino Room Occupancy (%)	Incline Village/Crystal Bay Hotel Room Occupancy (%)	Incline Village/Crystal Bay Condo-Vacation Home Occupancy (%)
1990	975,250	81.5	--	--
1991	896,307	75.3	60.0	25.9
1992	907,794	75.1	62.8	28.8
1993	1,019,007	77.4	66.2	31.7
1994	1,028,469	74.2	68.8	27.8
1995	1,028,140	76.6	69.0	24.9
1996	949,936	76.7	66.7	22.9
1997	934,834	76.0	64.5	25.1
1998	--	75.3	66.4	30.3

Sources: City of South Lake Tahoe 1990-1998, Incline Village/Crystal Bay Visitors and Convention Bureau 1990-1998.

basin is the USDA Forest Service's Recreation Inventory Management (RIM) system as applied to the Lake Tahoe Basin Management Unit (LTBMU), which accounts for 77 percent of the basin's land base. The RIM system provides estimates of total annual visitation to the LTBMU and of total levels of participation in more than 60 activities. The estimates are based on various methods, including campground registrations, records of wilderness permits issued, automatic traffic counters (e.g., at building entrances), and occasional counts of people or vehicles at selected locations. Although all of these methods measure the same variable (recreation visitor days, or total number of visitor-hours divided by 12), they vary greatly with regard to the statistical reliability of the results. Consequently, time-series data on aggregated use (e.g., total annual use of the LTBMU) are a more reliable indicator of trend than time-series data on participation in most activities or activity groups. Between 1972, when the LTBMU was established, and 1993, estimated total annual use of the LTBMU increased from approximately 2.3 million RVDs to approximately 3.0 million RVDs.

Since then, total use has been relatively constant (Lane 1999). However, a comparison of LTBMU figures with the other estimates of the total number of visitor days spent in the basin each year (23 million) (Elliott-Fisk et al. 1997) suggests that differing measurements of visitation used in the basin make it difficult to establish accurately the actual level of facility use and visitation. Given the critical nature of this kind of information for planning and policy, the lack of consistent measurements or data on visitation is highly problematic. Several other public recreation providers systematically collect data on recreation use. For example, the California Department of Parks and Recreation and the Nevada Division of State Parks both prepare monthly summaries of use of state park facilities in the basin. These summaries are based on paid attendance records and on occasional counts conducted by rangers. The California Department of Parks and Recreation also manages the state's SnowPark program, which involves sales of parking permits for use at trailheads and other snowplay areas in the northern and central Sierra Nevada, including four locations in or near the basin. SnowPark permit sales records are the best source of data on levels of cross-country skiing and similar snowplay in the basin (Finster 1999).

The recreation agencies of the city of South Lake Tahoe, Douglas County, and the utility districts serving the Incline Village, North Tahoe, Tahoe City, and Tahoe-Paradise communities also collect data on the use of community parks and related facilities that they manage; however, their systematic data collection efforts typically are focused on just a few aspects of facility use.

Special studies occasionally are conducted on various aspects of basin recreation and tourism, including recent surveys of watercraft use (Hagler Bailly, Inc. 1998), bike trail use (Tahoe Coalition of Recreation Providers 1997), and visitors' attitudes (JD Franz Research 1998). Assessments of the adequacy of and need for community recreation facilities also are periodically conducted (The Dangermond Group 1999; Parsons Harland Bartholomew & Associates, Inc. 1998).

Qualitative Trend Analysis—In addition to quantitatively documented trends in basin tourism and recreation discussed above, several emerging trends have been observed by local recreation managers and tourist service providers, as described below.

- The most important trends driving changes in the recreation patterns in the Tahoe basin are the increased ethnic diversity of visitors and residents and the increased emphasis on family-based recreation. The average size of families visiting the basin has increased, with more generations (including grandparents) participating. More family visitation has resulted in increased demand for affordable snowplay facilities and for larger campsites and picnicking sites. While demand for tent-camping facilities is declining, demand for campsites that accommodate large recreation vehicles is increasing. Demand is increasing for recreation experiences that include an education component, such as visits to museums, historic sites, and Washoe cultural sites. The need is increasing for bilingual signage and interpretive displays (Lane 1999; Michaely 1999; Gustafson 1999b; Teshara 1999).
- Demand is increasing rapidly for recreation trails, including both high-standard urban-suburban trails and backcountry trails, for bicycling, hiking, inline skating, equestrian use, and wheelchair use. Growing trail use is correlated with an increased societal emphasis on fitness and health. Substantial trail use is indirectly associated with alpine skiing in that family members who elect not to ski on certain days or parts of days often recreate on trails instead (Gustafson 1999b; Michaely 1999; Lane 1999).
- Large groups of cyclists frequently use the basin's roads for organized rides. In addition to bicycling for recreation, bicycles are increasingly used as an alternative to motor vehicles for commuting and shopping. The basin is becoming an

important destination for mountain bikers of all skill levels. Old logging roads are being converted to bike trails to accommodate this demand (Tahoe Coalition of Recreation Providers 1997; Lane 1999; Michaely 1999).

- Increasing recreation demand, particularly for access to the Lake Tahoe shoreline, is not being met because of inadequate facility capacity, limited public access, and congestion. Public parking lots and shoreline resorts (e.g., Camp Richardson and Zephyr Cove) are frequently full during the recreation season. Fees are being charged for access to more areas and facilities. Charging fees tends to displace potential users to free-use areas, increasing congestion at these areas, and resulting in more driving, both to find available facilities and as an alternative to using fee-use areas (Lane 1999).
- Demand is rapidly increasing for youth soccer facilities and programs to serve residents. There is unmet demand for indoor facilities for swimming, basketball, exercising, and other activities. Demand for such adult team-sport programs as softball is decreasing. Although community park facilities historically were intended to serve primary resident populations, they are an increasingly important attraction for visitors (Weiss 1999; Gustafson 1999b; Michaely 1999; Lane 1999).
- Participation is increasing in individual-participant activities that require skill and specialized equipment. These activities include golf, mountain biking, cross-country skiing, snowshoeing, snowmobiling, equestrian activities, river rafting, windsurfing, kayaking, and flyfishing (Michaely 1999; Gustafson 1999b).
- Visitors are more interested in pursuing outdoor activities and using such facilities as campgrounds and trails in the traditional off-seasons of spring, fall, and winter (Michaely 1999; Gustafson 1999b).
- Fueled by the proliferation of sport utility vehicles, driving on backcountry roads and off-road is increasing (Lane 1999).
- As indicated by increasing deplanements at the Reno-Tahoe International Airport, the basin is attracting more visitors from distant locations seeking a destination resort experience (Teshara 1999).
- Fewer visitors are participating exclusively in high-stakes gaming; visitors tend to participate in gaming for shorter periods, on a relatively recreational level (Teshara 1999).

Key Data Gaps—The basin's economic health and social well-being depend heavily on the quality, availability, and sustainability of local recreation opportunities. Better information on recreation and tourism trends would be useful not only to recreation planners and tourist business proprietors but also to community and regional planners and decision-makers and all residents concerned with the area's future. Some of the key gaps in data on recreation and tourism that could be filled to help improve and sustain the basin's economic health and social well-being are listed below.

- *Better information on the demographic profiles of visitors and resident-recreationists, including age, ethnicity, household size, income, and recreation preferences*—The demographics of the populations of California and Nevada (the sources of more than half of the basin's annual visitation) are changing rapidly, increasing the diversity of the visitor populations to the basin.
- *More reliable estimates of basinwide visitation levels, disaggregated by community, by day use and overnight use, and by tourists and seasonal residents*—More reliable information on the total number of people who visit the basin each season and how those numbers change over time would improve general understanding of basin's popularity as a tourist destination, of the dependence of the basin's economy on recreation and tourism, and of the health of this economic sector.

- *More comprehensive seasonal estimates of the activities in which visitors participate and better assessment of the reasons they choose not to participate in other activities*—A key to recreation destination success is providing the varieties and qualities of recreation opportunities that satisfy the desires of all types of visitors. The basin provides an extraordinary variety of recreation opportunities, but much is unknown about how these opportunities interact to define the Lake Tahoe recreation experience.
- *More reliable estimates of seasonal basinwide use of shore and lake areas, disaggregated by community and recreation activity*—The Lake Tahoe shoreline is the single most important focus of basin recreation. The ability to obtain access to desirable beaches contributes greatly to the quality of recreation experiences for a large proportion of visitors, especially during summer. Most communities (Incline Village being an exception) compile relatively little information on beach use.
- *More comprehensive and reliable estimates of use of high-standard (urban-suburban) trails, desegregated by type of use (for example, pedestrian and bicycle) and community*—High-standard trails are a growing focus of recreation activity in the basin for both visitors and residents. Some communities, such as Tahoe City, already have effective programs in place to assess trail use, and a good baseline estimate exists for basinwide bike trail use (Tahoe Coalition of Recreation Providers 1997). Enhancing the comprehensiveness and reliability of trail-use assessments would require implementing relatively small expansions to existing assessment efforts. Urban-suburban trail use also can displace a substantial amount of vehicle use.
- *More reliable estimates of basinwide seasonal use of backcountry roads and trails, desegregated by recreation activity and community*—An increasing share of the basin's total recreation use occurs in backcountry areas, often by people willing to spend relatively large sums to enjoy their recreation experiences. The basin provides excellent opportunities for backcountry recreation, but increasing pressure on the facilities and resources required for such recreation could lead to decreased levels of satisfaction, user conflicts, or increased environmental impacts. Better information on backcountry use would enhance recreation managers' ability to meet users' expectations and to maintain and protect backcountry facilities and resources.
- *More comprehensive assessment of the use of community parks and related facilities by visitors and residents, including current levels of satisfaction with available facilities and sources of dissatisfaction*—Community parks are a critical recreation resource for large shares of both the resident and visitor populations. They are important places for residents to take their visitors to share in the Lake Tahoe recreation experience. Better information on park users' desires and the factors that contribute to their satisfaction would help recreation managers meet their clients' expectations.

Economic Impacts of Visitor Activities

Visitors to the Tahoe basin affect the regional economy in several ways. Most notably, visitors purchasing goods and services from local businesses directly infuse money into the regional economy by supporting local businesses, the workers they employ, and the workers' households. To accommodate tourists, local businesses purchase goods and services from their suppliers, many of which are also in the basin, and these purchases also generate income and employment. On the cost side, tourism increases the need for a wide range of public services beyond the levels needed by basin residents. Finally, because the amount that most tourists would be willing to pay to enjoy the Lake Tahoe recreation

experience exceeds the amount they actually pay for the experience, tourists incur what economists call a "consumer's surplus" when they visit the basin. This surplus represents a net economic value to the tourists and to society.

Visitor Spending—Each quarter, the Lake Tahoe Visitors Authority and the North Lake Tahoe Resort Association commission surveys visitors to the south and north Lake Tahoe areas, respectively, to assess (among other things) visitor demographics, length of stay, activities, preferences, and spending patterns. The reported spending levels by category of expenditures are averaged to develop spending profiles for summer and winter visitors. The results for 1997 expressed in terms of per capita daily spending are shown in Table 6-28. [illegible] total annual visitor days in the basin estimated at up to 23 million (Elliott-Fisk et al. 1996), annual visitor spending probably amounts to several billion dollars.

Employment and Income Effects—Economists refer to the effects of purchases of the products of an economic sector on jobs and income within that sector as direct economic effects. Jobs and income generated when those revenues are spent on the inputs needed by that sector are called indirect effects. Finally, the jobs and income that result from the spending of wages and salaries by people employed in the directly affected sector are referred to as induced effects. The direct, indirect, and induced income and employment effects generated by visitor spending vary by category of spending. Labor-intensive economic sectors (i.e., sectors that allocate a large share of their total purchases to labor) tend to have relatively large direct employment effects per dollar of sales. Sectors characterized by relatively high wages, salaries, and proprietors' income (profits) also tend to have relatively large direct income effects. Sectors with high value-added levels (i.e., that buy relatively few cents worth of inputs from other sectors per dollar of sales) usually have relatively large direct employment and income effects. Sectors that purchase large amounts of inputs from other businesses in the region tend to have relatively large indirect economic effects. High value-added sectors convert a large share of sales to personal income and thus have relatively large induced effects.

Most visitor-serving businesses are retail outlets that typically have moderate labor intensity, relatively low average wages and salaries, and moderate or high value-added levels. Some visitor-serving businesses, such as restaurants, purchase many of their inputs locally or regionally, while others, such as service stations, import most of their inputs. Based on these characteristics, visitor-serving businesses tend to have moderate direct effects, relatively small indirect effects, and moderate induced economic effects per dollar of sales. Although these general results are likely to hold for most visitor-serving businesses in the basin, many exceptions also could apply. For example, specialized recreation services, such as outdoor guides, probably have relatively high levels of labor intensity and value added and relatively high average salaries.

Table 6-29 summarizes data on average earnings, labor intensity, value added, and the relative magnitude of direct, indirect, and induced effects on employment and income for main industrial sectors that serve visitors. These results were obtained from IMPLAN, a county-based input-output model designed to project the interindustry effects of changes in the production of a specified industry (Minnesota IMPLAN Group, Inc. 1994). For the purposes of this assessment, IMPLAN was used to construct a region that included the four counties (Placer, Washoe, Douglas, and Eldorado) that encompass the Tahoe basin. Carson City was excluded from the region because there is virtually no business activity in the basin portion of Carson City. Although a large share of these sectors' sales are made to visitors, the sectors (except for hotels and lodging places) also depend heavily on sales to residents. These results therefore, should not be interpreted as describing the visitor-serving portion of the regional economy exclusively; these sectors serve varying combinations of visitors and residents.

As shown in Table 6-29, of the principal visitor-serving sectors, only automotive dealers and service stations have average annual earnings in in excess of $25,000 per job; average earnings in the miscellaneous retail, amusement and recreation services, and eating and drinking places sectors is

Table 6-28—Average daily per capita spending (in dollars) by summer and winter visitors to the North and South Lake Tahoe areas, 1997.

	North Lake Tahoe		South Lake Tahoe	
	Summer	**Winter**	**Summer**	**Winter**
Food and drinks	41	45	23	40
Lodging	40	44	38	24
Transportation	9	6	6	6
Entertainment	13	12	25	19
Gaming	18	20	56	34
Other	74	62	44	43
Total	**195**	**189**	**192**	**166**

Sources: RRC Associates 1992; Strategic Marketing Group 1998.

Table 6-29—Employment and income multipliers and related characteristics for tourism-related industrial sectors in the four-county region.

Sector	Average Earnings ($)	Labor Intensity[a]	Value Added[b]	Type I Multiplier[c]		Type III Multiplier[d]	
				Income	Employment	Income	Employment
Food stores	22,213	0.774	0.856	1.07	1.07	1.78	1.76
Auto dealers and service stations	32,172	0.649	0.761	1.13	1.18	1.66	1.93
Eating and drinking P1	14,583	0.401	0.504	1.23	1.11	2.64	1.82
Miscellaneous retail	10,420	0.563	0.732	1.19	1.08	2.71	1.78
Hotels and lodging P1	24,144	0.491	0.590	1.27	1.28	2.04	2.10
Amusement and recreation services	11,340	0.418	0.630	1.33	1.16	2.83	1.92

Source: Minnesota IMPLAN Group 1994.

Notes:
[a] Employee compensation as a fraction of total production.
[b] Sum of employee compensation, indirect business taxes, proprietary income, and other property income as a fraction of total production.
[c] Type I multiplier is the sum of the direct and indirect effects on employment or income divided by the direct effect.
[d] Type III multiplier is the total effect (i.e., sum of direct, indirect, and induced effects) on employment or income divided by the direct effect.

less than $15,000. In comparison, the average earnings per job in all sectors in the four-county region is $27,389 (US Department of Commerce 1998). Food stores and automotive dealers and service stations are the most labor intensive of the major tourist-serving sectors, which suggests that they have relatively large direct effects per dollar of sales. These sectors also have the largest relative value added, another indicator of comparatively large direct economic effects.

Table 6-29 also shows type I and III multipliers for the visitor-serving sectors. Type I multipliers are defined as the sum of the direct and indirect effect, divided by the direct effect; they indicate the relative importance of the indirect effect. Type III multipliers are defined as the sum of the direct, indirect, and induced effect, divided by the direct effect; they indicate the combined importance of indirect and induced effects. None of the sectors has a Type I multiplier (for either employment for income) that exceeds 1.33, which indicates that the tourist-serving sectors of the region generate relatively little income and employment through their purchases from other businesses in the region. However, four of the sectors have Type III income multipliers that exceed 2, which means that

employees who respend their earnings generate substantial amounts of income.

A major limitation of the results shown in Table 6-29 is that the basin makes up such a small portion (in terms of area, population, and economic activity) of the four-county region. The unique economic characteristics of the basin are likely to be masked by the economic dominance of the region's larger population centers, such as Reno and Roseville. The reliability of economic impact assessments for the basin is expected to be substantially improved, however, by the further development of the input-output models specifically designed for each community region in the basin. Once completed, the community-region models will be publicly available to assess the income and job impacts of a wide range of policy options (e.g., implementing the EIP) and to refine and expand a basin-wide socioeconomic impact model.

Fiscal Effects—Besides the employment and income effects of visitor spending, the presence of large numbers of visitors (who easily outnumber basin residents during peak tourism periods) creates a need for public services beyond the levels needed by residents. Public services potentially affected by visitors include park and recreation services, law enforcement, emergency medical services, search and rescue services, water and wastewater services, solid waste disposal, and fire suppression. Visitors' demands for public services have been taken into account in planning and developing the basin's existing infrastructure and programs.

If the fiscal impacts of visitation are assumed to include only the incremental operations and maintenance costs to meet visitors' needs, as opposed to also including a share of the capital costs of infrastructure development, the cost of providing public services to visitors can be relatively small. For example, on the one hand, a recent study of recreational demands on utility capacities estimated that the total rate of water consumption associated with summer recreation in the basin at approximately 4.0 million gallons per day (mgd) (3.6 million of which is attributable to golf course watering, which serves residents as well as visitors), compared to a total estimated rate of water supplied by local agencies of 10.3 mgd. Similarly, the average summer wastewater flow attributable to recreation in the basin was estimated at 0.75 mgd, compared to the estimated wastewater flow of 14.2 mgd. (RRC Associates and Vasey Engineering 1996). On the other hand, by affecting the peak demand for some public services, visitors can be an important impetus for capacity expansions. This is particularly true in such areas as ski resort villages, where visitors greatly outnumber residents during the peak season of use.

Consumer's Surplus—In addition to the economic effects of visitor spending, recreational visits to the basin result in consumer's surplus, representing the amount visitors would be willing to spend on their visits in excess of the amount they actually spend. Use value (i.e., the net economic value that accrues to users of a recreation resource) is only one component of society's total willingness to pay to protect valuable natural resources, such as Lake Tahoe. Economic research has shown that outstanding natural resources also have existence value (peoples' willingness to pay to know that the resource exists, even if they have no plans to visit it), option value (willingness to pay to know that they will have the option to use the resource in the future, if they choose to), and bequest value (willingness to pay to know that future generations will be able to enjoy the resource) (Sanders et al. 1990). Of these four types of net economic value, use value is the only one that qualifies as consumer's surplus because none of the others actually involve consumption of a good or service (for example, use of a recreation resource). Unlike the effects of recreation spending, consumer's surplus does not involve monetary transactions nor does it generate jobs or personal income. Nonetheless, as a reflection of the quality of

a recreation experience, consumer's surplus affects visitors' well-being and sometimes influences public investment and other political decisions. Also, as a reflection of the value people place on an experience or participation in an activity, the surplus of consumers accounts for a portion of each individual's participation level and, in this sense, explains a portion of the associated monetary transactions.

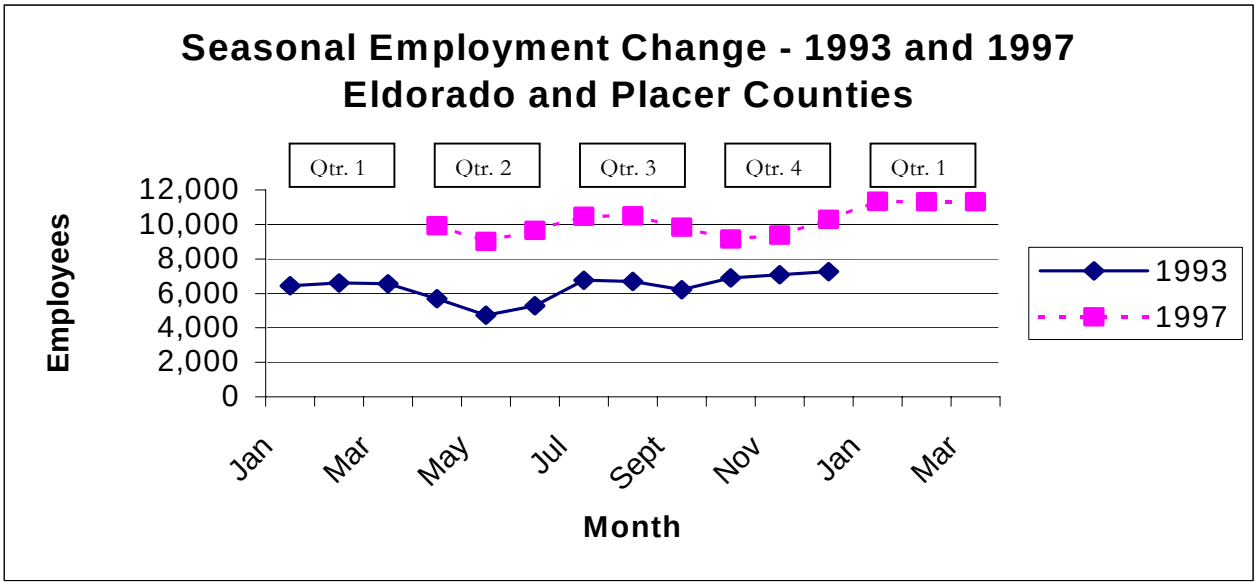
Consumer's surplus is usually measured by conducting visitor surveys, often through experiments where visitors are asked how much they would be willing to pay to continue to use a resource in its current condition, as opposed to using it in some alternative condition. This approach, the contingent valuation method (CVM), is one of two methods recommended by the US Water Resources Council for valuing outdoor recreation in federal benefit-cost studies. No CVM studies have been conducted or consumer's surplus estimates been made for Lake Tahoe or other resources in the basin. However, a CVM study of nearby Mono Lake found that each visitor to the lake would be willing to pay an average of $76 per year (in 1998 dollars) if the lake's water level were increased by seventeen feet from 6,375 feet above sea level to 6,392 feet, the elevation to which the California State Water Resources Control Board ultimately stipulated that the lake be raised (Jones & Stokes Associates, Inc. 1993).

Translator Models for Economic Impact Analysis—In addition to affecting visitors' willingness to pay, changes in the quality of recreation resources can affect peoples' decisions of whether to visit and their frequency of visiting. For example, if the clarity of Lake Tahoe continues to decline to a level typical of other Sierra Nevada lakes, this change in lake clarity could adversely affect the number of visitor days spent in the basin. Reduced visitation would result in lower tourist-based personal income and employment. Assuming that reductions in lake clarity beyond a specified threshold would affect visitation, and, assuming that the relationship between lake clarity and visitation is known, lake clarity could be specified as a "translator" for use in conjunction with the visitor spending patterns (Table 6-28). Community-region input-output models (described above) could be used to assess the local economic effects of alternative future levels of lake clarity. Similarly, other translators could be developed to project changes in visitation in relation to changes in recreation facility capacity, highway congestion, or other basin conditions likely to affect visitation.

The Effect of Seasonal Variation in Tourism and Recreation on the Socioeconomic Dynamics of the Basin

As with most recreation economies, the Tahoe basin experiences pronounced cycles of economic activity. From the seasonal recreation visitation patterns, which drive the local economy, to larger business cycles, which affect the regional economy at large, Tahoe's financial system has been characterized in the past as one of booms and busts. Seasonality in Tahoe generally describes the bimodal seasonal influx of visitors, and commensurate increase in employment, that occurs with the onset of the winter and summer tourism seasons. However, while many ski communities outside the basin are striving to establish summer markets to mitigate the seasonal visitation fluctuations associated with the ski industry, Tahoe has firmly defined a market niche for both winter and summer visitors. Using California employment data as a proxy for visitation, total employment during the third-quarter summer season surpassed first-quarter winter season employment in both 1993 and 1997. The data suggest that summer visitation exceeds winter visitation (Figure 6-8).

While these cyclic trends in visitation and employment may have existed in the past, net seasonal employment fluctuations decreased from 1993 to 1997. For example, 1993 third-quarter employment was 25 percent higher than second-quarter employment. In 1997, the difference between the spring employment and summer employment displayed only an eight percent increase. Annual average employment increased from 6,353 in 1993 to 10,187 in the first three quarters of 1997 and the first quarter of 1998. This increase represents a 60 percent rise in employment between 1993 and 1997 (EDD 1999).



Sources: California Employment Development Department; Authors' calculations

Figure 6-8—California basin-wide employment, 1993 and 1997.

With changes in employment come changes in demographics. Census data, taken every ten years, does not display the temporal resolution necessary to convey this type of information. Potential sources of information available with the necessary temporal resolution might include rental listings in the local newspapers. Many Tahoe locals have observed that during the fall, the availability of rental homes increases dramatically. This might suggest that the cyclic flux of employees into and out of the basin could be estimated through short-term rental housing figures.

As basin-wide visitation increases, traffic congestion, scenic quality, air quality, and most quality of recreation measures show a notable decrease (NLTRA 1995). One might hypothesize that seasonal changes in population densities and the resulting patterns of short-term residence affect community well-being. However, until indicators of community well-being are established through a broader process it will be difficult to evaluate the impacts of seasonal economic fluctuations. In the absence of a richer suite of community indicators, TRPA's thresholds of environmental carrying capacity remain the best available indicators by which a rough correlation to community well-being might be established. Certain thresholds, such as scenic quality, noise, air quality (connected to vehicle miles traveled, or VMT), and recreation, play a role in socioeconomic dynamics and are directly affected by the seasonal nature of the Tahoe economy. These TRPA thresholds however, are not sufficiently specific to be used as quality of life indicators to facilitate a broad evaluation of community well-being. In addition, the five-year evaluation cycle of the thresholds is not frequent enough to address socioeconomic impacts of seasonal variability.

Issue 3: Understanding How Land Use Trends Affect the Basin's Environment and Socioeconomic Dynamics

The total land area of the basin is 207,561 acres, and, although most land use discussions often do not include bodies of water, clearly any discussion of land use in the basin must include "jurisdiction" of water bodies. While state and federal authorities govern use of navigable waters, the total area that must be considered part of the basin is 328,671 acres, including the lake itself (Table 6-30). The basin has seen dramatic changes in the distribution of ownerships over the past several decades. During the 1930s, only about 15 percent of the total land area was in public ownership, and most of that was

in bequests to the California State Parks system. By the 1950s, the public ownership portion had risen to only about 20 percent. Since that time, acquisition strategies for environmental protection have altered patterns of ownership substantially. As of 1999, 87 percent of the land area in the basin is in public total ownership (Table 6-31). While only 13 percent of the land area in the basin is in private ownership, 56 percent of the shoreline around the lake is in private hands (TRPA 1999a).

Table 6-30—Land areas by county in the Lake Tahoe basin.

County	Land Area	Lake Area	Total
Alpine	4,182	0	4,182
Eldorado	105,057	35,240	140,297
Placer	46,383	50,435	96,818
Washoe	20,092	13,499	33,591
Carson City	6,328	7,708	14,036
Douglas	25,519	14,228	39,747
Total	**207,561**	**121,110**	**328,671**

Source: TRPA 1999

Table 6-31—Lake Tahoe basin ownerships.

Federal	161,898	78%
State	16,605	8%
Local	2,076	1%
Private	26,983	13%
Total	**207,562**	**100%**

Source: TRPA 1999

Land use, as used in this section, includes three levels of human impacts on the land and in the water:

1. High-intensity uses that visibly and permanently modify the biophysical attributes of the land or water, such as changes in soil profiles and vegetation structure from housing and roads, dams and diversions, piers and marinas;
2. Land uses that are less visible and transient, such as mountain biking, hiking, fishing, and motor boating, that may have less visible effects but that are cumulative and may be as significant as permanent modifications; and
3. Land uses that have the least impact on the biophysical attributes, e.g., viewing, educational, informational and uses that may change future behavior toward elements of the ecosystem (and, as a result, will change ecosystem structure and function) at all three levels of intensity.

The boundaries among the three levels are not discrete and are used here mainly for organization and presentation purposes.

This section focuses on the impacts the three classes of land use have on the environment. To clarify the use of terminology in this section, "ecosystem" is meant to include social, cultural, economic, and institutional elements. The term "biophysical system" is used to denote the nonhuman components of the ecosystem. Occasionally, "the environment" is used synonymously with biophysical system. The approach taken in this issue section reflects observations by the assessment team, and some of these observations are not referenced to published literature. The statements in this section are based on a synthesis of disparate sources, such as newspaper articles, speeches, informal conversations, interviews, and publicly available flyers and meeting materials.

The Effect of Permanent Land Use Changes on the Environment

This level of land use change is limited to the effects of existing built and modified surfaces, construction on previously unbuilt land, redevelopment of built land, and acquisition of parcels to be retained in their natural state.

Environmental Impacts of Existing Development—Since the end of the intensive Comstock Era logging, the basin's biophysical system has had to adjust to over 100 years of increasing numbers of buildings, roads, and ski areas. There is no geography of settlement over time that can be used to isolate the effects of building on the biophysical system. This could be accomplished by constructing a series of maps that describe the geography of built and modified surfaces (modified surfaces refer primarily to permanent ski areas) as they have accumulated over time. This historical geography can be quantified so that it would become an independent variable in the equation linking building to changes in the biophysical system,

especially water flow, erosion, sediment transport, and lake clarity. A historical geography of building-induced sediment and nutrient production can inform interpretations of lake sediment cores and historical nutrient fluxes.

The accumulation of permanent land use changes is referred to as the process of urbanization and contains two general patterns. The first pattern manifests a high aggregation of impervious surfaces, as is found today around Stateline; the second pattern is more dispersed, with important quantities of vegetation growing in the interstices of the impervious surfaces. The basin has both patterns with gradations in between, and it is useful to include in any future analysis of land use impacts a picture of these changing spatial gradations. These can be displayed, simply, as ratios of pervious/impervious area. In areas of aggregated impervious surfaces, there are significant and well-known increases in runoff velocity, peak flows, downstream erosion potential, and deterioration of water quality from both eroded material and exotic chemicals and particulates from roofs, roads, and parking lots. As impervious areas are reduced in size or dispersed, these impacts diminish. The spatial distribution of pervious and impervious areas, with amounts and kinds of interstitial vegetation, governs precipitation interception, water flow and quality, some forms of air pollutant flux, fire behavior, and the distribution, health and recreational availability of wildlife and biota.

Because built surfaces in the basin were placed within a vigorous presettlement forest, the role of vegetation—especially trees—is significant in modifying the negative environmental effects of settlement and urbanization. The trees, shrubs, herbs, and grasses in the interstices of impervious surfaces mature, die, and are modified by people; their effects are not static over time, and their environmental role has not been quantified (McDonnell and Pickett 1991; Rowntree 1998). This matrix of vegetation is a functional link between the built environment and the biophysical system. This functional link operates as an interactive, two-way relationship; for example, tree crowns over parking lots remove pollutants from the air, but these pollutants also affect tree health.

The management of interstitial, or "urban," vegetation appears to be governed by an effective set of guidelines and regulations at TRPA (TRPA 1998a). These are designed to ensure that careful consideration is given to removing trees from private land and that the resulting stand of trees on any parcel optimizes benefits and minimizes costs. The Tahoe Regreen Project is a cooperative effort of 32 government and private organizations, devoted to reducing fuel loads and restructuring urban interstitial vegetation in a fire-safe configuration. The guidelines in the basin for managing urban vegetation appear to be effective for mitigating a small portion of the negative effects of existing development.

In summary, it has been common knowledge for some time that the effects of settlement and urbanization in the basin have increased the flow of nutrients, sediments, and pollutants to the receiving waters (Goldman 1994; Reuter et al., Chapter 4, this document). Thus, the period of urbanization has had a significant, permanent, and continuing impact on the rivers and lake in spite of erosion control and restoration efforts.

Environmental Impacts of Construction—Each year, TRPA allocates 300 residential development parcels among the counties in the basin, and this total will remain constant until all parcels are allocated. Of the 300 parcels, approximately 250 to 280 a year are converted to building permits (Baetge 1999). Most of the remaining parcels are in Eldorado County (Pepi 1999). The number of parcels left to develop in the basin depends on where the line is drawn between buildable and nonbuildable parcels. This line is a numerical score, aggregated from ratings of several environmental factors, called the Individual Parcel Evaluation System (IPES). From 1985 to 1987, TRPA worked with a large number of interest groups and government agencies to develop a consensus resolution of the issues affecting final approval of the 1987 Regional Plan. A TRPA ordinance was developed from this process, which replaced the older Bailey land capability system, using a more objective classification system. The IPES system and procedures for scoring and appeal are described in Chapter 37 of the TRPA Code of

Ordinances. A timeline of early acquisitions, based on the Bailey and IPES systems, shows the influence of those systems on development (see Figure 6-10 and Twiss 1997).

The IPES assigns a numerical score to vacant parcels and ranks the parcels within each local jurisdiction according to their relative suitability for development. Any owner of a parcel with a score above the minimum score established by the TRPA Governing Board may obtain a development allocation from the jurisdiction in which it is located, after which TRPA may issue a building permit.

Over a period of several years, the IPES line is expected to be lowered in order to allow more parcels to be developed. This process will depend on a suite of environmental protection goals being met and on such requirements as expanded water quality monitoring programs and purchase of a number of low-scoring parcels through one of the public acquisition programs.

The IPES score does not apply to residential parcels that are already developed. Scores are established by teams that include at least a soils scientist, a hydrologist, and a planner/engineer and are based on an actual on-site analysis, which includes a small pit dug for analyzing the soil profile. Eight criteria are used to develop the IPES score, as follows:

1. Relative erosion hazard, based on the soil sample, slope data, and precipitation data (450 points maximum);
2. Runoff potential, referring to the potential for overland runoff, based on vegetative cover and the ease with which soil absorbs precipitation (200 points maximum);
3. Access, based on the amount of excavation and vegetation removal necessary to construct driveways and parking (170 points maximum);
4. Stream environment zones (SEZ), based on the extent to which utilities, excavation, and grading will encroach on SEZs (70 points maximum);
5. Condition of watershed, which considers the overall status of the watershed in which the parcel is located (70 points maximum);
6. Ability to revegetate, evaluated on the inherent ability of the site to be revegetated, considering soil and site properties (50 points maximum);
7. Need for water quality improvements in the vicinity, a broad evaluation factor that examines the lot's relationship to surrounding areas with stable cut and fill slopes, adequate and stable drainage, and paved roads (50 points maximum); and
8. Distance from lake, which receives a higher score depending on distance from the shore of Lake Tahoe (50 points maximum).

Appeal procedures are established through which the appellant's parcel is reviewed by an alternate IPES team. After the second score is issued, property owners may appeal their score directly to the TRPA Governing Board.

As of 1999, approximately 4,000 parcels remained to be allocated for development or mitigation purposes in the basin, some portion of which are not buildable because they lie in sensitive areas. Under current IPES ratings, there will be no parcels left for allocation after approximately 2010 (Baetge 1999).

All construction requires the application of designated best management practices for reducing sediment and nutrient flux from the site. While these techniques may be effective for reducing sediment flux, many technical experts agree that they cannot prevent nutrients from leaving the site with lateral movement of ground water (Pepi 1999). Even when sediments are trapped on-site, for example, in a dry well, the water from many sites is thought to flow below the surface and emerge downslope to produce erosion and transport nutrients. Lateral subsurface flow is also a problem with established buildings that are using on-site settling basins or dry wells. The runoff from roofs, walks, and driveways may appear to have been trapped on-site, but in fact the water infiltrates and is concentrated in the lateral ground water stream, emerging at the surface and inducing erosion downslope. Additional environmental impacts of construction come from having utility connections that must cross SEZs.

The current trend in construction has three key factors that contribute to greater or lesser environmental impacts over time (Pepi 1999). First, it is assumed that negative environmental impacts accumulate with each increment of construction. Second, the *per unit* negative impact is increasing (more on the Nevada side of the basin) because of the increased need for crossings through stream environment zones and the likelihood of increased building on more sensitive lots. Third, the process negotiating the line between buildable and non-buildable parcels lacks sufficiently detailed data on a parcel-wide and basin-wide scale. TRPA has identified a need to analyze all remaining parcels in terms of the environmental costs and impacts of development (Baetge 1999).

Environmental Effects of Commercial Redevelopment—Commercial redevelopment in the basin seeks to lessen the environmental impacts of urbanization by enhancing environmental infrastructure (e.g., water treatment of selected commercial nodes), by consolidating impervious surfaces to make pervious surfaces available, and by improving the visual quality of the urbanized portions of the basin to enhance the basin experience for visitors and residents. As examples, the Ski Run Boulevard redevelopment created just less than 10 acres of permeable surface (i.e., surfaces through which runoff and precipitation can infiltrate into the soil), and the planned Heavenly Valley redevelopment at Stateline will create several acres of permeable surface while building a more pedestrian-friendly and aesthetic setting. While commercial redevelopment may the reduce impervious area in small amounts, continued residential construction under current permitting schemes is likely to offset these reductions by increasing dispersed impervious surfaces.

Environmental Effects of Land Acquisition: Selected Considerations—Many portions of the basin's urbanized area display a unique ownership pattern rarely seen outside of the basin. Public land acquisition programs, initiated in California by voters in 1982 through the passage of the Lake Tahoe Acquisition Bond Act, by Nevada voters in 1986 through the passage of a $31 million bond issue, and through federal legislation in the 1980 Santini-Burton Act (PL 96-586), have created a mosaic of publicly owned lots within privately developed subdivisions. Both Santini-Burton and the Nevada bond act provide funding to purchase environmentally sensitive lands in the basin. On the California side, the Lake Tahoe Acquisition Bond Act, administered through the California Tahoe Conservancy (CTC), provides funds that may be used to acquire property for protecting the region's natural environment, for providing public recreation areas, for providing public lake access, for preserving wildlife and habitat areas, and for making miscellaneous purchases needed to ensure access to or management of other public lands.

Table 6-32 shows total investments, acres, and numbers of parcels acquired through the three programs from 1982 to 1999. Of the nearly $187 million dollars spent on acquisition during this period, Santini-Burton funds accounted for almost half (47 percent) and the California bond act contributed more than a third (38.2 percent) of the total investment (Table 6-33). Twice as much Santini-Burton money was spent acquiring Nevada parcels as was spent on California parcels, reflecting

Table 6-32—Public lands acquired 1982 to 1999.

Year	Acres	Parcels	Direct Costs
1982	12	55	12,363
1983	1,847	219	8,229,000
1984	679	280	7,309,100
1985	756	309	8,304,163
1986	335	1093	14,013,910
1987	953	1272	21,663,993
1988	454	1101	30,370,050
1989	359	969	25,993,550
1990	202	827	19,122,814
1991	113	417	15,386,970
1992	110	286	13,836,419
1993	36	163	4,210,575
1994	64	200	8,053,400
1995	16	124	3,747,600
1996	6	104	1,839,365
1997	28	80	2,306,275
1998	8	60	1,116,403
1999	6	2	1,325,000
Total	**5,986**	**7,561**	**186,840,950**

Sources: California Tahoe Conservancy; Nevada State Lands Division; USFS Lake Tahoe Basin Management Unit

Table 6-33—Public acquisition costs 1982 to 1999.

	Santini-Burton (California)	Santini-Burton (Nevada)	Santini-Burton via CTC	California Bond Act (CTC)	Nevada Tahoe Bond Act	Total
1982	$363	$12,000				$12,363
1983	$6,029,500	$2,199,500				$8,229,000
1984	$4,519,100	$2,790,000				$7,309,100
1985	$4,164,200	$4,139,963				$8,304,163
1986	$3,625,525	$1,033,000		$9,355,385		$14,013,910
1987	$334,500	$8,395,680		$12,933,813		$21,663,993
1988	$95,700	$14,586,460		$15,687,890		$30,370,050
1989	$74,925	$6,386,800	$2,514,800	$9,594,025	$7,423,000	$25,993,550
1990	$56,300	$3,805,800	$1,813,200	$4,969,514	$8,478,000	$19,122,814
1991	$58,000	$5,380,250	$720,500	$3,188,720	$6,039,500	$15,386,970
1992	$836,898	$5,635,300	$927,250	$4,638,411	$1,798,560	$13,836,419
1993	$264,000	$611,250	$435,200	$2,330,625	$569,500	$4,210,575
1994	$893,000	$1,026,000	$209,500	$4,758,900	$1,166,000	$8,053,400
1995	$62,800	$2,375,900	$118,500	$1,086,400	$104,000	$3,747,600
1996	$20,400	$0	$828,400	$945,565	$45,000	$1,839,365
1997	$0	$868,500	$180,100	$1,257,675	$0	$2,306,275
1998				$746,403	$370,000	$1,116,403
1999					$1,325,000	$1,325,000
	$21,035,211	$59,246,403	$7,747,450	$71,493,326	$27,318,560	$186,840,950

Sources: California Tahoe Conservancy; Nevada State Lands Division; USFS Lake Tahoe Basin Management Unit

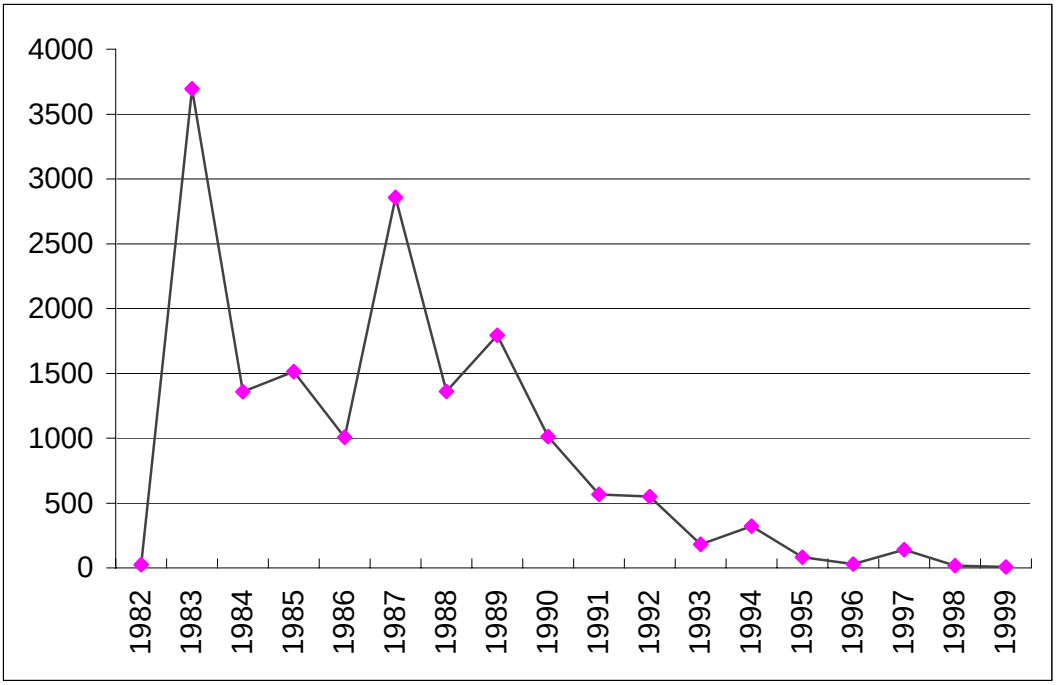
much higher purchase prices in California. However, so far, the total acquisition investment of $187 million has been divided about equally between the two states.

Most of the 16,513 acres acquired were purchased during the first decade of the various programs, with sharp declines in funding and purchases beginning in 1990 (Figure 6-9). The vast majority of total acquisition program acreage has been purchased on the California side of the basin (California, 12,232 acres; Nevada, 4,281 acres) (Table 6-33).

The three programs' funds have acquired a total of 7,561 parcels, many of which are large and are scattered throughout the urbanized areas of the Lake Tahoe basin. The large parcels are most often located on the periphery of the urbanized area and expand the ecological and socioeconomic benefits of the existing large public holdings. This section of the report notes some of the potential environmental effects of the array of small lots distributed throughout the residential land uses of the basin's urbanized area. The hydrologic and water quality benefits are obvious, though very difficult to quantify. Preserved lots mitigate peak flows, high runoff velocities, and erosion from the surrounding developed areas. Precisely how the array of preserved lots affects fire behavior is not well understood at this time. When the lots contain an understory of light, easily ignited fuels, they are sources of ignition, particularly when they are play areas for children who can start fires or when they contain refuse and green waste that adds to ignition potential.

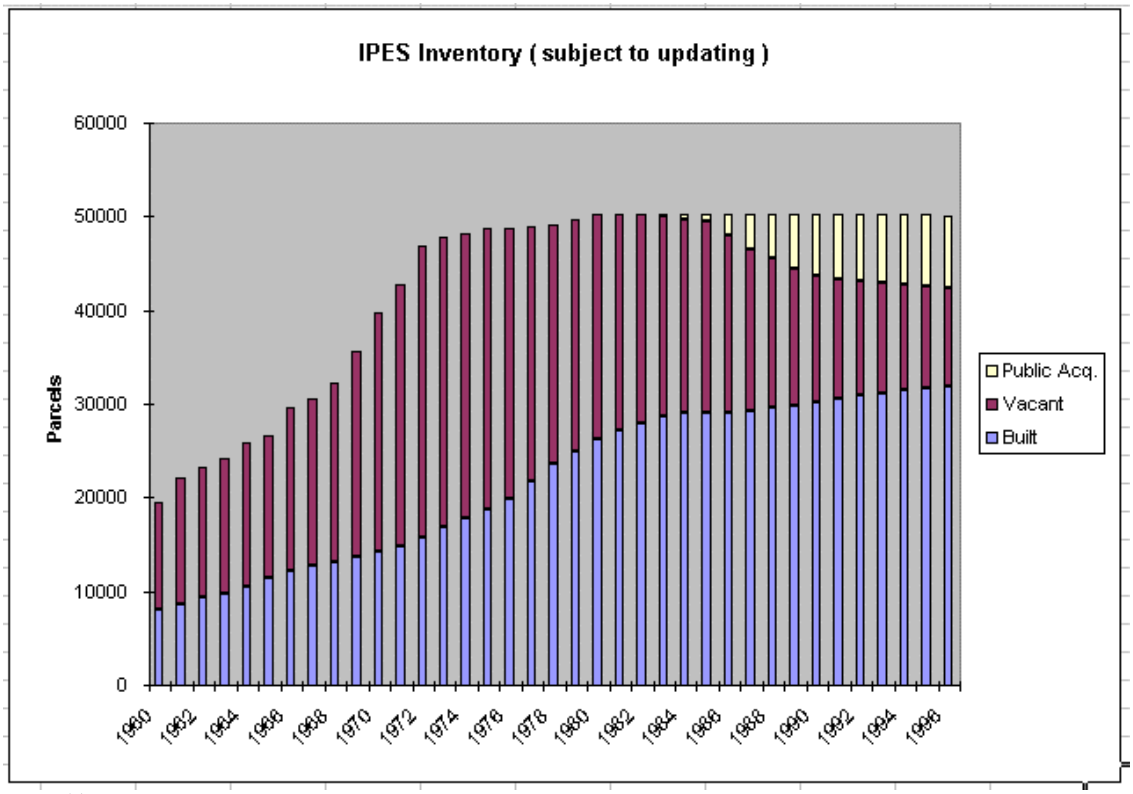
Interviews with agency managers showed that the CTC and USFS take different approaches to managing their lots and that both agencies are seeking the means for knowing how individual lots and the total combined array of lots can be managed to optimize environmental and socioeconomic benefits. The CTC maintains a comprehensive spatialdata base of its lots, and USFS is advancing its data acquisition and management programs to make its lot data spatially explicit for use in GIS analyses.

Because of the large investment in acquiring and managing the lots and because of the critical role they may play in mitigating the negative environmental effects of the urbanized portion of



Sources: USFS Lake Tahoe Basin Management Unit; Nevada State Lands Division; California Tahoe Conservancy

Figure 6-9—Historical public parcel acquisition, 1982 to 1999.



Source: Twiss 1997

Figure 6-10—Integrated parcel evaluation system timeline.

the basin ecosystem, a better understanding of their ecological role would support more effective management. Two key areas of research, according to program managers, concern the influence of publicly owned lots on fire behavior in residential areas and the role of publicly owned lots in supporting biodiversity. Groups of lots can be viewed as "archipelagos" made up of a set of biotic "islands." When an archipelago of lots provides a high degree of connectivity between the inner urban zones and the extensive unfragmented forest adjacent to the edge of the urbanized area, movement of organisms back and forth may be facilitated that would not occur if the distances between the lots were greater or if the number of lots were fewer. One current study finds that the larger the lot and the farther it is from the undisturbed forest, the higher the plant diversity and the lower the fuel loading (McBride and Boniello 1999). The increase in diversity with distance from the undisturbed forest into the urbanized area is purportedly correlated to the addition of exotic species from disturbed sites and gardens in the urban area.

Another preliminary study under way is seeking to understand the role of undeveloped lots in filtering pollutants that would otherwise transport through streams to the lake (Johnson et al. 1999). Many of the lots have dense upper tree canopies and are islands of very high leaf surface areas that remove particulates from the atmosphere. However, it is unknown what the subsequent disposition of these quantities of particulates might be. Follow-up studies would need to track needle washoff during precipitation and snow melts.

Land Acquisition and Increased Property Values—The following section suggests an experimental method to test the hypothesis that public acquisition of parcels enhances the property values of surrounding residences. Real estate professionals have generally acknowledged that publicly owned lots affect the desirability of certain neighborhoods and individual parcels and in some cases can influence property values by as much at $25,000 to $35,000 (Hedley 1999). The exercise below is a preliminary test of this hypothesis using a method of spatial analysis of housing locations and values on the California side of the basin. A secondary purpose of the exercise is to determine some of the capabilities of the lot data placed within a geographic information system (GIS). Available data layers from several agencies include parcel boundaries, roads, streams, watersheds, and several other types of data. Public ownership information was obtained directly from each of the land-owning agencies. Assessed property values and other information were assembled from the Eldorado and Placer county assessors' offices, as reported monthly (TRW 1998). Data relating to ownership and assessed value were linked to the digital parcel maps and were analyzed in the CTC's GIS.

Displayed below is a timeline of subdivided lot availability and public land acquisitions. This trend may be compared to the neighborhood assessed values to give a longer term history of the impacts of public land acquisition on land values in the basin.

While increasing socioeconomic well-being is not an objective of the public acquisition programs, it is a general belief that the more than 7,700 publicly held lots on the California side of the Tahoe basin enhance the lives of people who live near them (Willmett 1999). Enhancements vary from improved access to larger forested tracts of USFS property, to greater assurance that existing views will not be obscured by future development, and to more available open space and wildlife viewing. This preliminary study tests the hypothesis that the most tangible socioeconomic indicator of these benefits would be variations in property value. However, accurate regional measures of property values are expensive to generate and therefore are rare. Conversely, assessed property values are readily available from the county assessor's office.

Assessed property values often are not used as indicators of property worth for two reasons. First, an individual parcel is reassessed only upon transfer of title or through major renovation. Consequently, if a parcel does not change hands, frequently assessed values can lag behind market values. Second, in 1978 California voters approved Proposition 13, a constitutional amendment that effectively lowered property taxes and restricted their rate of increase. The effect of these two factors

causes the assessed value of comparable lots to vary widely.

The format for this analysis is a neighborhood-based approach comparing average assessed property values for 19 neighborhoods. Neighborhoods were selected according to the following criteria:

- Each neighborhood was subdivided at roughly the same historical moment (i.e., the time when it was put on a map and certified by the county);
- Each neighborhood contained at least 350 parcels;
- Most of the parcels are less than an acre; and
- Each neighborhood must have active public land acquisition programs acquiring property in the subdivision (i.e., Santini-Burton, California Tahoe Conservancy, and/or Nevada State Lands).

The size of the neighborhoods was designed to overcome some of the limitations in assessed property values discussed above. The smallest of the neighborhoods had 350 lots, the largest 3,500, with an average of 1,168. Average neighborhood values were used comparatively to analyze the effect of open space. Therefore, differences between assessed value and true market value, while potentially substantial, generally will be unimportant at the neighborhood scale; that is, while average homes in Cedar Flat and Kings Beach may not sell for $153,065 and $103,007, respectively, as a measure of the value of homes in Cedar Flat versus Kings Beach, the ratio $153,065/$103,007 may be appropriate. In other words, comparing the average assessed values of individual neighborhoods is appropriate. Other potential sources of error include geo-referencing in the GIS parcel maps, property value variation resulting from the age and quality of the development, and other significant factors affecting property value, such as mountain or lake views.

First, the California side of the basin was divided into 19 separate neighborhoods using an "expert knowledge" technique (Figure 6-11). Each neighborhood represents a tract of housing units, which generally share such characteristics as age, quality of construction, and desirability of vicinity. Second, the total count of public lots and private lots for each neighborhood was computed. Included below are smaller scale maps of the neighborhoods used in this analysis, separated by Eldorado and Placer counties (figures 6-12 and 6-13, respectively). Notably excluded is the Tahoe Keys neighborhood in South Lake Tahoe and the Dollar Point subdivision in North Lake Tahoe. Neither the CTC nor the USFS acquisition programs are currently active within Tahoe Keys or Dollar Point because of strictly enforced property assessments within the boundaries of each subdivision; consequently, they were not included in this analysis of the impacts of the public acquisition programs. Third, a metric was computed for each neighborhood, the ratio of total public acreage in the neighborhood divided by the total acreage in the neighborhood. Finally, these three computations—average assessed value for vacant lots, average assessed value for developed lots, and the ratio of private property to public property within each neighborhood—were compared (Table 6-34).

In order to verify the usefulness of the data presented, the model must establish the strength of the correlation between two continuous data sets. A Pearson correlation was computed only for the neighborhoods listed on Table 6-35 of this analysis. Correlation coefficients were calculated to detect the sensitivity to outlying data points. For example, had Tahoe Keys and Dollar Point been included in the analysis, the results would have differed significantly because both are high density developments without significant public holdings. Analysis suggests that there is a statistical relationship among average neighborhood, assessed developed property value, and neighborhood density of public ownership. As shown in Table 6-36, there is a less than five percent chance that the observed correlation is the result of random variations. The **P** value describing the relationship between assessed vacant property value and the density of public ownership indicates a 20 percent chance that the observed correlation is the result of random variation. Consequently, while these data suggest that as the density of public

Table 6-34—GIS analysis of land values and acquisitions.

Neighborhood	Ratio of Public Acreage to Total Acreage	Average Value Developed	Average Value Vacant
Al Tahoe	8.73%	$107,182	$25,303
Bijou	9.13%	$104,895	$17,441
Gardner Mountain	8.15%	$93,776	$18,370
Meyers	22.67%	$98,985	$17,277
Montgomery Estates	21.23%	$166,430	$26,742
N. Upper Truckee	41.52%	$123,077	$19,389
Rubicon	26.32%	$199,413	$69,516
Sierra Tract	9.08%	$79,161	$15,548
South State Line	8.38%	$89,070	$17,433
South "Y"	8.48%	$81,306	$15,294
Tahoe Island	6.30%	$91,172	$16,055
Tahoe Paradise	32.77%	$116,729	$19,350
Tahoma	7.09%	$75,991	$10,871
Agate Bay	6.67%	$147,056	$29,860
Cedar Flat	5.28%	$153,065	$34,973
King's Beach	12.69%	$103,007	$19,307
Kingswood West	32.24%	$198,980	$34,527
McKinney, Chambers and Tahoma Vista	21.74%	$142,417	$29,526
Talmont	23.77%	$185,428	$38,404

Sources: TRPA GIS Database; California Tahoe Conservancy GIS Database

Table 6-35—Pearson correlation coefficients.

	Ratio of Public Acreage to Total Acreage
Average Value Developed	0.52
Average Value Vacant	0.32

Source: Authors' calculations

Table 6-36—P values for determining chance of error.

	Pearson Correlation Coefficient	P Value	Chance of Type I Error
Developed property versus ratio of public ownership	0.52	2.498	< 5%
Vacant property versus ratio of public ownership	0.32	1.393	~20%

Sources: Authors' calculations

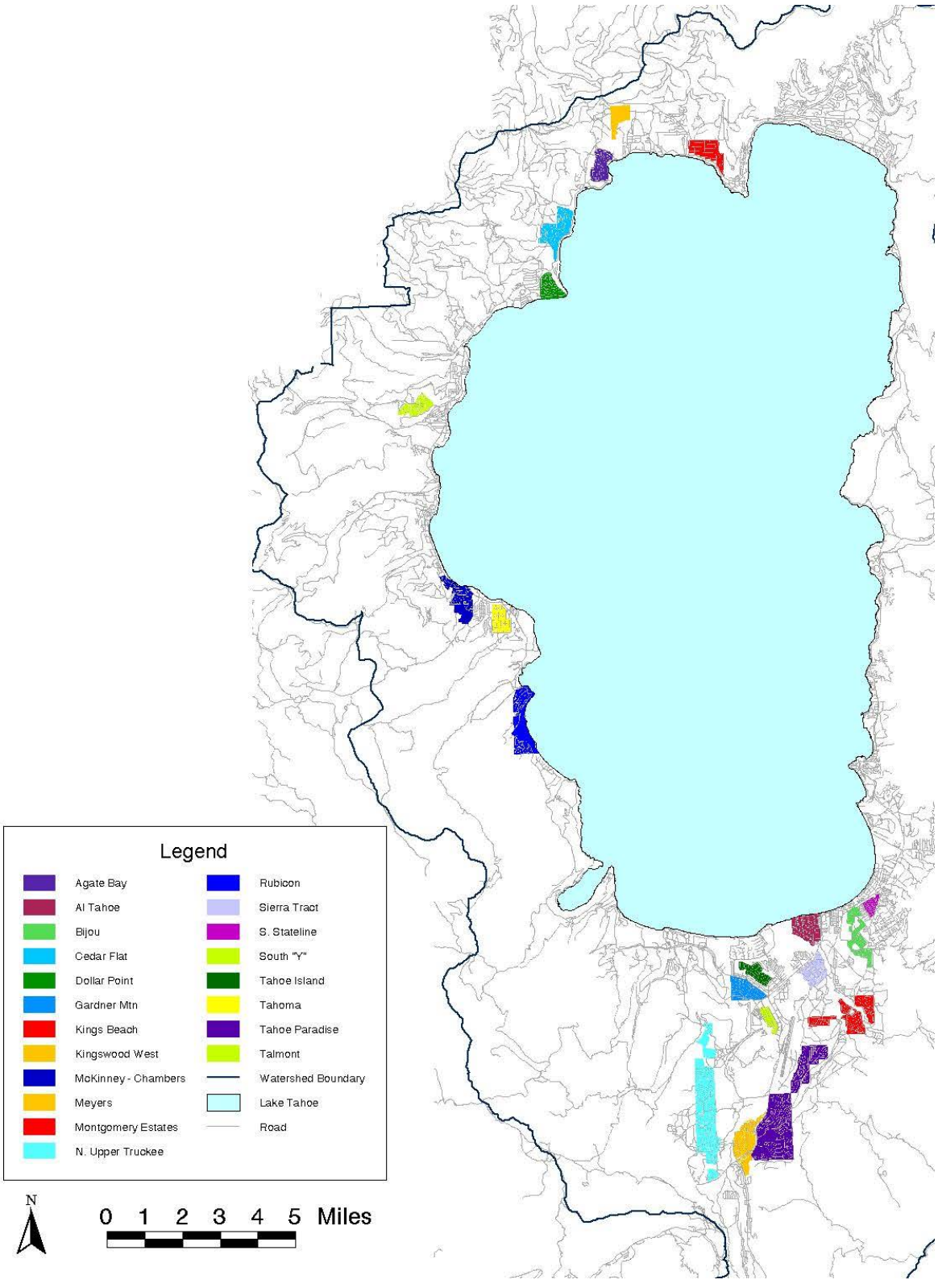


Figure 6-11—Neighborhood locations, Placer and El Dorado counties.

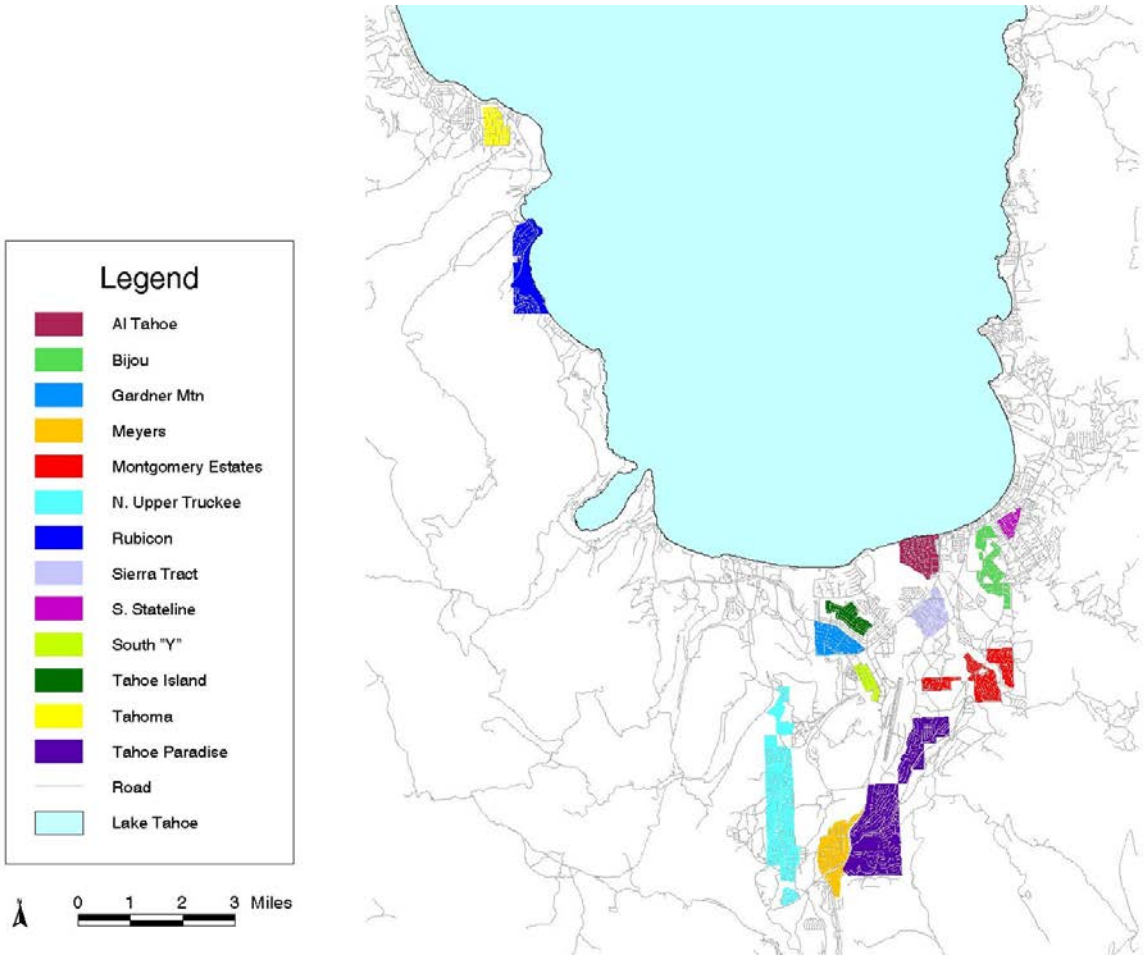


Figure 6-12—Neighborhood locations, El Dorado County.

property increases in a neighborhood, property values might be expected to rise, this exercise does not conclusively prove this. One reason is that the frequency of reassessment is higher for developed lots than public lots. Consequently, assessed values more closely reflect the developed properties' market value.

A more exact model would be required before the full economic impacts of the basin's parcel acquisition programs can be accurately quantified. Factors that would need to be evaluated in such a model include temporal variations in property prices that are not accurately reflected in the county assessor's data, proximity to other attractive or unattractive features (such as the lake, roads, parks, views, and schools), connectivity to lake, forest, or other amenities, an evaluation of how the form of all public ownership within an area affects the amenities available to property owners in that area, and TRPA-identified development potential.

This section on effects of permanent land use changes does not include an evaluation of the environmental effects of the many erosion control, habitat restoration, public access, and facility improvement programs, all of which have many benefits. Nor does this section attempt to describe socioeconomic effects of land use change beyond the preliminary analysis of acquisition parcels and property values. The environmental effects considered were either those reasonably well understood and examined in other chapters of this assessment—such as the hydrologic effects

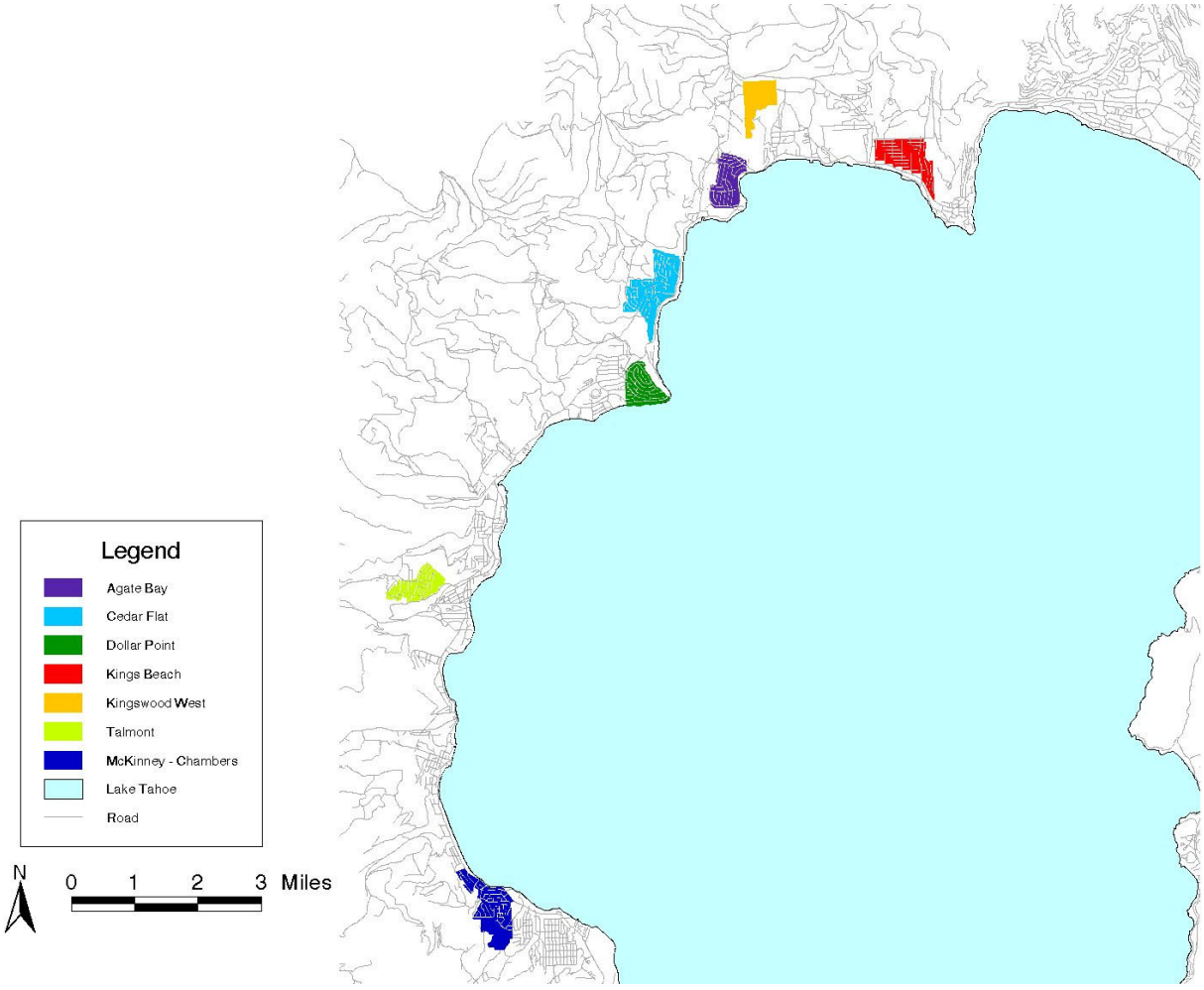


Figure 6-13—Neighborhood locations, Placer County.

of urbanization—or examples of those effects that require further in-depth study, such as the biotic effects of public lot locations and conditions.

It is clear from this section and from discussions elsewhere in the watershed assessment that residential and commercial development have increased the flow of nutrients and sediments to the lake above what would otherwise be a "natural" background level. However, there are insufficient data about the combined and cumulative effects of many land uses to give a clear answer to the often-asked question, "How much more and what kinds of land use change should be allowed if we are to halt degradation of lake clarity and preserve the integrity of the biophysical system?" While the answer to this question has key economic and social consequences, evidence suggests that much more information and research is required before a reliable quantification of impacts can fully inform policy- and decision-making.

How Transient Land and Water Use Affect the Environment

Transient use, in this section, focuses on selected environmental effects of tourism and recreation that have not been highlighted in other sections of this report.

Land-based Use—Land-based use includes a spectrum of activities, from camping in the backcountry to driving around the lake. This section

is limited to several uses that seem to require special attention. In most parts of the West, mountain biking is increasing rapidly (Chavez 1999). The basin is a site where rates of increase, while inadequately measured (Tahoe Coalition of Recreation Providers 1997, 1999), appear to be among the highest in the country. Mountain biking can be divided into on-trail and off-trail use for purposes of discerning environmental impacts. On-trail use, where trails are paved or stabilized, tends to result in minimal impact. On-trail use of unpaved trails on slopes contributes importantly to erosion and sediment/nutrient transport. Off-trail use within 50 meters of a stream, where sediment and nutrients can be easily transported into the stream network, is an issue that has not been adequately assessed (Miller 1999). As off-trail mountain biking increases in popularity, near-stream erosion will increase, assuming current trends in education and mitigation programs.

Off-highway vehicle (OHV) use in the basin is highly regulated because of the need to minimize soil and vegetation disturbance. However, when vehicles use unpaved trails or roads, sediment and nutrient movement either by water or air is highly likely (Miller 1999). Airborne dust is under consideration as a source of sediments and nutrients (especially phosphorous) moving to the lake. OHV use in the basin is a candidate for further study in terms of its cumulative environmental impact.

The environmental impacts of backcountry hiking and camping were evaluated in this assessment through interviews with USFS recreation staff. As population growth continues within the 1.5-hour radius from Desolation Valley, significant increases in day-use demand and use during the shoulder seasons can be anticipated. Because Desolation Valley is one of the most intensely used wilderness areas in the US, this trend of increasing day and shoulder season demand suggests a need for monitoring recreation trends and environmental impacts more closely.

Driving around the lake is a popular form of recreation in the basin. As population growth on the nearby west and east Sierran slopes continues, this form of recreation is expected to increase environmental and social impacts. Increases in day use and shoulder season traffic will add to existing congestion. Gasoline evaporating from parked vehicles in unshaded parking lots around the basin has not been studied, but evidence suggests that this source of airborne volatiles could add a measurable increment to other pollutants. McPherson and Simpson (1998) have quantified this problem at sites outside the basin and are experimenting with tree shade to reduce vehicle temperatures and evaporation.

Water-based Use: Impacts of Motorized Watercraft—Trends in motorized watercraft use affect most residents and tourists using the lake, the shoreline, the near-shore zone, and—in the case of noise pollution—much of the uplands in the basin. Primary considerations are noise, water pollution, safety, and the degree to which motorized watercraft use enhances or detracts from the recreational experience of both visitors and residents. Also important is the effect motorized watercraft have on wildlife near the lake, especially nesting birds. This section on motorized watercraft is based primarily on recent investigations by Morrison (1999).

Because two-stroke engines discharge as much as 30 percent of their fuel/oil mixture into the air and water unburned, a new regulation against these engines went into effect June 1, 1999. This law bans two-stroke engines with five exceptions:

1. Two-stroke engines with direct fuel injection (DFI), such as the four-person, 65 horsepower "Polaris" personal watercraft (PWC), which came on the market during the 1999 boating season, are permitted because these are much cleaner than other two-stroke engines. The following two-stroke engines will be permitted until October 1, 2001:
2. Outboard motors under 10 horsepower;
3. Auxiliary outboard motors on sailboats;
4. PWCs with electronic fuel injection (one model of Bombardier Seadoo purchased by concessionaires in good faith before the regulation was finalized);
5. PWCs that meet the EPA 2001 emissions standards. As of 1999, one model of Yamaha with a catalytic converter falls into this class.

There are three other TRPA boating rules that have been in effect for the last two years that affect PWCs:

1. All motorized watercraft are restricted to five mph within 600 feet of the entire Lake Tahoe shoreline;
2. Motorized watercraft are not permitted in the tributaries to Lake Tahoe; and
3. Discharge of any waste into Lake Tahoe is prohibited.

Until the summer of 1999, enforcement of TRPA boating rules has been minimal and, many believe, ineffectual. Beginning in the 1999 boating season and using two law enforcement boats, TRPA enforced the two-stroke ban at launch ramps and marinas in Nevada and California. In addition, new legislation in Nevada requires local, county, and state marine law enforcement patrols to assist TRPA with its education and enforcement programs. As of June 1999, no formal action had been initiated in the California legislature regarding enforcement. TRPA's current proposal is to educate first-time offenders, who will be logged into a database, and to cite repeat offenders.

TRPA has begun a publicity campaign in Nevada and California that includes mailing brochures to boat owners. The objective is to prevent large numbers of violations and to discourage boaters who may travel long distances with noncompliant boats only to be turned away upon arriving at Lake Tahoe. There is already great concern that Donner Lake (near Truckee and outside the jurisdiction of TRPA) will have a higher number of noncompliant boats because of restrictions in the basin. No data are available yet from the 1999 Donner Lake boating season.

The recently completed TRPA report on watercraft use states that approximately 20 percent of motorized watercraft use on Lake Tahoe, prior to the new regulations, was with PWCs. The new regulations will reduce PWC use on the lake to a relatively small number of exempted and compliant PWCs for a few years. As compliant PWCs are marketed, one can infer from both national EPA estimates and the TRPA data that soon PWC use on Lake Tahoe again will reach 20 percent of all motorized watercraft use (EPA 1996; TRPA 1999b).

Newspaper and magazine articles and interviews conducted by the SEI assessment team revealed serious concerns among boaters and shore users about continued PWC use, aside from the problem of water pollution. These concerns appear to focus on a combination of noise, safety, and erosion of the Tahoe recreational experience. One common concern focused on the character of the noise, rather than on the actual decibel levels produced by PWCs. Because much of the PWC experience is based on near-shore wave and wake jumping, the noise is relatively high-pitched and variable, therefore annoying to those within hearing range. TRPA's 1997 Motorized Watercraft Environmental Assessment found that noise from PWCs produced "impacts to fisheries and wildlife from watercraft usage in general, which include[s] noise impacts, and disturbance of fish breeding grounds and bird nesting areas" (TRPA 1999b). One manufacturer of a compliant model advertises that its new PWC will have a 60 percent noise reduction compared to the older models. This, together with enforcement of the 600-foot reduced speed zone, is expected to diminish the noise problem.

Safety is a second key concern. As the number of PWCs increase and as they become capable of higher speeds with more people aboard, the risk of accidents increases. Motor boaters observe that many PWC users come from behind and begin wake jumping in the motor boater's blind spot. According to interviews, this is quite distracting to the boater (Morrison 1999). The use pattern of PWCs is often one where two or more PWC operators play together in close proximity to one another and to other boats. This, together with the high speeds and erratic course changes of PWCs, creates an accident environment and an experience of significant anxiety for boaters.

An important part of Tahoe cultural history is the antique wooden speedboat, known as a "woody." The Sierra Boat Company on the north shore stores and maintains approximately 360 wooden boats through the year. Anecdotal estimates indicate that there are an additional 350 boats at other locations around the lake. An additional 100 wooden boats are brought into the basin during the summer. The combined number of 800 antique

wooden boats have a total value in excess of $200 million. Sierra Boat Company employs and provides benefits to 28 year-round skilled workers. Based on interviews and employment data, there are an estimated 10 to 15 additional skilled wooden boat workers elsewhere on the lake. The Tahoe Yacht Club sponsors an August showing of antique wooden boats, and this invitational event brings in about 130 high quality restored wooden boats from various parts of the US. About 5,000 visitors attend the two-day event. The sponsor donates the annual proceeds of about $20,000 from the event to local charities. Wooden boat engines (if they are original) pollute more than contemporary four-stroke machines, but they comply with state and federal regulations. Average use is on the order of 12 to 15 hours a year for each of the 800 boats on the lake, and fuel consumption is about five gallons per hour. This is 61,500 gallons per year, or about 3.5 percent of the total fuel consumption on Lake Tahoe. Thus, the antique wooden speedboat is a small percentage of total motorized watercraft use, but they are seen as part of the "Tahoe experience" by many who use or see them.

Many more recent models of speedboats do not use the kinds of underwater exhaust systems that reduce exhaust noise. Inboard and inboard-outboard speedboats having above-water or water-muffled (cooling water mixed with the exhaust) systems are more likely to exceed the TRPA noise threshold. If they do not, they still provide a threat to the recreational experience of many using the lake, the shore, and the upland hiking and camping areas. Estimates by TRPA find that approximately 20 percent of the boats on Lake Tahoe have exhaust systems producing noise in excess of Nevada, California, and TRPA regulations. There seem to be two causes for this. Noise regulations are poorly enforced and manufacturers make high-noise systems available. For example, the popular "captain's call" system allows the operator to route exhaust either above or below water (TRPA 1999b).

Projections of future motorized watercraft use can be found in Hagler Bailly (1999), TRPA (1999b), and EPA (1996). Use is governed in part by supporting facilities. In TRPA's 1999 shorezone study, the preferred buildout alternative projects significant increases in the numbers of piers, slips, buoys, ramps, and floating docks. TRPA's surveys and projections strongly suggest that PWC use nationwide and on Lake Tahoe will continue to increase (TRPA 1998b, 1999b).

Examples of Ecosystem Elements and Processes that can Contribute to the Knowledge Component of the Tahoe Experience—The basin ecosystem has numerous processes, structures, and functions that can provide visitors and residents with ecological knowledge. As the basin comes to be seen more and more as an ecosystem, the opportunities for learning and for augmenting the current Tahoe experience with ecosystem-level knowledge is considered potentially valuable. No research has been performed to assess whether there is an increasing demand for a knowledge-augmented experience.

Prescribed fire may provide a useful example for future investigation. The Presidential Forum of 1997 resulted in a mandate to increase prescribed burning by approximately ten-fold in the basin. This dramatic proposal focused the public mind on some of the concerns about prescribed burning at a time when this management practice enjoys a high degree of popularity in both technical and lay circles. Expert testimony to the Forest Health Consensus Group and recent technical reports to the USFS show that low-to-moderate intensity fires were fairly common in presettlement times. These fires may have been set by Native Americans, by lightning, or, around the middle of the 19th century, by sheep herders. As the demand increases for more and better information about the structure, function, and management of the basin ecosystem, one may anticipate questions about the appropriateness and practicality of reintroducing fire to an ecosystem that has developed into an entirely different state than when presettlement fires were a part of the forest.

There has been little formal study of the reactions of residents and visitors to prescribed burning while it is happening or to the visual attributes of the forest after the prescribed burn (Litton 1999; McBride 1999). A limited number of interviews with basin residents and visitors found that—with the exception of complaints about smoke—a prescribed burn in progress is an

evocative sight that stimulates curiosity. Prescribed burning, no matter how it is perceived afterward, may be one of the most powerful attributes of the basin's future ecosystem as a repository of knowledge and as a visible form of ecological management.

Summary: Environmental Effects of Land Use Changes

An integrated understanding of the relationships between land use processes and ecosystem processes is incomplete. A systematic evaluation of how accurately environmental impact statements (for all basin projects) predicted the impacts that have occurred would add to a better understanding of the extent to which it is possible to predict the effects of a given land use change.

Issue 4: Determining Appropriate Institutional and Organizational Aspects of Adaptive Management in the Lake Tahoe Basin Context

The Effect of Institutional Capacities and Arrangements on Collaborative Processes and the Use of Information in Adaptive Decision-making and Management in the Basin

The basin has a complex history of institutional evolution, and collaborative and cooperative efforts among those institutions. The most complete documentation of this history to date is contained in the Lake Tahoe case study produced for the Sierra Nevada Ecosystem Project (SNEP) report (Elliott-Fisk et al. 1996). The SNEP case study paints a backdrop against which the current constellation of institutional relationships can be viewed. It also summarizes several lessons that can be drawn from the Lake Tahoe case, the first of which is that it "takes time and effort to create a unified vision." The degree to which the basin community is able to work cooperatively or collaboratively toward environmentally and socially sound solutions is a function of its own history. As the SNEP case study observed,

> "the institutional framework in the Lake Tahoe basin is a cumulative response to evolving public values and the strong link between the environmental and economic health of the region. It follows many decades of controversy, litigation, the establishment of new regulations and a major shift in the ratio of public private land ownership in the Basin" (Elliott-Fisk et al. 1996: 243).

One year after the publication of the SNEP report, the Presidential Summit of 1997 came to two similar conclusions. First, the larger regional community has recognized close links between economic and environmental health. Second, the complex web of interagency efforts, collaborations, and coalitions is essential to achieving sustainable economic and ecological outcomes in the basin. As one of several outcomes of the 1997 Presidential Summit, the authors of the watershed assessment were charged with assessing the status of ecological and social knowledge in the basin. Perhaps their greatest challenge is to present that knowledge so that it complements and enhances efforts that have already taken place within the complex web of institutional relationships in the basin.

While the SNEP case study offered a valuable story of the evolution of institutions in the basin, it did not fully account for the structures of governance and decision-making that are likely to affect adaptive management solutions in the near future. The purpose of this institutional assessment is twofold. First, it is to identify key stakeholders, institutions, and relationships in the basin. Second, it seeks to highlight some of the existing pathways of communication and decision-making that will require more precise understanding in order to build adaptive management and collaborative relationships among public agencies, public interest groups, non-governmental organizations (NGOs), and the public at large.

The information gathered for this portion of the assessment comes primarily from more than 30 in-depth interviews conducted with experts and leaders in the community between April and July 1998, and from discussions held in the Socioeconomic and Institutional Working Group in early 1999.[9] And a caveat is due: this institutional assessment was developed in the context of this

[9] Cited as Adair 1999; Ames 1998; Broughton 1998; Chilton 1998; Coambs 1998; Farrell 1998; Ferrari 1998; Greenwood 1998; Hansen 1998; Hasty 1998; Hill 1998a, 1998b; Lacey 1998a, 1998b; Machida 1998; Manley 1998; McGowan 1998; McIntyre 1998; Nason 1998; O'Daly 1998; Palma 1998; Shannon 1998; Teshara 1998a; Wallace 1998a; Wilcox 1998.

larger watershed assessment, one of several of the presidential commitments in the basin. One of its underlying goals is to integrate biophysical and socioeconomic assessments. The institutional assessment is presented to help anticipate structural opportunities for and barriers to developing a more comprehensive and integrated array of relationships among science, policy, and management. While it was clear from the outset that the political community in the basin already operates at a level of sophistication that exceeds that of many regions, evidence gathered for this report shows critical gaps in the sharing of information and resources among public agencies and between public agencies and key private sector coalitions and interests. The task here is in part to note some of these gaps and to identify opportunities for building bridges across them.

Governance, Institutions, and Stakeholders: The Geography of Power and Influence in the Basin—Political representation in the basin is more fragmented and complex than in many other regions. For example, the California portion of the basin alone has nearly 30 state-authorized special districts (Milbrodt 1988), and there are over 25 state and local jurisdictions on the Nevada side of the basin. At the level of citizen expectations for the delivery of services, the fragmentation means a dispersed range of governmental and non-governmental authorities to which one may appeal for assistance or redress. Several studies in the basin already have noted that permitting processes are more complex and the rules more constrained than in most other political jurisdictions (Milbrodt 1988; R/UDAT 1989; Sabatier and Pelkey 1990; NLTRA 1995).

This complexity is due in part to the predominance of state and federal public lands and the admixture of public land management and private land development. Also, political representation is made more complex because services, decisions, and oversight typically handled by local government jurisdictions are divided between a bi-state regional regulatory agency (TRPA), various special districts, and a plethora of boards and commissions that lack either general or comprehensive authority. While one might expect such a fragmented structure to produce incoherent outcomes, there has been robust institutional adaptation and innovation in bringing coherence to basin-wide issues.

There are several dozen jurisdictions that have impacts on land and resource management in the basin. Listing all the basin's federal, state, and local jurisdictions is less useful than describing key agencies and informal institutions that implement most of the regulations and carry out the bulk of management responsibilities in the basin. This central group of institutions can be called "core institutions," although no objective hierarchy is applied. They are identified because of their relationship to the three key biophysical issues that focus the watershed assessment: air quality, water clarity, and watershed integrity and biotic health. These substantive areas are in large part affected by decisions generated within the core group of institutions. The following agencies, associations, and coalitions are considered "core institutions" for the purposes of this assessment:

- TRPA;
- USFS;
- CTC;
- Lahontan Regional Water Quality Control Board;
- California Department of Parks and Recreation;
- Nevada Department of Conservation with nine divisions, including, among others the Division of State Lands, the Division of Parks and Division of Forestry (NDF), and the Division of Environmental Protection;
- Public utility and other special districts, including the Tahoe City Public Utility District (TCPUD), the North Tahoe Public Utility District, the South Tahoe Public Utility District (STPUD), the Incline Village General Improvement District (IVGID),

and General Improvement Districts (GIDs) in Douglas County;
- City of South Lake Tahoe (CSLT);
- The chambers of commerce and visitors and convention bureaus;
- NGOs and coalitions, including League to Save Lake Tahoe, the Tahoe Center for a Sustainable Future, the Lake Tahoe Transportation and Water Quality Coalition (TWQC), the Tahoe Truckee Regional Economic Coalition (TTREC), the Tahoe Coalition of Recreation Providers (TCORP), and the Forest Health Consensus Group (FHCG);
- Nevada Department of Transportation and California Department of Transportation;
- Research institutions, including University of California, Davis, particularly the Tahoe Research Group, the University of Nevada, Reno, the Desert Research Institute, The University of California, Berkeley, the USGS, the USFS Pacific Southwest Research and Experiment Station, and Stanford University;
- Counties and equivalent jurisdictions in the basin, including Eldorado and Placer counties in California, Douglas and Washoe counties in Nevada, and Carson City rural area.

Note that the coalitions and groups listed above are not formally empowered to make decisions or to formulate policy agendas, nor do they explicitly or implicitly claim that power. However, the management of environmental issues in the basin inevitably must take into account the involvement, investment, historical knowledge, and perspectives of these institutions and quasi-institutions. Moreover, there are key individuals who frequently are consulted, but who do not necessarily express or exercise their interests through these institutions or associations. Collectively, these institutions, quasi-institutions, and key players form a broader geography of power and influence in the basin.

Interagency Coordination and Cooperation—Although a greater focus at the policy level on interagency cooperation among the core institutions has developed since the 1997 Presidential Forum, the capacities for collaboration and cooperation among the core institutions has only partially penetrated to the line and operational strata of core public institutions. The institutional analysis literature would suggest that the behavior of key institutional players is perhaps better explained by the exercise of prerogative and authority in the service of agency goals and missions (Ostrom 1992; Singleton and Taylor 1992; Keohane and Ostrom 1994; Thomas 1997b). A more thorough analysis is required in the basin. However, many feel that cooperation and collaboration in the public sector lags behind the extra-governmental sector and, in some cases, impedes progress on issues that require broad-based, multisector cooperation.

TRPA stands squarely at the center of land use regulation and management in the basin. TRPA is responsible for making land use decisions down to the parcel level, which in most other locations are made by municipal and county planning entities. The most critical elements in the regulatory framework of TRPA are the regional plan and the "environmental threshold carrying capacities," or more simply the thresholds.[10] Both form the legal and political framework for basin-wide collaboration and cooperation.

[10] An "environmental threshold carrying capacity" is defined under TRPA Resolution 82-11 as "an environmental standard necessary to maintain a significant scenic, recreational, educational, scientific or natural value of the region or to maintain public health and safety within the region" (Tahoe Regional Planning Agency 1996: 1). The thresholds were adopted as a result of the recommendations of the Western Federal Regional Council's Task Force report. Based on the ecological concept of "carrying capacity," developed in the 1960s, most of the thresholds were developed from analyses of the ability of the environment to sustain activities in each of the threshold areas. While carrying capacity has been criticized as an ecological concept (Rees 1996; Lindberg and McCool 1998), it remains the basis of the thresholds today.

Since the establishment of the nine threshold categories in 1982, the basin political community has gone through cycles of legal challenge and political compromise that have both clarified the management implications of the thresholds and helped to consolidate working relationships among TRPA, other key management agencies, important political constituencies, and the general public. The recently adopted EIP was compiled in 1996 in part as a means to shift emphasis from regulation to restoration and mitigation projects in order to move the basin toward attainment of the thresholds. As a political strategy, the EIP was important in order to offer some incentives to an increasingly burdened public. Through the presidential forum, the EIP became the document around which the basin community has rallied, even though its scientific basis is not yet generally accepted. The EIP functioned, in any case, as a positive focal point that has demonstrated unity among disparate interests.

TRPA does not have exclusive land use decision-making authority in the basin. However, TRPA does have the authority to approve plans, to regulate disturbances in sensitive environmental areas, and to require mitigation of the impacts of development projects. These powers have been the source of conflict, particularly with regard to private property rights. Several legal tests have occurred that clarify TRPA's regulatory authority on private land. However, it appears to be a commonly held opinion that, despite controversy over the criteria for achieving the thresholds, TRPA is the only existing institutional framework in the basin with the political authority and the political legitimacy to convene diverse perspectives and interests at a basin-wide scale. Significant differences of opinion still exist about which issues are truly regional in nature, but there appears to be little serious contest of TRPA's authority to regulate development, to scope issues, and to focus institutional resources at the regional scale.

The USFS is another critical player among the core institutions. Technically the USFS is responsible for managing approximately 77 percent of the land area in the basin.[11] Approximately 20 percent of USFS land ownership is classified as "urban interface lands" or "urban or subdivision lots."[12] The USFS lands in the basin technically lie within the jurisdictions of three separate national forests: the Tahoe, the Eldorado and the Toiyabe. In the 1970s, during the early years of the TRPA, it became clear that managing the basin national forest lands required a single management authority. In response, the LTBMU was formed in 1973 and given independent management and fiscal authority. The LTBMU is functionally equivalent to a national forest; however, its challenges to manage a large urban interface area in a predominantly recreation-focused region has given the USFS unique budgetary constraints and staffing characteristics when compared to other national forests in Nevada and

[11] LTBMU shows figures for its total acreage at about 158,500; the regional office in San Francisco figures show about 157,500. Variations occur because of differences in where the boundary of the basin is supposed to lie.

[12] Discussions with the LTBMU lands officer revealed that accurate measurement of the interface with urban lands is difficult at best. A 1995 environmental assessment of urban lots showed approximately 100 miles of interface between USFS and private lands in the immediate area of the lake. Depending on the management prescription, the "depth" of treatment or management will vary substantially. In the case of current fire management strategies, the Defensible Fuel Profile Zone (DFPZ) normally works within the first ¼ mile of USFS land. Applied roughly, the USFS manages anywhere from 16,000 to 20,000 acres as "urban interface." The Santini-Burton acquisitions database, maintained by the USFS LTBMU, does not support a precise analysis of total acreage under "urban interface" classification. Many of the approximately 3,500 Santini-Burton parcels (~11,000 acres) have been acquired within the "general forest" areas because of ecological significance and do not fall within the urban interface. Additionally, some urban interface lands cannot be managed because they are designated wilderness (e.g., Mount Rose Wilderness Area, which abuts several private holdings in Incline Village). However, a rough estimate for the purposes of this report would put USFS land influenced by urban or developed lands at approximately 30,000 acres, or about 20 percent of the total land managed by the LTBMU.

California (within regions four and five of the USFS).

The predominant human activity on LTBMU lands is recreation in various forms. This reality places the USFS in a key relationship with the basin's recreation economy, which accounts for more than $1 billion per year, or half of all recreation generated revenues in the entire Sierra Nevada annually (Stewart 1996). Notwithstanding the importance of recreation in the basin, the LTBMU's recreation funding has remained fairly constant (approximately $1 million per year), despite the increasing demands on resources and the general declines in national budgets. The USFS's experimental "fee demonstration program," initiated nationwide by Congress in 1997, provides some opportunities for the LTBMU to increase and capture 80 percent of program revenues for local national forest reinvestment in facilities and services. However, the program is not without controversy in some areas, and its full impacts are still to be analyzed (San Jose Mercury News 1999). At this time, the so-called "Fee Demo" program is used only on a limited basis in the basin.

There appears to be some divergence in both the missions and styles of operation between TRPA and USFS in the basin. Several interviewees expressed concern that the overall orientation of the USFS appears to be excessively focused on "desired conditions." The desired-condition orientation of the USFS derives largely from the National Forest Management Act of 1976 and signifies a major transition in agency thinking over the last several years. However, it is seen by some in the basin as divergent from TRPA's Regional Plan, the thresholds, and the intent of the EIP.

This apparent divergence can be understood by examining the historical orientation of each agency. Until the passage of the Santini-Burton Act (PL 96-586, 1980), USFS land acquisition and management programs were focused on wildland in the basin (Fink 1991). TRPA's regulatory authorities, on the other hand, were focused on already developed lands and mitigation for parcels proposed for development. Through the joint development of the "Land-Capability Classification System," under the leadership of Robert Bailey, a geomorphologist with the USFS, TRPA and the USFS began to use the same criteria in evaluating sensitive lands for acquisition and management (Bailey 1974). However, while the USFS was increasingly focused on acquiring sensitive lands, TRPA continued to focus on offsetting the impacts of development. As the relationships between land acquisition and environmental protection have become more quantifiable, the missions of the two agencies have moved closer together, in practice.

Further, TRPA and the USFS have different means for developing management focus. The TRPA thresholds encompass clear and measurable regulatory limits while expressing a desired condition for developed lands throughout the basin. Progress toward threshold attainment is documented every five years, and threshold standards are evaluated regularly for their consistency with the best available science. The USFS on the other hand regulates its management activities through its Land and Resource Management Plan (LRMP), which is updated every ten years. The LRMP divides the basin into 24 management areas, each with distinct resource goals or "desired future conditions." According to the legal requirements guiding USFS management and planning (set by TRPA), standards and guidelines are then developed to steer management activities toward desired conditions. While the standards and guidelines for each management area may differ, all management areas incorporate TRPA thresholds.

A key difference lies in the two agencies' public processes. Both agencies engage in extensive consultation and public involvement, normally going well beyond the strict requirements of the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA). Through exhaustive public review processes, management standards usually end up looking nearly identical for the two agencies. However, changes in TRPA's management guidelines are evaluated through both the Advisory Planning Commission, which has strong local representation, and the Governing Board, with representatives from all

levels of government from local to both states to federal. TRPA's public process may appear to slow down changes in management and planning, but it ensures a thorough public airing of issues and increases the likelihood of broader consensus on controversial issues.

The USFS has put extraordinary effort into making its management strategies more transparent and public involvement accessible. As a practical matter, the desired future condition approach itself is an example of how the agency has attempted to engage disparate public interests within a common framework. But formal access to USFS decision-making processes is limited to public comment, which is interpreted by USFS staff, or appeal, which formalizes objections to proposed decisions. Without a formally designated and appointed federal advisory committee, there is no institutional mechanism to ensure robust public debate in USFS decision-making processes.

The FHCG created an innovative governance opportunity for both agencies. The FHCG was initiated by the TRPA Governing Board to engage a broad public dialogue in the search for solutions to a severe forest health problem following years of drought and beetle infestation. When the FHCG began its work in 1992, a broad range of stakeholders relatively quickly developed consensus on a statement of desired future conditions for the basin's forests (Forest Health Consensus Group 1992). The FHCG's next step was to identify ecosystem management strategies and techniques, including indicators to complement the thresholds, that would help to steer forest structure toward the pre-Comstock Era conditions identified in the group's desired future condition statement. That process has taken several years and continues to meet with institutional resistance when the group approaches agency prerogatives and interagency review protocols too closely (Nechodom and Kusel, forthcoming).

Technically, the USFS's desired-condition approach and TRPA's thresholds are nearly identical. Historically the USFS has been one of the most active contributors to the development of both the science and management frameworks that underpin the biotic thresholds, yet political perceptions in the basin indicate that the USFS often distances itself from the thresholds. Speculations about the causes of this apparent contradiction tend to point to the LTBMU's reluctance to cede management authority to a local or regional jurisdiction, whether it is a county in the basin, the Lahontan Regional Water Quality Control Board, or TRPA. This appears to be the source of a great deal of frustration in the management community in the basin. Observations at this time would suggest that the institutional divisions visible in the tensions between desired condition and the thresholds have more to do with agency prerogative and allegiance to disparate institutional clienteles than they have to do with the technical feasibility or scientific credibility of either approach (Sabatier 1986; Wondolleck and Yaffee 1994; Sabatier, Loomis, and McCarthy 1995; Nechodom 1996; Thomas 1997a).

From the perspective of those interviewed in the political community, the difficulties of sharing information and the uneven record of cooperation between the USFS and TRPA appear to be among the more salient institutional disconnections in the basin. However, this lack of cooperation and communication is intelligible from an institutional and political perspective. Until the Presidential Forum, and presidential commitments that followed the forum, little specific mandate has existed for cooperative action at the larger institutional scale. While the two institutions consult regularly with one another at the program and project scales, neither the structure of the bi-state compact (as revised in 1980) nor explicit congressional directives suggest a superstructure within which TRPA, the bi-state regulatory agency, and the USFS, the predominant federal land management agency, can share authority and power without losing autonomy. The absence of such a mandate reduces the ability of administrative leadership to sustain interagency cooperation or collaboration. While historically USDA Forest Service forest supervisors and TRPA executive directors occasionally have taken significant risks to

overcome interagency barriers, experience suggests that administrative risk without sufficient mandate or adequate constituency demand often fails (Berry et al. 1984; Berry et al. 1993).

Some of those interviewed speculate that excessive focus on the institutional disconnections between TRPA and USFS has been a red herring. Continuing to emphasize that particular problems obscure other perhaps more critical systemic disconnections between and among other important institutions. Institutional gaps are not uncommon in the basin, particularly at the periphery of the "core institutions." These gaps can be identified in several substantive areas, including transportation planning, water quality monitoring, recreation facility planning, tourism infrastructure development, and links between air quality and prescribed burning. Efforts are underway to close some of those gaps, and a number of interviewees expressed hope that funding from the presidential commitments, as well as eventual funding for the EIP, would help to facilitate better data coordination and interagency communication.

An overriding theme in many of the in-depth interviews was a perceived procedural mismatch among decision-making, implementation, and monitoring. Implementing the right kind of process or making sufficient investment in the processes themselves appeared to be the areas of greatest deficiency. One of the reasons the CTC is highly regarded in the basin is because of its position as an interagency and community facilitator. Its deliberate strategy is to invest heavily in public process, including very aggressive consultation with key interest groups in venues that are compatible with the communication styles of those groups. It is not at all unusual for CTC representatives to attend meetings of local interest groups (including homeowners' associations, business associations, and community planning roundtables) in order to provide general programmatic information and to give advance information on proposed projects prior to a formal public process. This often requires a substantial expenditure of agency overhead, as well as a direct budgetary commitment to developing constituencies for projects and helping specific sectors increase their knowledge in order to make informed contributions to the planning process.

In this context, the CTC has important advantages over other Tahoe basin public agencies. It has no regulatory responsibility or police powers; and, more importantly, it has a substantial budget for land acquisition, project implementation, and management. Moreover, the CTC has played an important historical role that has contributed to its position as a facilitating and implementing agency. In 1987, after the new bi-state compact was negotiated, the legal challenges were cleared, and the thresholds were approved, the fiscal burdens of the new regulatory framework in the basin were nearly insuperable for local governments and special districts. Environmental mitigation measures were needed to make progress toward threshold attainment, but few local entities could afford them. The CTC played a critical role in moving fiscal resources into place and providing relief to local jurisdictions.

Contributing the means to meet new environmental standards carried two additional advantages. First, because the requirements for CTC funding include projects that improve basin-wide environmental quality or provide "visitor-serving recreation amenities," partnerships between the CTC and local agencies serve to increase the likelihood that the local jurisdiction is able to link its needs and actions to a regional context. Second, without the CTC's substantial infusions of capital, progress toward threshold attainment would have been far more difficult and would have undermined the legitimacy of the thresholds. Many interviewees reflected on the fact that cultural and political attitudes toward the fairly strict regulatory environment in the basin have progressed from outright hostility, to acquiescence, to—at least in some sectors—solid support over the past two decades. Preparedness in the Tahoe basin for collaborative approaches to collective regional solutions is importantly rooted in the kinds of institutional relationships that have evolved between local jurisdictions and regional agencies.

Several local jurisdictions have realized great advantage in developing strategic partnerships with the CTC. Beyond increasing the flow of resources to those jurisdictions, these partnerships take advantage of combined educational and project implementation resources to advance mutually compatible agendas.

A key example of this partnership is the TCPUD, which is in the unusual position of providing multiple services to local constituents beyond its strict public utility service delivery mission. In order to deliver a broad range of services, it has developed strategic alliances with several institutions, including the CTC, the North Lake Tahoe Resort Association (NLTRA), and others, in order to leverage resources and to serve multiple constituencies.

Experience from the CTC's strategic relationships is suggestive for institutional evolution in the basin. Many have observed that the basin, as a regional community, is far more advanced politically and institutionally than many other regions. This was also one of the SNEP case study's conclusions in 1996 (Elliott-Fisk et al. 1996). Particularly over the last decade, the region has developed exceptionally high levels of social and human capital. Having high levels of social capital means that "networks of reciprocity and exchange" (Putnam et al. 1993: 169; Doak and Kusel 1996) are particularly well developed. The sense of interdependence and mutual obligation, reaching beyond barriers of personal preference, has been apparent through in-depth interviews and observations in public meetings. Further, human capital refers to the levels of skill, competency, and education an individual brings to his or her participation in the public domain (Kusel 1996).

These two forms of capital combine relatively easily with an unusually well-developed foundation of scientific information and collective social history in the basin to bring the political community to the point where process and communication are high priorities. Many key players understand the necessity of scientific verification of the assumptions behind the regulatory and restoration strategies in the basin. However, they tend to put the emphasis more on the way that scientific information flows through the community and contributes to advancing the collective needs in the basin. This is entirely consistent with observations from elsewhere regarding the readiness of communities to integrate scientific information into decision-making and dispute resolution processes (Lee 1993; Weeks and Packard 1997).

The Role of Coalitions—The basin's increasing focus on the exchange of information and the communication of ideas helps us make sense of the inordinate importance of coalitions within the political community. Many noted in interviews that there are sufficient formal venues through which one may obtain information or seek redress of grievances. However, most are aware of the essential importance of informal venues for generating and developing new ideas and innovations. In many other contexts, particularly in land and resource management in the American West, these informal venues are the causes of wariness and cynicism because they preclude open access to critical decision-making processes and enable local capture of state or national resources (McConnell 1967). It is for this reason that "sunshine laws" have been developed to interrupt the more typical patterns of power consolidation at the local level. In contrast, the robust and complex avenues of communication apparent in the basin reflect a great deal of transparency, as well as frequently articulated demands for access. Therefore, the fear of local capture and the unfair advantages gained by local power elites is minimized in the basin by a relative symmetry of power among several very disparate interests.

For several reasons, a clear sense of interdependence exists among diverse and often fractious interests in the Tahoe basin. Increasing economic diversity, the competition for scarce resources (such as transferable development rights, "coverage," or commercial floor space) and the shared sentiment that the environmental health of the basin is directly tied to economic and social well-being in the basin all create an environment ripe for cooperation and collaboration.

Thus, the Lake Tahoe Transportation and Water Quality Coalition (TWQC) is logically a very powerful quasi-institution through which information circulates and innovative ideas are generated. The group initially formed in 1989 as the Tahoe Transportation Coalition (TTC) and soon brought $2.5 million to the basin to help coordinate disconnected transportation systems on the south shore. The TTC evolved into the TWQC prior to the Presidential Forum, signaling a need to broaden

its focus to include water quality and lake clarity. The coalition's membership waxed and waned in the months prior to the Presidential Forum. However, it became increasingly clear to representatives of the various sectors who attended the coalition's meetings that a coherent voice was needed to show commonality and solidarity among sectors that typically competed with one another for scarce resources. Co-chaired by the League to Save Lake Tahoe, the Lake Tahoe Gaming Alliance, and a ski resort representative, the TWQC quickly evolved into a highly effective representative body that could speak with one voice in Washington, DC, Sacramento, and Carson City. Following the Presidential Forum of 1997, the TWQC has become an effective venue for the exchange of ideas and a forum attended periodically by key managers and line officers of public agencies.

The TWQC also has proved to be an effective lobbying body and has been known to use its collective voice to build support for public programs and budgets in the basin. Members of the TWQC make frequent trips to Sacramento and Carson City to submit formal testimony before state legislative committees and to meet with legislators to educate them about the complex multi-jurisdictional efforts in the basin. Similarly, TWQC members coordinate educational efforts in Washington, DC, and have been credited with keeping legislators and administrators at the national level focused on basin issues.

As a further testimony to their informal power, the TWQC frequently has been referred to as a "de facto FACA committee." One of the key provisions of the presidential commitments was to form a federal advisory committee (often called a "FACA committee") to provide oversight and legal legitimacy to collaboration among the governmental and non-governmental interests and to formalize policy-oriented discussions with various sectors of the public. It took several months more than anticipated to form the FACA committee. In the interim, the de facto power structure, characterized in significant measure by the TWQC, became increasingly important in providing guidance and helping the federal agencies' fulfill their roles in meeting the presidential commitments in the basin.

On more than one occasion, interviewees commented that the unelected and unappointed body appeared to be the forum at which critical policy decisions were being made. However, members of the TWQC insist that any decision by the coalition to pursue a particular policy direction should be carried forward to appropriate governing bodies and be subjected to full public process. It is difficult to determine at this time the relative equity or efficacy of the relations currently being built through such coalitions as the TWQC. Apropos the earlier discussion of local capture, state and federal agencies are likely to play a key role in ensuring transparency and access in the processes of information exchange, communication, and political representation.

There are three other major coalitions in the basin that have importance in to collaborative strategies flowing from the presidential commitments. The first, noted above, is the FHCG. This group was formed in 1992 at the request of the governing board of TRPA to provide a broader public forum to advise the agency on ways to manage the forest health crisis. The FHCG now serves a much broader purpose than was originally anticipated under its original charge as an advisory group. Beyond evaluating proposed changes in thresholds or management practices, the FHCG has the additional effect of increasing levels of social capital and fostering collective learning curves among diverse stakeholders (Nechodom and Kusel forthcoming). Moreover, scientists working on forest health and watershed integrity issues for the watershed assessment have found the group a ready source of local knowledge and a useful venue for dialogue.

The TTREC was formed in 1992 as an evolution of the earlier Economic Round Table, had met informally for several years to discuss various economic issues facing the resort community in the larger region, including the Tahoe basin, Donner Lake, and Truckee. TTREC's ultimate focus is on the nexus between economic and ecological sustainability in the region. For several years prior to the Presidential Forum, TTREC was considered to be the most focused economic forum in the region. However, TTREC has been a less active player in

formulating and advancing a regional economic vision for the basin. Evidence suggests that other interest groups and coalitions have taken up similar activities, albeit perhaps at a more limited geographic scale. These interest groups and coalitions include the NLTRA, the Incline Village/Crystal Bay Visitors and Convention Bureau, and the Tahoe-Douglas Chamber of Commerce. While these associations are active at a subregional scale, representatives interviewed stressed the need to focus their constituents' attention more at a basin-wide scale. The business community is highly diversified, even fragmented. Recreation industries in the basin focus their attention on entirely different markets but integration of these markets is left to the lodging associations and visitors bureaus. Small businesses are well represented through some chambers of commerce but not all. There is no comprehensive effort to integrate small business concerns at a basin-wide scale.

One of TTREC's early convictions was that regulation on behalf of environmental quality would increase the value of natural assets in the basin and would translate into economic vitality and social and economic development. From an institutional perspective, one may conclude that the stratification of the business community into large corporate ownership, large private ownership, and small businesses contributes to continued fragmentation and reduces the ability of the business community to support environmental improvement and restoration activities. For example, based on discussions held by the socioeconomic and institutional working group during the watershed assessment process, significant disagreement exists over the ultimate purposes and design of redevelopment efforts in the basin. A more complete analysis of redevelopment and regional economic development would need to clarify both socioeconomic goals and intended markets.

A third coalition focused primarily on public access and recreational services coordination is the TCORP. Formed in 1991, TCORP recognized that the recreation economy ultimately depends on the perceived environmental health of the basin. The problem TCORP confronted was that visitors' recreation experiences are often diminished by uncoordinated and fragmented services and infrastructure. TCORP's main focus is to coordinate planning among key recreation providers, particularly those in the public sector. One focus of their efforts was to create connections among bicycle trails on the north and west sides of the basin, which previously had been completed without a comprehensive plan. Additional examples are found in jurisdictional disjunctions between local transportation districts or in the parking management problems between, for example, the USFS and California State Parks on the west shore. Among TCORP's accomplishments has been to persuade local agencies to use the same signage conventions throughout the basin and to establish location markers to help orient tourists. Not only does this make visitor access to facilities and services easier, it tends to foster a greater sense of the basin as a whole ecological and social system.

TCORP's purpose is to provide an informal and regular forum in which coordinated solutions to institutional disjunctions can be found. Many of the same people who participate in TCORP also attend TWQC meetings, indicating that both coalitions may be focused on solving many of the same problems from different perspectives. While this may appear redundant, from an institutional perspective it is a good example of where redundancy in the system can serve to sustain attention on problems without creating costly institutional solutions.

The importance of coalitions in the basin should not be underestimated. Coalitions are often forced into existence by changes in markets or clients that make existing institutional arrangements unable or unwilling to respond. In most cases, the existence of a broad-based coalition signifies disjunctions between formal governing institutions and constituent needs. However, the existence of coalitions should not be taken necessarily as a criticism of formal institutional performance, nor should they be seen as necessarily compensating for deficiencies or incompetencies within or among formal governing institutions. Furthermore, coalitions should not be seen as mechanisms to circumvent normal governing processes. Together

they form a more or less tightly woven fabric of social and political communication.

Key questions regarding public policy and institutional performance revolve around how formal governing institutions interact with, share information with, and occasionally provide support for coalitions and informal associations. It is not a question of whether they should do so. The difficult puzzle to be solved for any regional strategy involving significant public resources is how to integrate the informal pieces of the fabric into policy formation, decision-making, implementation, and monitoring processes, while preserving transparency and accessibility. In the basin, the experiment has been underway for some time; implementing the EIP will place even greater emphasis on the need for tighter integration and cooperation.

Political Representation—The structure of political representation in the basin has become highly adaptive, particularly over the last decade, with significant evolution in non-elected associations since the early 1990s. The timing of the emergence of key coalitions appears to correspond with several factors. The basin was beginning to experience the aesthetic impact of a massive tree die-off in its forests. Following several years of drought, 1991 estimates showed that nearly 40 percent of the trees in the basin were either dead or dying. During the same period, the regional economy had flattened. Gaming revenues had declined, beginning a trend that continues today. The tourist and recreation markets had stagnated, with major changes in the demographics and socioeconomic profiles of visitors (NLTRA 1995). A study of the North Lake Tahoe "resort triangle," including the Truckee and Donner Lake communities, had concluded that traffic congestion and low-grade facilities in the northwestern portion of the region were indications that the quality of community and environment had been sacrificed to short-term economic development (R/UDAT 1989). Finally, a comprehensive "tourism master plan" study found that the "separation of regulatory control (TRPA) and governance (Placer County) creates a disassociation between public policy and local needs" (NLTRA 1995: 3).

But these factors were only part of the picture. During the last decade, the populations of Reno, Carson City, Gardnerville, and Minden have expanded by up to factors of ten. The western slope of Eldorado and Placer counties has grown at a similar pace, with the Auburn/Nevada City corridor almost doubling its population, and the Folsom/Placerville area growing dramatically. Growth in the regions surrounding the Tahoe basin is more than just an increase in numbers. The socioeconomic status, preferences, and values of the newcomers to these regions have placed increasing pressure on county planners and administrators to respond to the growing diversity of their constituents. The capacity to represent political interests in the basin vis-à-vis general purpose government has diminished as population and demand have increased on the east and west sides, downslope from the basin. For this reason, this pattern has been called a "downslope power drain."

The result of this shift in representation and political influence is that basin issues and the need for services and political infrastructure in the basin portions of those counties have received less and less attention. The basin supports a permanent population of approximately 55,000. Nearly 23,000 live in the incorporated area of the City of South Lake Tahoe, the only general purpose government seated in the basin. Thus, well over a third of the population in the basin has direct local access to political representation and general services. One might expect that the remaining two-thirds of the basin's population would seek local government services through county supervisors and commissioners, or at least through the county's administrative representatives. This is not, however, predominantly what happens. Other public jurisdictions attempt to fulfill citizen demands for services.

To examine this more carefully, let us look briefly at the structure of formal political representation in the basin. While voter registration is often a clumsy indicator of political representation, the numbers are particularly revealing in the basin. With the exception of Washoe County, the most recent voter registration numbers are used to show the relative balance of political representation between the basin portions of the four counties encompassing Lake Tahoe. For Washoe County, actual voter turnout counts from the November

1996 presidential election are used.[13] There are five major political jurisdictions in the basin (excluding the City of South Lake Tahoe), including four counties from which voter registration figures are provided: Placer and Eldorado in California and Washoe and Douglas in Nevada. The fifth political jurisdiction is the Carson City Rural Area, which covers an area on the Nevada side of the basin between Washoe and Douglas counties with virtually no population. The present analysis applies only to the four counties cited above.

The total number of registered voters in the four counties is approximately 360,000, using the most recent registration figures (Table 6-37).[14] The total number of registered voters in the basin portions of those counties is just over 30,000, representing approximately nine percent of registered voters in all four counties. The county with the highest portion of voters in the basin is Douglas, with approximately 21 percent, although the actual number is about 5,400. Not surprisingly, Eldorado County has the highest actual number of registered voters, most of whom are concentrated in the City of South Lake Tahoe. Placer County has the highest number of total registered voters at 133,649, but there are only about 6,000 in the basin. The implication of these numbers for the purpose of this assessment is that basin voters carry relatively little weight in county-wide elections. The pattern is similar for state legislative districts and congressional districts.

That influential political voices exist in the politics of land use in the basin is clear; however, their influence is not necessarily exercised at the level of local government and the delivery of services. Most of that influence is exercised at the state, bi-state (i.e., TRPA), and federal levels, reflecting the jurisdictions and management regimes that hold the most sway over land use policy in the basin. Therefore, community-level services, such as public safety, health, and welfare, are even more disconnected from direct political representation than under more typical circumstances where county and municipal governments are held accountable for the delivery of services.

This pattern is exacerbated by an unfortunate composite of misperceptions; that is, that the basin is populated by wealthy people, that the need for county support for community services is minimal, and that such concerns as public assistance and affordable housing are moot issues. As an example, the City of South Lake Tahoe had a very difficult time justifying state assistance for affordable housing. The city recently completed a street-front inspection and found that 41 percent of its housing stock was substandard. The average annual household income in the basin falls between $31,000 and $35,000 per year. The broadest implication of this picture is that, while the basin may be an increasingly attractive destination for a wide array of tourists and recreationists, it is an increasingly difficult location in which to raise a family and to build a community.

Government by Special District—Despite the lack of formal local representation, municipal incorporation attempts have usually failed. The Stateline area (across the Nevada border from the City of South Lake Tahoe) has attempted to incorporate twice over the last decade, without success. The Placer County portion of the North Shore has initiated three incorporation attempts in the last decade, again without success. The cause for failure appears to be a fairly predictable reaction when voters get to the ballot box. No matter how logical the arguments are, and no matter how compelling the numbers are, voters still tend to think that incorporation means higher taxes and "another layer of government" (Sokolow 1981; Mumphrey et al. 1990; Musso 1997). Some speculate that the rejection of municipal incorporation efforts in California and the basin derives from "a pre-

[13] The actual turnout in Washoe County for November 1996 presidential election was 62 percent of registered voters. The focus here is on the *percentages* of the numbers of voters in the basin compared with the number of voters in the rest of the counties. Using registration versus turnout numbers is not likely to change those percentages significantly.

[14] Voter registration or turnout statistics are from the noted jurisdiction, current as of the following dates: Placer Co., 7/17/98; Eldorado Co., 7/8/98; Douglas Co., 7/1/98 and Washoe Co., 11/7/96.

Table 6-37—Voter registration in Lake Tahoe basin and surrounding counties.

	Total Voters All Counties	Total Basin Voters All Counties	Total % Basin All Counties
Total Registered or Voting	353,728	30,408	9%
Democrat	129,641	10,854	8%
Republican	168,730	12,704	8%
Nonpartisan	30,871	4,491	15%
Other	23,729	2,426	10%

Sources: County registrars; authors' calculations

Proposition 13 mentality," in which voters are concerned that a municipality will abuse powers of taxation.

In the breach, a fascinating matrix of special districts and quasi-governmental entities has gained increasing power and influence through a historical evolution of service delivery. In the case of the North Shore, the TCPUD and the NLTRA work hand in glove to build sidewalks, gutters, visitors facilities, and community recreation facilities for local permanent residents. The NLTRA contracts with Placer County to provide a wide array of services to local residents, even though its formal role is to represent the various private sector resorts on the North Shore.[15] NLTRA receives approximately $3 million per year in TOT (transient occupancy tax, or "bed tax") from Placer County, part of which is used to leverage other dollars (e.g., CTC funding for water quality improvements) to fund capital investments for transportation infrastructure. The 64-acre Tract Intermodal Transit Center in Tahoe City is an important example of a project that was moved along significantly by the TWQC, the North Tahoe Transportation Management Association, NLTRA, and TCPUD.

IVGID is another interesting case, wherein Washoe County essentially has ceded a broad range of authorities to a general improvement district. IVGID works very closely with the Incline Village/Crystal Bay Visitors and Convention Bureau to provide local services for many of the part-time residents that make up a fair portion of its population. IVGID also has one of the most aggressive prescribed burning programs in the basin, funded largely through cooperative agreements with the NDF. This funding originally was pursued at the behest of a local organization called Neighbors For Defensible Space, which worked very closely with IVGID's fire marshal to develop a program. No attempt was made to pursue funding through Washoe County. Instead, the small citizens' organization saw the IVGID board as the most logical location of political representation for its cause.

In Douglas County, there are seventeen GIDs, with varying powers. Historically, the county had the authority to create them but was not obligated to oversee them fiscally. Nor was the county obligated to provide services that the GID could not afford or was not chartered to provide. This prompted change in legislation approximately 15 years ago in Nevada, forcing counties to work much more closely with GIDs and to provide such services as snow plowing and trash removal that otherwise in some cases were neglected for lack of an accountable authority. As demands in Gardnerville and Minden grew rapidly, GIDs in the basin portion of Douglas County found it increasingly difficult to get the attention and support of county commissioners. This contributed to the so-called "secessionist movement," in which basin constituents in Washoe and Douglas counties mobilized to petition the Nevada state legislature to authorize the formation of Tahoe County on the Nevada side of the lake.

There is an additional constraint that is almost guaranteed to have an impact on the implementation of the basin's EIP. Nevada's

[15] Only recently formed (1994), the NLTRA's main mission is to provide coordinated links between tourists and resorts. Their key accomplishment is a centralized reservation system for North Shore hotels.

portion of the EIP funding will come from an $82 million bond act, requiring funding distributed in the basin to have state-local mechanisms for implementing projects. Because GIDs in many cases are politically and geographically well suited to implement, oversee, and monitor projects, it would be logical to channel funding through them. However, the language of the bond act stipulates that funding for GID-based projects must be authorized and administered through the county, a strategy designed to improve oversight and accountability of bond act funding. Discussions with administrators in the state of Nevada reveal an expectation that Washoe and Douglas counties would improve their working relationships with the basin portions of their jurisdictions. One way of forcing this issue is to require the use of the two counties' institutional capacities to support the implementation of EIP projects through the GIDs.[16]

In Eldorado County, the City of South Lake Tahoe and the STPUD are the two most important local government entities that affect environmental planning. The fact that the City of South Lake Tahoe is an incorporated, general service government means there are fewer links with non-governmental agencies in developing binding ordinance and policy. However, STPUD, as the public agency that provides water and sewer services to more than 30,000 people on the South Shore, is a key player in project implementation and monitoring.

There are, of course, several other special districts and local government entities to which citizens turn for services. For example, there are more than a dozen school districts represented in the basin. Two resource conservation districts (RCDs) exist whose role in planning, implementing, and monitoring could prove critical, especially as key federal programs funded through the Natural Resources Conservation Service (NRCS) are implemented in coordination with the EIP, such as the Clean Water Action Plan (CWAP). In recent years, the RCDs in the basin have not played a central role in setting priorities for projects basin-wide. It may be that the historical orientation of NRCS and the RCDs does not make watershed restoration in a recreation-driven economy a high priority. Because the relationship between NRCS and the RCDs, and the institutional and social capacity of the RCDs themselves, is potentially a very powerful contributor to accomplishing EIP goals, the RCDs' institutional processes and ways of relating to other entities warrant further investigation.

Summary—Political representation and access to political processes in the basin are mediated by a complex network of coalitions, special districts, chambers of commerce, visitors and convention bureaus, and special interest groups. While this constellation of local powers is not unique, what is striking about the basin is the degree to which both local citizens and larger planning institutions interact with this local network to achieve political goals. As in any other relatively bounded political system, many of the same individuals serve in official capacities in multiple local institutions. For example, one might at the same time be the vice president of the resort or business association and a member of the board of the PUD and serve on the board of the local chamber of commerce. While this is not at all atypical, in the basin it has meant that many of the key players in political decision-making processes have moved through critical learning curves on regional environmental issues and have benefited from having perspectives from a number of different capacities. This helps to explain the high levels of human and social capital in the system and why proposed changes in institutional relationships may require several iterations of consultation and negotiation.

The gradual evolution of this de facto form of government underscores the importance of understanding the social and political history of resource protection in the basin. The PUDs have a long-standing presence in the basin and a long record of delivering services to growing populations. Among the few entities with elected officials, PUDs and GIDs provide the context within which many citizens have become accustomed to political

[16] Some speculated that it would make implementing the EIP more politically attainable if Nevada were to use the distribution of bond funds to foster unity and head off a secessionist success, at least in the short term.

participation. Moreover, through competition for elected office, citizens develop political competencies and a sense of ownership in the power structure. This sense of ownership is invariably tied to the ability to deliver goods and services to constituents. As PUDs have been approached with greater frequency to meet citizens' demand for services and as other local government mechanisms have been unable to meet that demand, the political legitimacy of the PUDs and GIDs have been strengthened.

Finally, understanding the complex nature of local government in the basin is directly tied to the watershed assessment's charge to "display consequences of alternative management strategies" and to "design monitoring protocols." Because any management strategy has implications for institutional structure and response, it is imperative to understand the institutional capacities and opportunities to leverage resources and create collaborative strategies. Given the high expectations in the basin for participation in advancing the environmental agenda, it is essential to know how to integrate changes in management strategies with local decision-making structures that do not fit textbook descriptions. Not only does the institutional structure of local government in the basin challenge normal expectations, it is likely that the continued evolution of localized decision-making to reach regional goals will grow from the historical matrix of local decision-making.

The legal and statutory framework of the basin is complex and influences the range of legally and politically viable options for collaboration in the basin. While several cases have established clear legal precedents on key issues, collaborative solutions may depend to an important degree on legal ambiguity or lack of definition. The basin's legal and statutory framework represents years of litigation and compromise. And while the courts have provided important clarification on specific authorities or procedures, they do not provide the usual venues for give-and-take on which trust and compromise are built. Nevertheless, experience in the basin demonstrates that occasionally a legal decision can provide the circumstances within which effective collaboration and compromise may be carried out (e.g., the consensus process following the Garcia injunction in 1985). Therefore, one may assume that legal and statutory decisions only partially drive decision-making processes. There is a delicate balance at work in the basin between legal definition and political compromise. As the EIP process moves forward, and particularly when the full level of funding becomes available, scientific information will play an increasingly critical role in fortifying the balance between legal and statutory definition and collaborative processes.

Cooperation, Collaboration, and Definitions of Success—As was noted in the SNEP case study, the basin has a long history of multi-sector and multi-jurisdiction cooperation. The geography of the basin, the common focus on recreational and aesthetic experiences, and the relative sensitivity of the ecosystem to disturbance all contribute to the need for cooperation in the basin (Elliott-Fisk et al. 1996). Note, however, that while "collaboration" has recently become something of a buzzword, there is reason to be circumspect about its usage in the context of the basin. It is useful to make a distinction between cooperation and collaboration. Cooperation refers to people working together toward commonly held goals in which the ends or outcomes are largely determined. Collaboration brings together people with disparate interests and perspectives who first clarify the questions themselves before looking for solutions. Collaboration often involves a fundamental reframing of issues in light of new information or new questions.

Combinations of cooperation and collaboration have long operated in the basin to bring innovative ideas to the table. Particularly when responsible and accountable agencies lack sufficient resources to meet their mandates, cooperation is likely to be emphasized. But in cases where interagency cooperation has not yet accomplished sustainable solutions, despite years of planning and public meetings, a collaborative process may prove more effective. Transportation provides an example in the basin, as it has been focused largely on visitation and automobiles. Other modes of transportation, such as watercraft and bicycles, have been regarded as recreational activities, therefore

treated as a destination or "draw" issue in the transportation picture. In this circumstance, cooperation might solve the problem of a fragmented public transportation system, but collaboration could help to understand why and how people move from one place to another around the basin. This raises the question of whether basin-wide transportation issues might be ripe for collaborative processes—bringing fresh perspectives to the table to ascertain the nature of the problem—rather than focusing on increasing cooperation among the responsible agencies to solve the problem in its current expression. The recently formed Metropolitan Planning Organization (MPO) may prove to be a venue through which such collaboration can take place effectively.

Collaboration in the basin is most needed where important policy questions have not been fully clarified and institutional commitments and prerogatives are not directly threatened. In order to assess which issues are amenable to collaborative processes, it will be necessary to identify issues that are nonnegotiable. From the perspective of most interviewees, it is clear that the TRPA thresholds and the regional plan fall into this category. Therefore, in assessing the measures of success or failure vis-à-vis the presidential commitments, care must be taken to understand how implementing those commitments fits into the balance of negotiable and nonnegotiable issues.

Implementing the EIP and making progress toward achieving threshold compliance are the key components of a successful cooperative framework. Nearly every discussion of measures of success included three categories:

- *Funding and resources*—The Presidential Forum and the subsequent negotiation of the Presidential Commitments involve promises of very large sums of funding in several issue areas. The inability to deliver funding as promised was frequently cited as constituting failure.
- *Process*—The forum brought national media and political attention to the accessibility of the various forms of collaboration in the basin. Several interviewees commented that the President's visit helped the basin participants take themselves more seriously and "do what they kept saying they would do." A key measure of success therefore, will be the relative degree of openness with which EIP priorities are established, EIP projects are implemented, and EIP outcomes are monitored. A number of interviewees urged the watershed assessment science team to see their work as providing tools and scientific rationale to support these processes.
- *Distribution of benefits and burdens*—The basin's political and business communities feel they already live on a tight margin of taxation and regulation in order to support socioeconomic well-being and environmental quality. Some complain that a small adjustment in any direction will likely put someone out of business or make it impossible for public agencies to meet their mandates. The EIP, which will require spending nearly $1 billion to implement currently identified projects, provides hope for many that the basin will attain its environmental goals in an economically and socially sustainable fashion. Success will be measured by how the costs and benefits of this new phase of protection will be distributed.

There is an important political dimension to success of the EIP and presidential commitments as well. The EIP is perhaps as much a political document as it is a series of technical recommendations; therefore, the distribution of benefits must include political successes as well. One local government official described success as giving every local jurisdiction, board, or coalition in the basin an opportunity to approve an EIP project that benefits their constituents, so that they have something concrete to point to when the EIP project is done. This is no small formality. It is a critical acknowledgement that approval of local projects for regional benefits and that general support for improving environmental quality require broad support from a number of sectors and interests.

Gaps, Overlaps, and Institutional Relationships—A key element of this analysis was to examine areas of activity in which institutions interact, fail to interact adequately, or duplicate their actions. One purpose to this element was to see where efficiencies might be realized in agency and institutional management activities. Another was to identify where agencies are working at cross purposes. It is a common mistake among institutional analysts to propose remedies for communication and procedural problems by changing institutional structures (Swieringa and Wierdsma 1992; Watkins and Marsick 1993; Cook et al. 1997). Analysis of the Tahoe case suggests a greater emphasis needs to be placed on institutional processes, as opposed to organizational structure.

Relatively few instances suggest that two or more agencies are trying to accomplish the same goals in direct conflict with one another. In general, most planners and implementers in the core institutions are well aware of the activities of their peers and colleagues in other agencies. Disagreements and a healthy level of debate can occur when agency approaches are in conflict with one another. Centralized approaches or fully coordinated approaches often have an unintended outcome of suppressing innovation (Wheatley 1992; Senge 1994; Marquardt 1996). It may be more appropriate to ask whether institutional structures, communications, and relationships optimize competition for the desired benefits and outcomes.

It is rare in the basin to find two agencies implementing programs at cross purposes on the same piece of ground. Significant implementation and information gaps tend to occur in communications among institutions or sectors that are affected by common decisions, are potential clients for agency research, or are potential constituents for overarching directions in agency management strategies. Undoubtedly, agencies can have severe disagreements about the treatment of a particular piece of ground. In such cases, communication strategies and venues could be much improved with institutionalized modes of communication and information sharing .

Significant structural gaps generally are created by a mismatch between authorities and responsibilities (as in the case of the separation of planning and regulation cited by the R/UDAT team) or caused by disagreements over who should pay for which benefits. Transportation provides a good example in the basin. The fragmentation of the current transportation system both geographically and in terms of user base is not for lack of effort or because a problem is not recognized. Many in the political community agree that a coordinated transportation system (CTS) is a reasonable, logical and much-needed change. However, efforts to develop a truly regional transportation management plan—or at a minimum a viable public transit option—have periodically stalled because of lack of agreement about the distribution of cost and benefits or the statutory authority to garner and allocate public and private resources. One basin- or region-wide authority has been technically able to control revenue streams or allocations of resources at the geographic scale at which transportation needs are manifest. That agency, the Tahoe Transportation District (TTD), made two unsuccessful attempts in the 1980s to generate revenue through voter-approved taxes. Since then, the TTD has been largely inactive, and most transportation issues have been addressed to the extent possible at the subregional and local jurisdiction scale. The TWQC's strategy has been to encourage local jurisdictions to use their authorities to help integrate local actions at a basinwide scale.

Despite this deficiency, however, significant strides in transportation policy and funding coordination have been made over the past decade through the establishment of two nonprofit public-private transportation management authorities (TMAs). TMAs provide an institutional opportunity to combine public and private resources to solve complex transportation and air quality problems, guided by governing boards that represent both public and private agencies and organizations. While most TMAs in California are in densely populated urban areas and tend to focus on commuter transportation, the Tahoe TMAs were the first to try to integrate the needs of workers and visitors into a single regional intermodal system. Both TMAs were initially funded by seed grants from the California Department of Transportation (CALTRANS).

The Truckee-North Tahoe TMA (denoted in its own documents as TNT//TMA) was formed in 1990, one year after a comprehensive grassroots-driven study of Tahoe-Truckee regional patterns of development and visitor needs made strong recommendations for a coordinated approach to transportation infrastructure development (R/UDAT 1989). The TNT//TMA has accomplished a number of coordinated projects, among the most visible of which are the trolley and bus services on the Highway 89 and Highway 28 corridors, connecting the west shore and the north shore through Incline Village to Sand Harbor and Squaw Valley (TNT//TMA 1995). In addition, the TMA initiated a similar trolley service in Truckee.

The South Shore TMA (SSTMA) was formed in 1994 and has played an active coordination role in bringing significant amounts of funding from state and federal sources to bear on south shore air quality and transportation problems. As with the north shore, the various institutions with transportation policy responsibilities constituted an uncoordinated patchwork, including eight municipal, county, and state agencies. One of the SSTMA's explicit purposes is to provide an ongoing forum to coordinate policies and funding affecting transportation issues on the south shore (Leigh, Scott & Cleary 1993). It has helped develop trolley and shuttle services throughout the south shore area and links to north shore services. Among its key institutional roles, it has provided a forum for numerous stakeholders to examine the economic and environmental tradeoffs of several possible solutions to the traffic congestion and air quality issues that historically have been difficult to resolve on the south shore. A recent successful effort to develop the South Shore Coordinated Transit System (CTS) was aided by the public forums and negotiating venues provided by the SSTMA (Powers and Teshara 1999). Similar to the TNT//TMA, the SSTMA's diverse public and private representation, as well as its deliberate role in providing a transparent public forum, has added significantly to the cumulative experience with coordination and collaboration in the basin.

Other institutional gaps tend to be caused or exacerbated by a lack of communication, information, and knowledge. For example, preserving Lake Tahoe's famed clarity now drives land use management, land acquisition, and forest practices throughout the basin. But it appears that insufficient communication of knowledge about the relationships among upper watershed management, sediment, and nutrient budgets has contributed to uncoordinated and imprecise use of best management practices (BMPs). Design of BMPs has been based on the best available scientific knowledge, coupled with accumulated management experience. However, in many cases, the application of a given BMP may or may not have a significant effect on the problem it is designed to solve. The problem is not so much the design of the BMP itself, but its application in a particular location under particular conditions. Insufficient knowledge of site conditions, compounded with a lack of communication about how specific BMP objectives meld with larger watershed goals, often generates significant uncertainty for managers, regulators, and property owners.

A perception of duplication of services is more pervasive than actual overlap in the provision of services or the application of regulations. Little evidence can be found to support the perception that agencies tell conflicting stories, apply conflicting regulatory requirements, or recommend conflicting management strategies for the same clients or for the same piece of ground. While conflicts and disagreements about practices exist, it appears relatively rare that management decisions are made without knowledge of the disagreements. The explanation therefore for what appear to be gaps or inconsistencies must probe more deeply into the reasoning behind the decision, the information that supports the decision, or the political and social context in which the decision is made.

The structure of governance, decision-making, and political representation in the basin is part of a highly evolved and complex system. While a significant amount of energy and capital have gone into establishing the regional plan, the thresholds, the EIP, and related management practices, the scientific foundation for management actions in the basin is still under development.

A cursory review of the role of coalitions in policy implementation illuminates their volatility, but coalition behavior is generally responding to changing institutional and political conditions. As discussed above, the key public policy issue is to determine how to interact effectively with coalitions. The first step should be to understand thoroughly the conditions that gave rise to their formation. The various coalitions in the basin are fluid and adaptive; there are important lessons to be learned from their adaptive strategies. Coalitions and other consensus building processes develop and behave as quasi-institutions, and several common patterns of organizational development may be found in their behavior. Institutional relationships in the basin may be usefully analyzed in light of what is known about organizational development and learning organizations. Interagency efforts to coordinate information and management might well understand structural changes as phases of development in learning organizations (Senge 1994; de Gues 1998).

This analysis finds that collaborative efforts and innovations in institutional communication and coordination will grow predominantly from demand, not from command. The political community and the larger public in the basin have accumulated especially high levels of social and human capital. Collaboration and sharing information are not foreign notions in the Tahoe basin. The level and breadth of knowledge about environmental issues in the basin is high, but it is also clear that institutional barriers must be better understood and altered in order to facilitate more effective collaboration and cooperation. To accomplish this difficult task, three critical factors must be in place: mandates to solve problems in a collaborative manner, risk-taking leadership to support collaboration, and constituent demand—not to drive or control the process but to participate effectively (Berry et al. 1993). Effective collaboration in the basin can be measured by the degree to which those who have invested effort and political capital feel they have a share in concrete and enforceable outcomes. Continued investment in iterative and broadly based cycles of implementation, monitoring, and adaptation will be increasingly required to ensure balanced achievement of environmental, social, and economic goals.

In his historical analysis of land acquisition programs in the basin, Fink (1991) found that increasingly precise quantitative measures of the relationships between sensitive parcels and water quality have been essential to the success of the programs. As the information base became more robust and as greater consensus developed among scientists about the relationships among disturbance, coverage, and water quality, the basin was able to move from qualitative to quantitative criteria for acquisition. Further, Fink attributes the success of the CTC's acquisition program in large measure to the use of "its land acquisition power in specific ways to attain the broader goals of 'enhancing . . . governmental effectiveness in the region [CA PRC § 66905.2].'" (Fink 1991: 544). Collaboration as a policy implementation strategy is fundamentally dependent on developing and communicating reliable scientific information. The core institutions' effectiveness in adaptive management in the basin will depend increasingly on the links they are able to create and maintain among well-defined policy directions, scientific information, and stakeholder participation.

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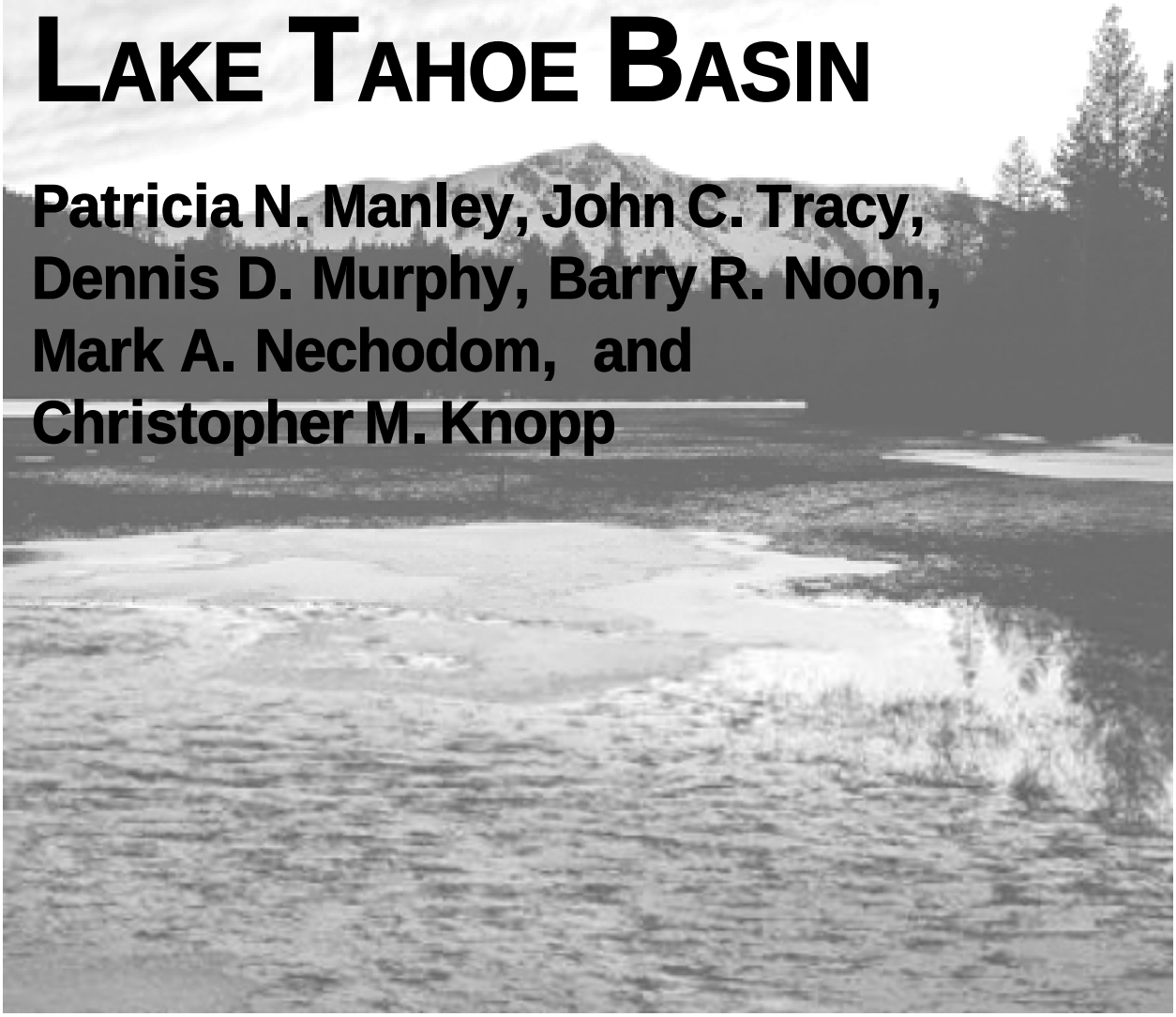
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CHAPTER SEVEN
ELEMENTS OF AN ADAPTIVE MANAGEMENT STRATEGY FOR THE LAKE TAHOE BASIN

Patricia N. Manley, John C. Tracy, Dennis D. Murphy, Barry R. Noon, Mark A. Nechodom, and Christopher M. Knopp



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CHAPTER SEVEN

ELEMENTS OF AN ADAPTIVE MANAGEMENT STRATEGY FOR THE LAKE TAHOE BASIN

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Introduction

Adaptive management is resource management informed by research and monitoring. This chapter presents some key elements of an adaptive management strategy that can help managers and policy-makers in the Lake Tahoe basin proceed with restoration efforts in the face of limited information. With constant feedback and revision, management can become more effective, efficient, and accountable. Because adaptive management essentially entails "learning by doing," as well as "action based on learning," management actions, data gathering, and decision-making must interact and keep pace with each other. Ideally, management and research are designed to maximize information gain, the course of management is readily evaluated in light of new information as it becomes available, and management direction is efficiently revised in response. To do so, coordination of science and management in the Lake Tahoe basin will be paramount—new lines of communication and inter-organizational links will be necessary.

Establishing an effective adaptive management process will take time and investment. The Lake Tahoe basin has already made substantial investments in data acquisition, information management systems, and formal and informal mechanisms of communication. However, the rate at which management and restoration activities must be applied in the basin in order to meet current conservation and restoration goals suggests that time is of the essence and that development and implementation of an adaptive management strategy is critical.

Previous chapters of this assessment have documented degraded elements of the Lake Tahoe basin ecosystem. If left unchecked, this degradation poses a threat not only to the sustainability of natural ecosystem processes within the Lake Tahoe basin but to the sustainability of the basin's social, cultural, and economic systems. Lake Tahoe's recreation-based economy depends to a large degree on the health of its forests, the availability of scenic alpine vistas, and the quality of the lake's waters. The simple recognition that the health of the society and economy of the basin is related to the health of the environment underscores the need to assess the conditions and trends of the basin as a whole system.

Although a complete understanding of the integrated nature of resources in the Lake Tahoe basin has not been achieved, restoration activities need to proceed. Approximately $200 million already has been spent since the early 1980s on improvements to ecosystem health within the basin. Another $187 million has been invested in state and federal acquisitions of ecologically significant lands in urban intermix areas. The Tahoe Regional Planning Agency's Environmental Improvement Program (EIP) in 1998 identified $900 million in future projects to restore the Lake Tahoe basin to a more desirable condition. However, no specific process has been developed for integrating the role of science into the implementation of the EIP. Scientific research will continue within the basin, but, without focused effort, it cannot be well coordinated with management nor can it efficiently contribute to meeting management goals.

The concept of adaptive management was developed more than three decades ago, based on the observation that science and management were engaged in an inefficient partnership (Walters 1986). It is often described as a cycle analogous to cycles of

birth, death, and rebirth. New information and changing perceptions, needs, and desires force the death of old ideas, structures, and processes. A period of disorganization is followed by revitalization, as the birth of new approaches, paradigms, and directions emerge from the synthesis and evaluation of new information and context. When new directions and approaches become solidified, a period of stability follows in which management direction, procedures, and protocols are made institutional and routine. This stable phase abides until new information and changing social preferences once again precipitate a period of reorganization.

In a much more applied sense, the cycle of adaptive management can be described in four phases: information needs, information acquisition and assessment, evaluation and decision-making, and management actions. This chapter focuses on two of the four phases: an in-depth discussion of the information acquisition and assessment phase of the cycle and a brief reference to how information can best be transferred to the evaluation and decision-making phase. The other two stages are critical to developing a fully functioning adaptive approach to the management of resources in the basin; however, they largely pertain to public policy development and participatory evaluation processes rather than to the direct relationships between scientific research and management.

The information acquisition and assessment phase of the adaptive management cycle includes research, monitoring, and modeling activities, which provide new information for making management decisions (Figure 7-1). Each of these three activities is an essential and complementary component of the information gathering stage of adaptive management. Research, monitoring, and modeling are identified in Figure 7-1 as three distinct activities in the

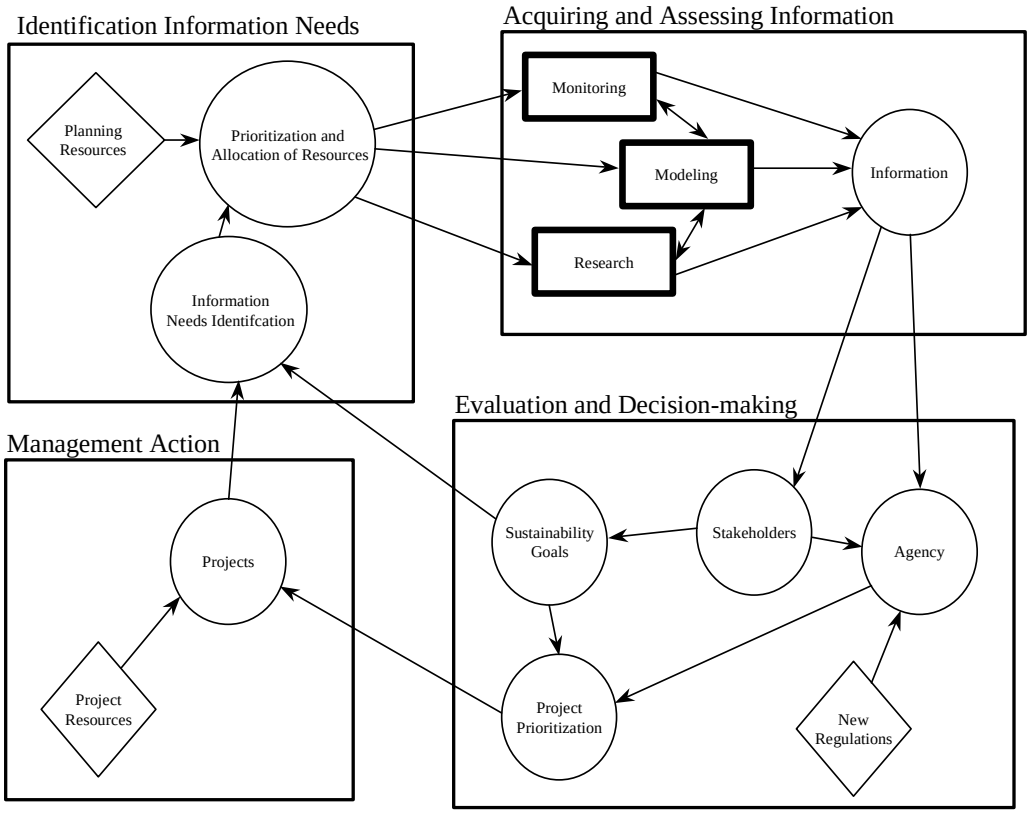


Figure 7-1—A schematic diagram of an adaptive management planning cycle.

information gathering and assessment phase of an adaptive management cycle; however, in practice they are highly interconnected. Research provides new knowledge about system interactions and dynamics, including basic information about resource interactions and validation of assumptions used in developing management direction. Scientific research can be used to understand processes related to environmental conditions, which in turn can be used in making decisions about how to monitor a given activity. Monitoring helps us to understand the status and trends of resource conditions, to assess progress toward management goals, and to develop a better understanding of management effectiveness. Monitoring data can either be used directly as decision-making information (to assess compliance with existing regulations) or it can be synthesized to evaluate the effectiveness of decisions (whether a restoration activity is having the desired effect). Modeling can be used to extract more information and to learn from data collected through research and monitoring efforts. Synthesized monitoring and research data can also be used to improve process descriptions or to adjust parameters in order to refine models that describe watershed behavior. Modeling tools can be used to support management decisions, to help decision-makers understand trade-offs among various management options, and to facilitate broader public involvement in decision-making. Together, research, monitoring, and modeling increase our scientific understanding of ecosystems and their responses to management actions.

This chapter outlines the key elements of an adaptive management strategy and discusses how scientific information can be efficiently generated and effectively applied to management in the Tahoe basin. To do so the chapter departs from the rest of the document by offering direct recommendations for developing and implementing an adaptive management strategy for the basin. The status of research, monitoring, and modeling activities in the Lake Tahoe basin are described in this chapter in relation to future acquisition and application of assessment tools and efforts. We present some approaches to adaptive management that have shown success in other geographic areas and then close with a description of some next steps that would bring the basin closer to the ecosystem health objectives articulated during the Presidential Forum in 1997.

The Role of Science and Research in Adaptive Management

The role of science in the adaptive management of ecosystems broadens scientific research as it is usually defined. While science in adaptive management includes the acquisition of new knowledge through basic research, scientists must also assist managers in the interpretation and incorporation of new knowledge as it applies specifically to management problems. Scientists have become increasingly involved in land management planning and analysis as concerns for the sustainability of biophysical and sociocultural systems have become more pervasive. Examples are many. Regional examples include the science-driven forest planning efforts in the Pacific Northwest, in which two decades of research focussed on imperiled species, the structure and function of old-growth forest stands, and the physical processes that sustain both have redefined management practices and definitions of sustainability. Closer to Lake Tahoe, the CalFed Bay-Delta Ecosystem Restoration Program uses focussed research, coupled with large-scale management intervention and pilot studies, all subject to scientific review, to provide conservation planning guidance in the face of political and economic uncertainties. Even on private lands, basic research and effectiveness monitoring are paired to inform a more than five-million-acre habitat conservation plan in response to endangered species concerns in Clark County, Nevada.

The newly expanded role of research encompasses the following activities: (1) developing new information of relevance to land management planning, (2) approaching research in a more integrated manner, working across disciplines and at larger scales, (3) packaging information so that its meaning and application are readily accessible to nonscientists, (4) working directly with managers to develop and implement adaptive management experiments and monitoring, and (5) participating in the planning process by providing scientific validity assessments of current information and its applicability to individual planning and implementation

efforts (Committee of Scientists 1999). These activities warrant the more detailed discussion below.

Development of New Information

The acquisition of new information through research can take the form of passive or active adaptive management (Walters 1986). Passive adaptive management refers to the linear sequential process of gathering information on system conditions and responses using a single model of system dynamics. The validity of the system model (i.e., the current understanding of resource links and interactions) and the management approach are tested with data. Modeling and management approaches are revised if necessary, then new data are gathered to evaluate the revised system model and management regimes. Active adaptive management, in contrast, is supported by the formulation and testing of multiple models simultaneously in an effort to speed the process of information acquisition and to improve management more rapidly. Actively probing areas of uncertainty on an experimental basis is a hallmark of active adaptive management.

In their recent report, which reviewed and recommended amendments to the National Forest Management Act, the Committee of Scientists highlighted the complementary nature of passive and active adaptive management and suggested that a combination of passive and adaptive management provides the strongest approach to information acquisition. Data acquisition that contributes to passive adaptive management consists of (1) monitoring system conditions to assess changes over time, (2) evaluating the effectiveness of specific management directions already in practice (effectiveness of riparian protection zones in meeting intended goals), (3) validating assumptions adopted in the formulation of existing management direction, and (4) generating new basic information on system form and function (Committee of Scientists 1999). The combination of these data provides useful information but may not reduce key uncertainties about system function, integrity, and trajectory. It is active adaptive management that provides this service.

Active adaptive management reduces uncertainty more efficiently than passive adaptive management through a number of approaches as follows:

- Identifying explicitly key areas of uncertainty;
- Formulating multiple competing models or hypotheses regarding system function;
- Assigning probabilities to alternative outcomes generated by competing models;
- Testing iteratively competing models at a scale commensurate with management;
- Whenever possible, designing management actions in an experimental framework (versus experimentation being carried out independently from management);
- Working collaboratively across disciplines and at large geographic scales; and
- Taking advantage of environmental "surprises" (large-scale stochastic events) by studying them to learn more about system dynamics.

These data are intentionally pursued to help answer specific questions related to key uncertainties about system function and trajectory in an efficient and cost-effective manner. However, the sometimes narrow focus of active adaptive management research can miss broader, perhaps unexpected, changes in system conditions that may convey a great deal of information. It is passive adaptive management that can provide this service. In addition, discoveries from basic research can and will provide unexpected keystones to understanding system dynamics.

Who decides which research questions are most relevant, what information to be obtained has highest priority, and who will be most successful in conducting the research in a timely manner are important open questions. Funds and time are always limited. At a broader scale, several institutions, such as the National Science Foundation (NSF) and the National Institute of Health (NIH), fund hundreds of millions of dollars of research each year. A peer review process has proved to be an effective and scientifically defensible means to evaluate and prioritize research proposals for funding. NSF, for example, establishes panels of scientists each year to allocate funds to scientists for research; in turn those panels call upon networks of peer reviewers to evaluate proposals in diverse topic areas. In the Lake

Tahoe basin, the process of information prioritization and resource allocation is not well developed and is often conducted ad hoc. Restoration goals within the basin would be better served by the establishment of a formal prioritization and allocation process that involved scientific review.

The coordination of scientific activities with management actions is at the core of an adaptive management approach. Scientific research used to increase knowledge of the Lake Tahoe basin must be closely coordinated with management activities in order to achieve the restoration goals set for the basin. For example, experiments can be designed around restoration activities. Active restoration efforts can constitute significant environmental disturbances, and therefore can be used as impact variables in research design. In this manner, a wider set of research experiments can be undertaken, potentially leading to a greater and quicker understanding of ecosystem behavior.

Integrated Research

The broad range of contributions demanded of research in adaptive management presents new challenges both to individual scientists and to the agencies that employ them. Among those challenges is the growing need for research institutions to work collaboratively with one another—acknowledging the normally competitive nature of funding and hiring practices. In addition, the rewards for participation of scientists in environmental planning commonly do not conform to conventional measures of productivity (peer-reviewed publications). Finally, adaptive management calls for new roles for science that lie outside the formal academic training of most scientists.

Full engagement of research in adaptive management will require a change in how scientists are viewed in the workforce. Both research institutions and management agencies need to invest in staff scientist positions that reflect the expanding spectrum of contributions required to approach land and resource management in an adaptive manner. As is suggested below, a coalition needs to be formed among the research institutions in the Tahoe basin, and, in turn, they need to join forces with management agencies and stakeholders to define a research agenda that most appropriately serves the breadth of contributions from science. Progress on these fronts will require risk-taking, motivation, institutional support, and funding.

Packaging Scientific Information

Generating new information is only one of several important steps in adaptive management. McLain and Lee (1996) posit that effective management requires societies not only to acquire knowledge but also to change their behavior in response to new information about the systems in which they live. An organization's effectiveness and responsiveness can be measured by its ability to translate information into appropriate action (Westley 1995). Receptivity to new information depends in part on the form of scientific information. Research has a role not only in generating new information but also in facilitating access to information and in packaging information in a manner that can be readily understood and assimilated. Based on the successes and failures of previous land management planning efforts, Westley (1995) identified characteristics that promote a rapid incorporation of information into decision-making processes: results are unambiguous and presented and explained simply, interpretation of the results is placed in a management context (i.e., low probability of multiple interpretations), and results and potential implications are packaged in the context of the problem at hand (place-based assessments with predefined issues and applications).

It is important not to underestimate the capacities of the management and policy communities to understand and assimilate scientific information. However, patterns of knowledge acquisition and use can differ widely among the end users of that knowledge (Weeks and Packard 1997). It is incumbent upon scientists actively involved in adaptive management to present results in a manner that is not unnecessarily laden with technical jargon, to assist in translating new knowledge into an applied language of management and policy, and to highlight links between new information and current land management objectives.

The Role of Monitoring in Adaptive Management

Monitoring will be an integral part of adaptive management of the Lake Tahoe basin. Also referred to as environmental surveillance, monitoring is 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 context of the watershed assessment, an expanded definition that encompasses three different forms of monitoring is appropriate: monitoring of management activities in relation to planned activities (implementation monitoring), monitoring of the status and trend of resource conditions and their change agents (status and trend monitoring), and monitoring of the effectiveness of current management practices in achieving desired conditions or trends (effectiveness monitoring).

It is helpful to further differentiate status data from trend data. The most common reason to monitor specific environmental indicators is to detect differences in values among locations at a given time (status) or differences in value across time at a given location (trend). For example, changes in observed Secchi disc depth as an indicator of lake clarity are useful in that they indicate adverse changes in the ecosystem of the basin. Such trend data are particularly valuable information because they can signal potential future conditions associated with system degradation. Nonetheless, the timeframe for status and trend monitoring is frequently left unspecified because of uncertainties inherent in funding and the impacts of human behavior and population growth. But while timeframes may not always be readily specified, three key features of monitoring efforts always serve the adaptive management process: identification of the goals, objectives, and questions to be addressed, selection of indicators and their interpretation, and application of monitoring data to management decisions. These three areas are addressed below.

Monitoring Goals, Objectives, and Questions

The overarching goal of monitoring is to determine whether current management practices are maintaining the ecological integrity of the target ecological systems, as well as achieving socioeconomic objectives related to needed goods and services. In the Lake Tahoe basin, the main objective of monitoring is to provide information on the condition of biological, physical, and socioeconomic resources and how management is affecting those resources relative to desired effects. A monitoring program for the Lake Tahoe basin must be able to describe the status and trends of resource conditions and to differentiate the effects of environmental factors that are outside the control of managers (intrinsic variation) from the effects of management activities (human-induced patterns of change) on resource conditions.

Specific management objectives and desired conditions have been developed for the Tahoe basin in the form of agency direction, primarily represented by TRPA's thresholds and the Forest Service's standards and guidelines, with additional direction in the form of specific management direction for state lands and municipal land holdings. These sources of direction need to be melded into a cohesive set of information objectives to be addressed through monitoring. Once these monitoring objectives are established, they need to be refined by considering the purpose that information will serve and how it will be applied to decision-making. The National Research Council (NRC 1995) has identified two general approaches, "retrospective" and "predictive" monitoring, to designing monitoring programs that serve to circumscribe the primary monitoring purposes. As the NRC suggests, "retrospective or effects-oriented monitoring seeks to find effects by detecting changes in status or condition of some organism, population, or community." Retrospective monitoring identifies resource attributes of interest, the primary environmental factors that could influence their condition, and the management actions that are likely to also affect their condition (intentionally or otherwise). Retrospective monitoring does not require knowing cause-and-effect relationships. In contrast, "predictive or stress-oriented monitoring seeks to detect the known or suspected cause of an undesirable effect (a stressor) before the effect has had a chance to occur or to become serious." Predictive monitoring is more narrowly focused on expected changes and requires the identification of cause-effect relationships between stressors and resource conditions.

Both retrospective and predictive effects monitoring have value for the Lake Tahoe basin. They provide complementary information about resource conditions, management activities, and the environment, improving the ability to differentiate the effects of management from other environmental influences. While retrospective monitoring provides a broad spectrum of information about resource conditions and potential influential factors, predictive monitoring provides more detailed information on a more limited set of conditions that are suspected to be at greater risk of detrimental change.

Once the balance of emphasis on retrospective and predictive monitoring is determined, monitoring questions can be developed. For example, monitoring questions to address the amount and distribution of old-growth forest at Lake Tahoe might include the following:

- Is management direction being followed in management actions? (implementation monitoring);
- What is the amount and distribution of forest age classes, including old-growth forests, at the landscape scale and how is it changing over time? (status and trend monitoring);
- What are the distributions of patch size, patch interior area, and interpatch distances for old-growth forests at the landscape scale and how are they changing over time? (status and trend monitoring);
- What is the biological diversity in old-growth forests and how is it changing over time? (status and trend monitoring);
- What is the correlative relationship between tree mortality and biological diversity in old-growth forests and key stressors (air quality, fire, recreational uses)? (effectiveness monitoring);
- What changes have been produced by management actions in the amount and distribution of forest stand structure? (effectiveness monitoring); and
- Is management effective at leading to an increase in the amount and distribution of old-growth forest? (effectiveness monitoring).

Monitoring is most informative if it includes monitoring of stressors as well as resource conditions. Environmental stressors are anticipated extrinsic factors that may compromise the integrity of the ecosystem and its component resources. Stressors, as defined here, can be both human-induced and "natural."

To return to the example of old-growth forest monitoring, stressors that might be included in a monitoring scheme that targets old-growth forests include the following (also see Barber 1994):

- Prescribed and natural fire as a link to loss of late seral habitat;
- Dams and diversions as links to alterations of hydrologic cycles;
- Altered climatic regimes as links to increased sediment loads to streams from storms;
- Urbanization as a link to the reduction, loss, or fragmentation of habitat;
- Road construction as a link to changes in the horizontal transport of mineral and nutrients; and
- Air pollution as a link to reduction in lake clarity from atmospheric deposits of nutrients.

Cause-and-effect relationships may be more credibly derived from a monitoring program when the status of stressors is accurately documented. Again, the choice of indicators and stressors is necessarily guided by the questions one seeks to address.

The Use of Conceptual Models for Indicator Selection

A well-constructed and well-implemented monitoring program should explicitly link scientific knowledge of ecosystem conditions to the selection and interpretation of indicators. The use of conceptual models of system dynamics to inform and document indicator selection is recommended by the NRC (1995) and is becoming an increasingly common practice (Noon et al. 1999; Manley et al. in press). The likelihood of choosing appropriate indicators is greatly improved if a monitoring scheme's conceptual model thoroughly characterizes system dynamics and accurately reflects the effect of stressors on system conditions. Furthermore, the use of

well-designed conceptual models can enable a monitoring program to investigate relationships between stressors and environmental consequences, and it can provide the foundation for developing detailed predictive models.

Well-developed conceptual models outline the interconnections among ecosystem resources (key system components) and between ecosystem resources and environmental stressors, the strength and direction of those links, and attributes that characterize the state of the resources and stressors. Models should demonstrate how systems work, with particular emphasis on anticipated system responses to stressors. Conceptual models also should indicate how systems respond to natural disturbances (changes in successional pathways) and how they develop resilience to disturbance. In most cases it will be sufficient to model restricted, but relevant, components of systems to identify appropriate indicators and to provide a foundation for more detailed modeling. In other words, complete descriptive models of ecosystems are seldom necessary in order to proceed with a reliable monitoring program.

As a general goal, management associated with most monitoring programs will strive to maintain ecological and associated sociocultural processes. Many ecological processes, however, are difficult or impossible to measure directly. Conceptual models can identify structural and compositional components of the resources affected by underlying processes. A conceptual model should clearly identify the processes and pathways by which stressors are linked to changes in ecosystem composition, structure, and process and how particular indicators are suited to represent these stressors, conditions, and processes.

The ability to measure and draw inferences from ecosystems is affected by the scale of observation. The temporal and spatial scales at which processes operate and resources respond must be estimated and identified in the conceptual model in order to determine the appropriate scale of measurement for a given indicator. Conceptual models with hierarchical structures are helpful in addressing multiple scales. Ideally, the model will reflect processes that operate at a range of temporal and spatial scales and that accommodate the constraints operating at each scale (Allen and Starr 1982; Allen and Hoekstra 1992). For example, Noon et al. (1999) developed a worksheet to characterize stressors and their anticipated effects on ecosystems and their component elements, where scale was considered by allocating the effects of specific stressors to various levels in the ecological hierarchy—landscape, community/ecosystem, population/species, or genetic levels (see also Noss 1990).

Selecting and Interpreting Indicators for Monitoring

Once monitoring questions have been articulated and a conceptual model has been developed, appropriate indicators can be selected. By convention, measured environmental attributes are referred to as indicators, under the assumption that their values in some way indicate the quality, health, or integrity of the larger system to which they belong (Hunsaker and Carpenter 1990; Olsen 1992). The ultimate success or failure of an adaptive management program may be determined by the selection of indicators. Even if a monitoring program is fully funded and implemented for many years, it will fail to be effective if the wrong indicators are selected. For purposes of this watershed assessment, environmental attributes at Lake Tahoe can be broadly defined to include biological, physical, and socioeconomic features that can be measured or estimated.

The task of detecting and recognizing meaningful change in ecosystems is complex because those systems are inherently dynamic and spatially heterogeneous. Moreover, many changes are not human-induced and in many cases are not amenable to management intervention. At least three kinds of changes are inherent in natural systems: stochastic variation, cyclic variation, and successional trends following disturbance. These changes, or sources of variation, need to be recognized and accounted for in a monitoring program in order to differentiate their effects from management effects on resource conditions.

Indicator selection processes should closely follow the goals, objectives, and questions established for the monitoring program. The same resource may be monitored using very different indicators, depending on whether the objective is to describe the status and trend of an ecosystem condition (retrospective monitoring) or to obtain an early warning of detrimental change in a condition (predictive monitoring). For example, on a parcel of

public land, the Endangered Species Act may require monitoring of the status and trend in the population of a high trophic level vertebrate predator, such as the bald eagle. The life history of this species (long-lived, high survival rate, low fecundity, and high site fidelity) exhibits lags in its response to environmental change. Status and trend monitoring would require measuring attributes that tend to change in longer cycles. However, if the goal were to seek early warning signals for declines in bald eagle populations, then related attributes that change more quickly, such as sizes of prey populations, condition of roost sites, or survival of young, would be more appropriate to monitor.

A variety of evaluation criteria are helpful to consider in selecting indicators. Once a conceptual model is developed and consulted, candidate indicators can be proposed for monitoring and subsequent field-testing. Indicators should meet the following criteria:

- They should reflect underlying ecological processes and changes in stressor levels;
- They should represent the larger resource of which they are a structural or compositional component; and
- They should be measurable.

Before field or simulation testing, the list of candidate indicators can be narrowed to identify *final* indicators by focusing on those with the following properties:

- They should exhibit dynamics that parallel those of the larger environmental component or system of ultimate interest;
- They should show a short-term but persistent response to change in the status of the environment;
- They should be accurately and precisely estimated;
- The likelihood of detecting a change in their magnitude should be high, given changes in the status of the system being monitored;
- Each should demonstrate low natural variability or additive variation, and changes in their values should be readily distinguishable from background variation (i.e., a high signal-to-noise ratio); and
- The costs of indicator measurement should not be prohibitive.

Additional evaluation criteria for screening candidate indicators are presented by the National Research Council (NRC 1990) and in Barber (1994).

Considerations in Data Collection

In general, determining the status of an indicator is a challenge in estimating the value of an unknown parameter within some specified bounds of precision. Estimates of trend address the pattern of change over time in the status of the indicator. How to efficiently acquire these estimates lies in the realm of survey and sample design (Cochran 1977). Proper design requires substantial statistical expertise; fortunately, there exists a large body of statistical literature on parameter estimation, hypothesis testing, and trend estimation that is relevant to monitoring (Sauer and Droege 1990). Some debate exists over whether parameter estimation or hypothesis testing is the correct statistical framework for monitoring (Stewart-Oaten 1996). For purposes of a Lake Tahoe basin adaptive management strategy, implementation and status and trend monitoring are best served by parameter estimation, whereas effectiveness monitoring is best approached through hypothesis testing.

Determining effect size and statistical power is an important element of monitoring design. Effect size (the magnitude of change to be detected), the precision of estimation (Type I error rate or alpha), and sample size are intradependent. A monitoring program should be able to detect the magnitude of change in the value of an indicator or, in statistical terms, the effect size. Acceptable levels for a type I error (concluding a change or difference when none exists), type II error (concluding no change or difference when in fact one exists), natural variability of the indicator, and the sensitivity of the test determine the effectiveness of a sampling effort for a given effect size.

Statistical power is a function of the probability that a difference of a given size will be detected (i.e., power = 1 - type II error rate). Managers must implement monitoring programs with sufficient statistical power to detect meaningful changes in the values of the indicators. For monitoring de-

signs and analyses to be meaningful, a desired statistical power should be selected before it is implemented to determine sample size needs. Also it should be calculated after monitoring data is gathered (post hoc) in order to interpret the true power of tests that failed to detect a change or to reject the null hypothesis differences (see Skalski 1995 and Zielinski and Stauffer 1996).

In practice, addressing questions of statistical power requires determining the minimal magnitude of change in the indicator variable that is environmentally significant (this value must be estimated by a scientifically defensible process). Initial estimates of an appropriate effect size applied to the indicator can be based on spatial or temporal variations under baseline or reference conditions (Skalski 1995). Given this information, practical sampling issues, such as numbers of samples and resampling intervals, can be addressed. A comprehensive discussion of statistical power and its relevance to decision-making in the context of responsible management of natural resources is found in Peterman (1990). Emphasis should be placed on minimizing the risks of type II errors as opposed to type I errors, particularly when declines in resource conditions are irreversible (see Shrader-Frechette and McCoy 1993).

Interpreting the Ecological and Management Significance of Indicator Values

Ecosystems are complex systems subject to stochastic variation and unpredictable behaviors. It should not be surprising that the task of monitoring whole ecosystems and drawing reliable inferences to system integrity has historically proven to be such a daunting task. Interpretation of the significance of changes in the value of an indicator is complicated by nonlinear cause-and-effect relationships between indicators and stressors. However, indicator values must be interpreted in reference to "trigger points" or "thresholds" in order for monitoring results to be applied to management decisions and actions.

The term "thresholds" is used in this discussion in a different manner than the legally binding "environmental carrying capacity thresholds" that underpin the regional plan in the Lake Tahoe basin. In ecosystem theory, a threshold is a magnitude of change or a particular value of an indicator (condition or stressor) that may herald declines in the larger ecosystem. At Lake Tahoe, the term threshold also applies to management thresholds, broad indicators of ecosystem health that were established to alert policy-makers to conditions incompatible with desired conditions for the basin. To avoid confusion, we use the term "trigger point" to refer to ecosystem thresholds associated with individual indicators.

Trigger points serve as red flags intended to raise awareness and prompt response by managers or policy-makers. Trigger points can be designed to provide an early warning of undesirable changes, or they can be poised at an estimated juncture of irreversible environmental degradation. Responses to such trigger points might range from simply revisiting conceptual models and management effectiveness to actions that include a moratorium on development (such as what occurred during the 1980s in the Tahoe basin), direct ecosystem intervention and restoration activities, and changes in land management policies and practices. The identification of a trigger point depends on the intended response; therefore, it is important to clarify the function of a given trigger point, as well as the appropriate response, during the design of the monitoring scheme. Importantly, effect sizes and trigger points should be considered in concert with one another. If trigger points are designed to serve an early warning function, then effect size can be calibrated to detect changes similar in size to differences between current conditions and the trigger point. However, trigger points that identify irrevocable degradation should be accompanied by effect sizes small enough to detect a trend toward that point.

Defining the trigger point of an environmental indicator that can determine a management response is difficult and complex. But existing management direction in the Lake Tahoe basin actually provides a solid basis by which monitoring thresholds may be determined. As a general rule, as the risk of environmental loss increases, trigger points should be made more sensitive. Threshold values for environmental indicators may be established by reference to documented historical values or preliminary baseline monitoring of a nonaffected or "pristine" system may be conducted. In the absence of

reference systems or adequate historical data, it is difficult to establish expected values or require a given future trajectory of indicator variables. Nonetheless, trigger points must be identified as thoughtfully as possible. Incomplete historical data combined with some notion of a "desired future condition" must serve as the basis for identifying trigger points (see discussion in Bisson et al. 1997). Models can help in this pursuit by providing predictive capabilities and appropriate trigger point values.

All evaluations of monitoring data, including trigger points, require that the appropriate data analysis also be determined before monitoring data are collected. For each indicator, will one summary value be estimated for the entire basin, or will values be estimated for multiple analysis units? Is the spatial distribution of conditions of interest? Each of these options likely calls for different sampling considerations, analysis approaches, trigger points, and management responses. Sampling and analysis approaches need to be fully developed before data collection begins, if data collection is to result in useful information.

Monitoring has limitations. Care must be taken to understand what can and cannot be inferred legitimately from monitoring data, particularly when the ability of a monitoring program to assess attainment of management objectives is judged. Monitoring programs can neither unambiguously ascertain the cause of a change nor decide on how much change is acceptable. Moreover, monitoring programs themselves cannot decide on the threshold values of indicators that will trigger specific management actions. Monitoring simply provides data as designed, much like any research effort. It is the responsibility of scientists and managers to ensure that the monitoring design is scientifically sound and that it meets the information needs of managers and policy-makers. If monitoring results indicate that conditions lie outside an acceptable range, specific changes in land management practices or resource policy should be triggered. Facilitating the transfer of monitoring results to the decision-making phase is a critical consideration in the design and implementation of a monitoring program. The reception and application of monitoring results belongs in the subsequent phase in the adaptive management cycle, the evaluation and decision-making phase (Figure 7-1). An effective information transfer strategy involves and informs decision-makers early and often in the processes of data collection and analysis. This is so that the data and results are familiar and decisions can be made. It provides frequent and readily understandable reports of progress in monitoring so that the information is available to interested parties. And information transfer strategy packages assessment and evaluation reports in a manner that is accessible to nonscientists and that directly addresses the questions facing management.

The Role of Modeling in Adaptive Management

As chapter five suggests, it may take up to thirty years to see changes in clarity that result from immediate reductions of nutrients going into Lake Tahoe. Some scientists have concluded that if the buildup of nutrients in the lake is not reversed within the next ten years, the costs of solving the problem will be so great and the impacts so extreme that they will exceed the currently available capacity for resolution. This situation creates a unique dilemma. How do we ensure that the actions taken during the next ten years will be effective when it may require three decades to obtain measurable results? The only practical solution is to understand the ecological system sufficiently to model accurately the effects of various management treatments and thereby to predict future consequences of today's actions. This challenging situation illustrates why computer modeling is an essential component of an adaptive management strategy for the Lake Tahoe basin. Modeling provides an opportunity to look ahead to the likely outcomes of management approaches and facilitates adjustments to management before thresholds are crossed.

Models are increasingly being employed in watershed management planning efforts. The South Florida-Everglades Restudy Project uses simulation models to illustrate ecosystem responses to water management strategies to direct research efforts in hydrology and ecology. A model developed in a consensus process involving agencies and stakeholders simulates hydrologic and economic processes in the

Devil's Lake, North Dakota, watershed allows for adaptive flood control and protection. And decision support systems, simulating key biotic processes, use economic and agricultural inputs to guide maintenance of the Upper Snake River Basin in Wyoming and Idaho.

Types of Models and Their Applications

Models can serve a variety of purposes. In a management context, models can clarify system functions, conditions, and trajectories and can facilitate translation of scientific data into information for decision-making. Ecological models can also serve as links between the natural sciences community and the public sector, using mathematical and statistical relationships to translate the language of the physical, biological, and social sciences into the language of social preferences (see Figure 7-2). Effective modeling depends on the availability of scientific information generated through research and monitoring. However, models can also be used to cope with information gaps in decision-making processes.

A variety of models exist, five of which can be outlined in terms of their general function and potential contribution to management and planning in the Lake Tahoe basin: conceptual, quantitative, statistical, predictive, and decision support models. Conceptual models illustrate the components of a system and their links but do not contain quantitative information regarding component interactions or their outcomes. Quantitative models display numerically defined relationships among ecosystem components, typically consisting of mathematical relationships or logical arguments. Statistical models are a subset of quantitative models in which quantitative relationships are established and derived through statistical analyses. Predictive models are a subset of statistical models in which statistically derived relationships are used to predict the value of a resource of interest through time or space. Finally, decision support models use a variety of models to establish a scientific foundation upon which multiple interests and stakeholders can weigh the consequences of various management options.

The ideal modeling tools for the Lake Tahoe basin will efficiently and accurately describe and predict the effects of background environmental factors or management activities on air, water, and biotic resources, and socioeconomic conditions. Such modeling tools can be used by agencies and citizens groups involved in decision-making in the basin to evaluate management options and to develop social consensus on expected conditions of each resource. It is unrealistic to expect immediate development of such modeling tools, primarily because they take many years to develop; however, a strategy for model development should be part of an integrated adaptive management plan for the Lake Tahoe basin.

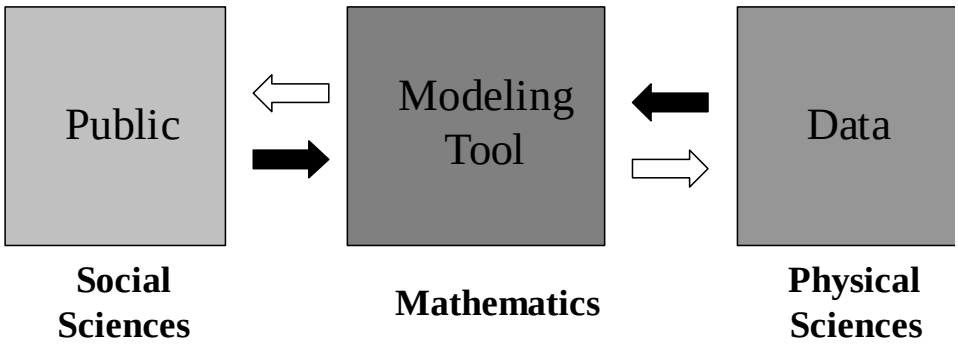


Figure 7-2—The role of modeling as a tool to aid decision-making.

Taking a Systems Approach

Models are simply manifestations of a view of certain discreet aspects of the world around us. A "systems approach" to modeling is particularly applicable to adaptive management for three reasons. First, a systems approach explicitly recognizes the dynamic nature of ecosystems and management direction. Management does not proceed in a linear fashion but rather adjusts in response to predictable, as well as unexpected, events as do natural systems. A systems approach builds into models the ability to accommodate unexpected changes and to amend models as scientific knowledge advances and the needs of decision-makers change. Second, a systems approach works toward linking the information acquisition and assessment phase (research, monitoring, and modeling) to the other phases of the adaptive management cycle. Foremost in a systems approach to modeling is development of a common set of environmental and socioeconomic variables that can serve as a common language shared by all contributors to the adaptive management cycle. In linking the elements of the adaptive management cycle using a common planning language, the flow of resources and information through adaptive management can be greatly enhanced. Third, a systems approach can readily accommodate both qualitative and quantitative models ranging from models of environmental interactions to models that can assist allocation of financial resources among research, monitoring, and modeling efforts. An ability to readily embed detailed quantitative models into broader conceptual models, such as the conceptual model supporting the selection of indicators, or the even broader model of the adaptive management cycle, is a highly valuable trait of the systems approach, allowing for a strong scientific foundation and useful informative tools for decision-making.

Criteria for Evaluating Model Utility

Four criteria are useful in helping to guide the development and evaluation of models in support of management: accuracy, efficiency, utility, and acceptance. The first model criterion, accuracy, describes the ability of a model to predict the behavior of a physical system, given a set of impulses to the system. Model accuracy can be assessed by comparing modeled output to actual measurements (empirical data), with the difference between the measured and modeled output serving as an index of accuracy. An alternative measure of model accuracy uses expert opinion to evaluate the accuracy of model predictions. To accomplish this, model simulations produce predicted outcomes based on a management scenario. Then, topic experts with knowledge of the focal system assess the accuracy of predicted outcomes. If no significant discrepancies are found between model simulations and expert opinion, the model can be considered accurate from a management perspective. If some significant discrepancies are found, further modifications to the model must be undertaken to resolve differences. The use of empirical data to assess model accuracy is preferable if data are available; however, the use of expert opinion is a legitimate and valuable approach to calibrating models in the absence of data.

The second model criterion, efficiency, refers to ready execution and updating of a model. Ideally, a fully developed model has no errors, never fails to execute, and is easily updated. Unfortunately, the more complex a model, the less efficient it tends to be. Complex models have a greater likelihood of embedded errors because they rarely go through formalized and rigorous error checking or debugging procedures. Errors in a model can render its results invalid, halt its execution, or make it difficult to be transported from one computer platform to another. In addition, ideally a model can be updated as improved estimates of model parameters are developed or a better understanding of system dynamics becomes available. As models become more complex, by necessity, modifications and updating become more expensive and tenuous. Models that have few problems related to these issues are referred to as robust, with the most robust models considered the easiest to maintain and execute by technical staff.

The third model criterion, utility, is an assessment of the accessibility and user-friendly character of a model. Specifically, the utility of a model typically relates to how well graphical user interfaces are designed to allow the user to input proposed management activities and to view predicted changes to the system. For models that are intended as decision-making tools, interfaces need to be developed

to produce a balance between ease of use and flexibility of simulation. Providing too detailed a list of all possible model outputs can result in information overload, making the results of the model difficult to interpret by the user. Alternatively, developing an interface that limits the range of management scenarios that can be modeled will prevent the evaluation of all possible management alternatives. To attain a high level of model utility, an equitable compromise between flexibility of simulation and ease of use for the model interface must be developed.

The fourth model criterion, acceptance, reflects how well users themselves believe that a model accurately predicts changes in the system submitted to modeling. In many respects, this is the most important consideration in the development of models to be used as decision-making tools for land management. A model that is not widely accepted can be used by an agency to develop management plans, but the risk is high that a debate among constituencies will focus on the validity of modeling results rather than on the effect of the management activities on the condition of the watershed. Acceptance will depend on the reliability of the information used to set parameters for the model, on the level of controversy associated with underlying assumptions used by the model, and on the socioeconomic relevance of the output.

Many of these criteria are conflicting and can be difficult to reconcile. For example, the accuracy of a model may require greater complexity. Every modeling exercise necessarily involves some level of compromise among each of the four issues, the appropriate balance will depend on the intended application of the model, and compromises in model performance should be determined based on communication and discussion between agencies and stakeholders, who ultimately will use the models, and the technical personnel involved in developing the models.

Integration through Modeling

Actions taken to improve the condition of one resource can significantly affect the condition of other watershed resources. Some understanding of the tradeoffs between the condition of each resource within the Lake Tahoe basin must be understood before satisfactory management goals and activities can be developed. In addition, where strong interactive variables exist between the resources, significant feedback loops can develop where the conditions of two or more resources sequentially interact to create a downward spiral in resource conditions. Feedback loops have been identified in the system dynamics literature as being important elements to consider in developing effective management plans for any system, natural or otherwise. If the feedback loops of a system are not thoroughly understood, an action taken to improve the condition of one resource within a watershed ultimately could degrade the condition of that very same resource or another. Models can provide substantial assistance in identifying, displaying, and describing such complex resource interactions.

An example of the challenges that resource interactions can present to managers is provided in Figure 7-3, which outlines how management activities can affect directly and indirectly the condition of multiple resources. A prescribed fire regime calling for more frequent fires may be intended to reduce fire risk to life and property and to improve the health of the forest ecosystem. However, a new prescribed fire regime may also have a number of unintended effects, such as smoke discharged into the atmosphere, increased nutrients released into the soil as ash, and increased water yield resulting from a reduction in plant cover. Additional unintended effects are likely to stem from direct effects and could include decreased visibility from airborne particulates, nitrogen deposition into Lake Tahoe from smoke particles, increased sedimentation from lack of plant cover, and potential declines in habitat conditions for species of particular concern. Qualitative and quantitative models can both be helpful in better understanding, anticipating, and avoiding undesirable unintended management effects in the course of pursuing management goals.

Decision Support Tools

Decision support tools are models designed to aid decision-making by clearly displaying what is known, what is uncertain, and what is predicted,

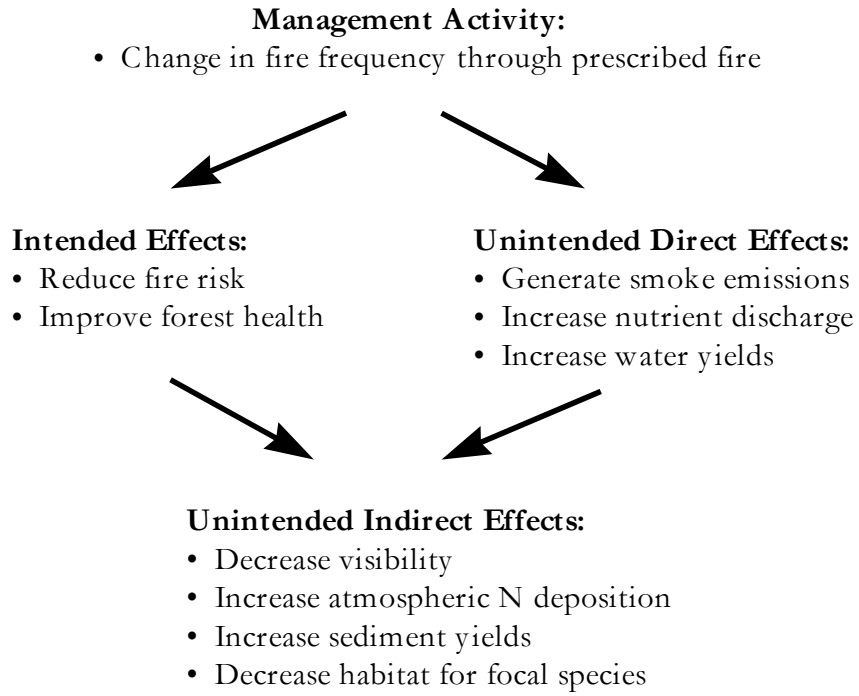


Figure 7-3—Example of intended and unintended effects that can result from a management action.

given various courses of action. A decision support tool for the Lake Tahoe basin should accurately predict the effect of any environmental factor or management activity on the condition of air, water, biotic, and socioeconomic resources within the basin. Decision support tools can be used by agencies and citizens groups involved in evaluating management options.

As discussed above, every model represents some balance of four basic attributes: accuracy, efficiency, utility, and acceptance. All of these attributes are critical to the success of decision support models, and model performance must be balanced among these attributes to achieve the best model for the application. A variety of previous studies have pointed out the need to compromise on these modeling issues (Keyes and Palmer 1995; Tracy 1995), especially when the models are to be used in a potentially contentious political environment. Keyes and Palmer used a collaborative process to develop "shared vision" models for conflict mediation in planning and management activities. Shared vision models attempt to represent resources and their links in a manner that can be understood and endorsed and that can make them accessible to all of the constituencies who are affected by or who influence decisions regarding the resource.

Ideally, a shared-vision modeling tool facilitates an integrated approach to information acquisition and allows decision-makers to predict and weigh the impacts of potential projects on management goals. A modeling tool that is intended to serve such a decision support role will have three primary elements: an input interface that allows decision-makers to input information related to regulatory and management activities, one or more technical modeling components, often referred to as "black boxes," and an output interface that allows decision-makers to view the impacts of their proposed actions on resource conditions. The combination of these three elements provides a powerful integrated management tool that can facilitate decision-making regarding difficult resource trade-offs. The elements that support such a tool warrant description.

The information required to develop an effective input interface element for an integrated de-

cision support model starts with a list of potential management and regulatory actions. Information on the spatial location, cost, time-scale of implementation, and expected physical impact are recorded for each action. A graphical user interface is needed to manipulate potential management and regulatory actions. A quantitative interpretation of how each management or regulatory action alters management variables in the resource models must be developed. Management agencies will have to collaborate with the scientific community to arrive at a consistent method to describe how the management variables will change due to a proposed activity. These methods obviously do not provide a perfect interpretation of how management activities alter parameters that govern the behavior of resources, but they can facilitate discussion and decision-making under uncertainty.

Only a small fraction of the processes that govern the condition of Lake Tahoe's resources currently can be modeled quantitatively. The quantitative models currently under development are state-of-the-science, hence their development was time consuming and expensive. It is not realistic to expect to be able to engineer quantitative models of similar rigor for every important process and resource interaction. A more tenable goal is to develop a modeling capability for each process that can be realized with existing information and that can be improved as better information and process models become available. Existing system dynamics modeling tools, such as STELLA and VENSIM, are available, but they do not have the capability of incorporating sophisticated process-based models in their simulations. Rather, a modeling platform that can integrate sophisticated process-based models with these more simplistic "stock and flow" modeling concepts should be developed. Such a modeling platform would allow for the rapid development of quantitative models for all of the watershed resource processes not currently being modeled within the Lake Tahoe basin.

Output Interface Element

The first step in developing an output interface element for an integrated modeling tool is to develop a set of variables that best describe the condition of each of the resources (air, water, biotic, and socioeconomic). The variables should be quantitative descriptions, which, if predicted accurately, will significantly help decision-makers understand whether regulatory or management actions improve or degrade the condition of each resource. Without methods to quantify the condition of each resource, no mechanism exists to convey how the condition of each resource is affected by regulatory and management actions. Variables that effectively describe the condition of each resource can be developed through a stakeholder process, where the variables are identified based on consensus among interested parties. An example of an integrated research, monitoring, and modeling effort at the watershed scale is provided in Table 7-1. It illustrates a design for collecting input data that facilitates useful output data in the form of appropriate descriptive variables. Ideally, these variables serve the needs to each phase of the adaptive management cycle, thus creating the common planning language discussed above in the context of a systems approach.

Information Acquisition and Assessment in the Lake Tahoe Basin

The preceding chapters provide in-depth information on the status of our knowledge in the four key issues areas addressed in the assessment. That information provides a base to answer three primary questions about the current state of knowledge and how best to improve on that knowledge:

- How well can we describe the processes that govern the behavior of air, water and biotic resources and socioeconomic conditions in the Tahoe basin?
- How well do we understand the relationships among air, water, biotic, and socioeconomic elements and the environmental, management, and interactive variables that link these resources in the Lake Tahoe watershed?
- How can current scientific information be used to evaluate potential future management investments and aid managers and decision-makers?

The current understanding of relationships among resources is examined here to better define data gaps regarding resource interactions (Table 7-2).

Table 7-1—Examples of information integration activities suggested by the watershed assessment that would immediately contribute to building an integrated information strategy.

Resource Area	Information Integration Activity
All	• Develop and implement a multiresource, basin-wide adaptive management strategy.
	• Develop, test, and refine a decision support model.
Air Resource	• Expand and improve air quality monitoring efforts.
Biotic Resource	• Develop and implement a prescribed fire implementation, research, and monitoring plan that integrates concerns and objectives across resource areas.
	• Develop and implement an old forest management strategy that includes monitoring and research elements.
	• Develop and implement a biodiversity conservation strategy for species and communities, including terrestrial and aquatic elements.
Water Resource	• Identify and quantify sources of biologically available nitrogen and phosphorus and adopt effective control strategies.
	• Integrate the results of the lake clarity model into a broader decision support model.
Socioeconomic Resource	• Embark on an effort to identify what constitutes a healthy and robust community for full-time residents of the basin.
	• Identify key links between socioeconomic well-being and environmental health.

Our analysis notes whether a given relationship can be described quantitatively or qualitatively, or if it cannot be described at the current time. Quantitative descriptions consist of equations that can be developed for use in predictive or descriptive models. For example, there is a relatively large body of knowledge on the relationship between traffic density and emissions from vehicle tailpipes; these relationships can be quantified and used to inform policy. Qualitative descriptions consist of statements regarding the positive or negative effect of changes in the state of one resource on the state of a linked resource. For example, it is understood that exposing bare soil by removing vegetation leads to a greater potential for hillslope erosion from precipitation. However, no quantitative descriptions have been developed that relate the increase in sediment load to streams as a function of the fraction of vegetative cover near a given stream. Relationships among resources that cannot be described at this time consist of interactions that are known but whose outcome is unknown—neither a positive nor a negative impact can be predicted. For example, little information exists on how a vegetated area disturbed by fire affects the flux of phosphorous to upland streams and eventually to Lake Tahoe. It may increase or decrease the flux of phosphorous to streams or the lake, but at the current time no scientific consensus exists on how the flux will change. This type of uncertainty precludes any predictive capability.

The vast majority of resource interactions can be understood only in a qualitative sense, with only a small set of links being understood quantitatively (Table 7-2). Some of the qualitatively described resource interactions are so uncertain that the direction, positive or negative, of the influence of a factor on a resource condition remains unknown. Opportunities to improve certainty about these interactions, including the ability to quantitatively describe and model relationships, vary by resource. In some instances, aspects of the relationship could be quantified if funds were made available to do so, whereas

Table 7-2—Current state of uncertainty regarding key links among resources and the factors that shape them.

Factors	Quantitative Links	Qualitative Links	Uncertain Links
Interactive Environ. Factors:			
Exhaust emissions	Air, socioeconomic.		
Nutrient flux		Air, biotic, water	Air, biotic, water
Sediment flux		Air, biotic, water	
Smoke emissions		Air, socioeconomic	
Visibility		Air, socioeconomic	
Development/urban landscape		Biotic, water, socioeconomic	
Water quality and quantity			Biotic, water, socioeconomic
Stream morphology			Biotic, water
Vegetative landscape		Biotic, water, socioeconomic	
Management Activities:			
Tailpipe regulations	Air		Socioeconomic
Fire management	Air	Socioeconomic	
Vegetation management		Biotic, water, socioeconomic	
Range management		Biotic, water, socioeconomic	
Fisheries management		Biotic, socioeconomic	
Wildlife populations		Biotic, socioeconomic	
Woodstove regulations		Air	Socioeconomic
Land use regulations		Biotic, water, socioeconomic	
Road management		Biotic, water, socioeconomic	
Independent Environ. Factors:			
Wind	Air	Biotic, water	
Temperature	Air, socioeconomic	Biotic, water	
Humidity	Air, water		
Precipitation	Biotic, water	Socioeconomic	
Evapotranspiration	Biotic, water		
Solar radiation	Biotic, water		

in other instances other factors are more limiting than funding, such as the difficulty in isolating a particular cause-and-effect relationship.

Where additional investments can lead to an improved understanding, the appropriate level of investment will vary depending on the uncertainty of the link. An improvement in the understanding of highly uncertain links typically is achieved by investing in scientific experiments to understand the basic behavior of the interaction more fully. An improvement in understanding of qualitatively described links is achieved typically by investing in monitoring activities that are designed to identify correlative relationships and to determine trend behavior. An improvement in existing quantitative models of links is achieved by investing in model development and monitoring activities that are designed to further calibrate and verify quantitative relationships.

Research Needs

The Lake Tahoe Watershed Assessment identified numerous issues of management concern that require further investigation through research and monitoring. Those efforts should include, but should not be restricted to, the research targets outlined below.

Air Quality

1. Increased air quality monitoring at several locations throughout the basin is a major priority. Desired information includes gaseous and particulate pollutant data that are important for lake clarity, forest health, atmospheric visibility, and human health. Measurements should include large particle phosphorous, nitrogenous species, nitrogenous gases, ozone, sulfate, and fine dust by particle size. At a minimum, collocating atmospheric monitoring stations with TRG deposition bucket samplers will contribute to reducing uncertainties that will otherwise limit the value of ecosystem management models. Ideally, these sampling sites would be placed in major watersheds to be representative of the entire basin-wide airshed.

2. Evaluating the contribution of prescribed fires and wildfires to diminishing lake clarity will be necessary to reduce the uncertainty regarding this important particulate matter source. For maximum utility this research should address both the amount and composition of particulate matter in domestic smoke, small, medium, and large prescribed fires, and wildfires. Forest fires are known to contribute large amounts of fine particulate matter to the atmosphere, but the coupling of this source of particulates to deposition and lake nutrification is necessary to make valid predictions of the ecosystem impact of fires used for forest management.

3. Research into transportation-related air quality concerns is needed to better understand the role of mobile combustion and re-entrained roadway dust at Lake Tahoe. Studies would best involve particulate and gaseous pollutant collection and analysis, detailed vehicle counts, and distribution of vehicle types by roadway, velocity, and acceleration. While it is unclear what the transportation contribution to ecosystem deterioration is, diesel and gasoline combustion is known to contribute substantial fine particles to the atmosphere. In addition, potentially large amounts of phosphorous and nitrogenous particulate matter may be re-entrained by automobiles mechanically grinding roadside dust. Evaluating these transportation-related pollutant sources could help reduce one of the largest uncertainties regarding pollutant sources in the Tahoe basin.

4. Mitigating air quality impacts depends on an accurate accounting of sources, both natural and anthropogenic (human-induced), and local and transported. Innovative sampling and analysis techniques will be necessary to provide information on gaseous composition, particle size and composition, and other signatures that link sources of pollutants to the basin or downwind receptor sites. Such studies will require detailed information about gases derived from the Central Valley, especially those arising from increased traffic on Interstate Highway 80 and State Highway 50. It is equally important to study aerosols on the western slope of the Sierra Nevada, especially those associated with potential increases in the use of prescribed fire.

Water Quality and Lake Clarity

1. There is a need to determine the portion of total phosphorus loading that is biologically available to algae in Lake Tahoe over ecologically relevant time scales. This information, in conjunction with increased knowledge of nutrient sources, is likely to provide the most immediate improvement in restoration efforts.

2. The preliminary nutrient input budget presented for Lake Tahoe should be further resolved to identify and quantify sources of nutrients and sediment within each of the significant categories—direct runoff, atmospheric deposition, and tributary discharge. This effort should be supported by basin-wide monitoring of direct runoff from both urban and nonurban regions, urban runoff to tributaries, streambank erosion, atmospheric deposition, and runoff from highways and roads.

3. Research and monitoring should identify and quantify the contribution of fine sediments and colloidal nutrients from their various sources. Focused research is needed to better understand the transport of those materials through soils and ground water and to determine the effects of both natural infiltration and BMPs to limit concentrations of those materials.

4. There is a need for more comprehensive information on nutrient cycling in watershed vegetation and soils in the Tahoe basin. Such information will allow a greater understanding of how management and development affect water quality.

5. Available LTIMP stream discharge and loading data should be subjected to analysis to determine long-term trends, differences among watersheds, and relationships among flow, sediment loading, and nutrient input.

6. The tributary sampling design for LTIMP should be reevaluated to accommodate current regulatory, monitoring, and research needs.

7. Relationships between land use and sediment-borne phosphorus loading should be elucidated at diverse and relevant spatial scales, including loading from single-family residences, residential neighborhoods and commercially zoned parcels, subwatersheds, and entire watersheds. Such a nested approach is needed to expand our understanding from site-specific scales to the larger subwatershed and watershed scales.

8. Available data from existing BMP and environmental restoration projects should be formally evaluated. A centralized clearinghouse for these data is needed. A listing and descriptions of historical, current, and proposed projects should be posted on an Internet website.

9. There is a significant need for comprehensively evaluating BMP effectiveness and project longevity with a standardized monitoring framework.

10. A formalized ranking system should be developed to prioritize restoration projects for use by all agencies implementing such projects.

11. A comprehensive geographic information system, which includes updated land use, demographic, geomorphic, and biological layers, is needed to support water quality-related management efforts. Such a tool will speed research development and data analysis and will provide a common foundation for restoration efforts.

12. Limnological studies of Lake Tahoe, including analysis of long-term data, must be continued. In addition, nutrient and sediment loss processes in Lake Tahoe need to be further quantified, along with phosphorus cycling in the lake.

13. Increased research and monitoring is required on all aspects of prescribed burning as it facilitates nutrient deposition to the lake. The mechanics of smoke deposition and nutrient cycling needs the most immediate attention.

14. Research on wetland and riparian zone ecology and nutrient cycling is needed. Wetlands are believed to provide a critical facility for removing nutrients from stream waters. Such information could provide key information to guide future wetland restoration efforts.

15. Further development and refining of water quality and lake clarity models should be encouraged. When complete, these models are expected to serve as guidance tools to assess lake responses to restoration activities and to develop quantitative targets for nutrient and sediment loading.

16. Ecosystem modeling efforts must be coordinated and modeling components should be designed to be interactive.

17. Research facilities in the Tahoe basin need to be upgraded and expanded to meet current and projected needs.

18. A science advisory panel is recommended to assist in guiding and coordinating adaptive management development, incorporating monitoring results into management actions, and setting research priorities.

19. Increased attention should be given to developing a volunteer monitoring program to assist ongoing and future restoration and monitoring activities.

20. There is a need for an "experimental watershed" to better understand the factors that affect terrestrial and aquatic ecosystems. Intensified data gathering in such a watershed could be used to better understand the complexity of nutrient cycling and to test directly the results of various management strategies.

21. One of the greatest hurdles to effective integrated ecosystem management in the basin is the lack of interactive data sharing among institutions. The best and most current information often proves to be the most elusive. Effective data sharing would greatly improve the ability to learn from research and to enhance application of results to restoration.

Biological Integrity

1. A quantitative scale of old-growth attributes by which any forest stand could be numerically expressed in terms of its ecological "distance" from old-growth status needs to be developed. A half-dozen or more attributes include the density of trees per hectare with dbh greater than some minimum, the amount of canopy cover by trees of such dbh, the leaf area index of the overstory, and the ratio of overstory tree density to understory tree density. The old-growth status of stands should be a sum of all attribute variables. Future research should lead to some minimum scale value, below which a forest stand would be labeled as non-old-growth.

2. A limited set of monitoring protocols should be developed to signal significant change in the old-growth status of any given forest stand. Monitoring indicators that might serve as surrogates for the attributes above include leaf area index above a fixed reference point, amount of litter shed during one portion of a year, soil N status at a certain depth, rate of litter decay or of N mineralization in the soil, annual growth rate at breast height of particular understory or overstory trees, or the abundance of particular shrub or herb species.

3. Locations should be identified throughout the Tahoe basin that can serve as nuclei around which vegetation can be managed toward old-growth status. Logical places to begin this process are the 38 old-growth polygons of lower and upper montane vegetation identified in this report. Those polygons should be revisited and the neighborhood vegetation should be quantified, referencing size and condition of the old-growth nucleus, topography of the neighborhood (in terms of ease of movement for managers), substrate stability in the face of foot traffic by managers, distance from nearest roads or structures (which may constrain the use of fire as a management tool), ecological distance of neighborhood vegetation from old-growth status, and ease of access for tourists and residents if the neighborhood is to be used as a management demonstration site.

4. Research should contribute to determining a minimum sustainable size for old-growth forest patches. This objective ultimately will be determined in reference to two factors: the minimum home ranges of old-growth-dependent animal species and the minimum patch size that contains enough heterogeneity for regenerating sites for characteristic tree, shrub, and herb species and enough area to permit random disturbances in future years (fire, landslide, windthrow, epidemic disease) to occur without entire site replacement.

5. More information is required to understand differences in effects on ecosystems of fire behavior among various mechanical treatments (thinning versus biomass removal), burning treatments (pile burning versus area burning), and no treatment. Important effects to analyze include measures of vegetation structure and composition that can be used to assess wildlife habitat, old forests, forest health, and fire hazard.

6. Predictive modeling of fire effects on forests and other plant communities requires models of mortality. Existing mortality models are based on generalized data from relatively few studies in the western portion of the continent. Mortality varies greatly with local conditions; therefore, customizing mortality models for the Lake Tahoe basin will necessitate a combination of fire effects monitoring and research.

7. Fire effects on vegetation (especially old-growth, wildlife habitat components, and fuels), nutrient cycling, and air quality are poorly understood in the Sierra Nevada in general and in the Tahoe basin in particular. Deriving better information will necessitate a well-designed monitoring scheme; however, some issues will require a more concentrated research effort.

8. Little fire history work has been conducted in the Lake Tahoe basin or elsewhere in the Sierra Nevada on vegetation types common in the basin. Restoring fire as a disturbance feature in ecosystem management is often based on assumptions of historic fire patterns, including mean and variations in fire return intervals. Fire history work is particularly needed in montane pine, mixed-conifer, and white and red fir forests in the basin. Because climatic patterns vary dramatically around the basin, research on fire history throughout the basin is needed to evaluate spatial variation in historic fire regimes.

9. Riparian communities are a key concern in the basin because of their important role in filtering nutrients from upland surface waters on their migration to the lake. Current restoration efforts in riparian areas are based on little underlying information on processes that shape these vegetation communities. Fire is seen as one potential tool for restoring riparian vegetation, but the historic role of fire on riparian vegetation patterns and functions is poorly understood. Research on the effects of prescribed burning on riparian vegetation, soils, and associated functions, such as nutrient cycling, is needed to assess the effects of fire as a restoration tool in riparian areas.

10. Fire behavior predictions are based on models that incorporate fire behavior and weather. There currently is only one weather station that can support fire behavior modeling in the basin. At least one additional station on the north shore of the basin would greatly improve information on weather and would provide inputs to predictive models of potential fire behavior.

11. Documenting landscape-scale effects of various forest restoration treatments is necessary to better understand changes in forest health, wildlife habitat, old forests, and fire hazard. Currently, no comprehensive system exists for tracking the spatial distribution of restoration activities. A coordinated, spatially based monitoring system should be put in place.

12. The effects and effectiveness of fire hazard reduction and vegetation restoration projects are largely unknown. Measuring vegetation structure and composition before and after using one of these projects would address this lack of information.

13. Several of Lake Tahoe's most immediate research needs concern the basin's aquatic ecosystems, including an assessment of the effects of livestock grazing on the integrity of meadows, riparian zones, and stream communities, the impacts of nonnative trout species on reintroduced mountain yellow-legged frogs, and the efficacy of available control measures for Eurasian watermilfoil. More generally, there is a need to characterize the influences of various types of disturbances on the biotic integrity of lentic and lotic ecosystem types and to evaluate the effectiveness of various management strategies. Additionally, modeling "potential habitat" for rare aquatic community types, such as bogs, fens, and springs, is advisable, as is modeling habitat for all amphibian species in the Tahoe basin. Indicator species for use in monitoring aquatic ecosystems types should be identified and tested.

14. Studies should be undertaken to assess the influences of different anthropogenic disturbances on the biotic integrity of ecologically significant areas. In support of that effort, those areas should be validated through modeling efforts using remotely sensed vegetation data, and an indicators monitoring scheme should be developed. A reference condition measure for each ecologically sensitive area type can serve as a standard for directing current and future management planning efforts. Focal activities should include identifying minimum patch sizes for ecologically significant stands of aspen, modeling and validating in the field the locations of cushion plant communities, and evaluating deep-water plant beds as spawning grounds for nonnative fishes.

15. Impacts of anthropogenic actions, such as direct harassment and common land use practices, on such focal species as bald eagle, northern goshawk, spotted owl, willow flycatcher, pine marten, and amphibians) should be better understood. Likewise a better understanding of the effects of exotic

fish and bullfrogs on native fish, amphibians, and aquatic invertebrates will be necessary for successful reintroduction efforts targeting extirpated species and those at risk of extirpation in the basin, such as mountain yellow-legged frog and Lahontan cutthroat trout.

Socioeconomics and the institutional context of adaptive management

1. A key area of research should focus on visitors and part-time nonworking residents whose spending and recreational preferences affect the social and economic dynamics of the basin. More specifically, there is a need to investigate the numbers of tourists and seasonal residents, activities that visitors participate in and their reasons for choosing to participate in them, patterns of visitor use of shore and lake areas by season, and patterns of use of urban-suburban trails and backcountry roads and trails. Within these research areas there is a growing need to stratify studies by ethnicity, race, and socioeconomic status in order to inform social policy questions concerning environmental and social justice issues.

2. A "creative tension" is identified in this document that describes the Tahoe community's attempts to serve visitor recreation needs, while providing a healthy and robust community environment for those who live and work in the basin. Significant research is needed to focus public discussion and to reduce the use of anecdotal and impressionistic data in determining social policy. In particular, research should be directed toward the following:

- Refining the affordable housing needs assessment (begun by TRPA in 1997) in the light of the census 2000 results;
- Accounting for and analyzing the need for and availability of educational, social, and recreational services focused on full-time and part-time working residents;
- Analyzing the impacts of economic redevelopment and community reinvestment strategies to determine whether intended outcomes are achieved and for whom;
- Tracking and analyzing trends in labor populations, particularly those in the hospitality, amenity, and recreation industries; and
- Developing social, cultural, and community indicators by providing expertise in methodologies and approaches.

3. Key links between socioeconomic well-being and environmental health are perhaps best observed in the patterns of land use and development in the basin. Who lives, works, and plays where and why and with what effect on the environment? Multidisciplinary approaches need to be brought to bear on determining the economic and ecological roles of the nearly 8,000 publicly owned parcels in the urban interface areas of the basin and the likely effects of further acquisitions. Moreover, the economic and social impacts of BMP implementation need to be analyzed in light of continued site-specific biophysical effectiveness studies. The social, economic, and cultural effects and impacts of mitigation and restoration need to be better understood. Determining the values held by different interests, whether residents, visitors, or those who never visit the basin but consider it an important public asset, should be a high research priority. Failure to connect willingness to pay for or to accept impacts with proposed management strategies to protect the basin (prescribed burning, restricted access to sensitive ecological assets, and transportation strategies) will only exacerbate social conflict. Research should focus on quantifying held values and the relationships of those values to actual management actions in order to guide policy choices.

4. The strength and complexity of public-private coalitions and social networks in the basin is a key theme of the institutional assessment in this document. Given historical emphasis in the Tahoe basin on collaboration and partnership building, it is important to continue researching organizational response options to scientific and social knowledge. Specifically, the institutional capacity for implementing an adaptive management strategy in support of the EIP should be a focus of policy and social research. The experimental nature of public policy and social network processes in the basin, and their capacity to inform other regions encountering similar socioenvironmental issues, suggests that a great deal can be learned by careful research and observation.

The Status of Monitoring

The environment in the Lake Tahoe basin is monitored by many university and government programs. The primary universities involved are University of California at Davis (UCD), University of Nevada at Reno (UNR), and the Desert Research Institute (DRI). These efforts include activities such as monitoring elements of lake clarity (UCD), monitoring air quality (UCD), and monitoring ground water (UNR).

Monitoring conducted by government agencies varies widely in its focus and application. The US Geological Survey primarily monitors water quantity and quality. The USDA Forest Service conducts a variety of monitoring efforts related to water quality, forest health, and recreation use. The Forest Service also conducts surveys of wildlife populations, such as marten, northern goshawk, osprey, bald eagle, and spotted owl. Most wildlife surveys, although conducted annually, are not designed to function as monitoring programs. The state parks departments in California and Nevada also monitor air quality, plant and wildlife populations, fire effects, and recreational use in the parks. The Tahoe Regional Planning Agency monitors the status of the environment with respect to basin thresholds, such as air quality, water quality, plant and animal populations, and land coverage. The Lahontan Regional Water Quality Control Board primarily monitors compliance with regulatory standards and performance requirements.

Typically, monitoring data collected by universities and agencies have limited applicability to basin-wide ecosystem issues because they are designed for organization-specific purposes, they are not formally structured monitoring efforts, and they are not coordinated across agencies or topics. The benefits of coordinated and collaborative monitoring are many, including the ability to pool funds and expertise across agencies and to address complex issues across jurisdictional boundaries. The liabilities of conducting disparate monitoring efforts is that large-scale environmental problems may go undetected because we are not measuring attributes that are meaningful from a system perspective or we may fail to comprehend its utility to the broader context of reaching restoration goals. The Lake Tahoe Interagency Monitoring Program is an example of an effort at coordination and collaboration with regard to monitoring water quality conditions in the basin. More collaborative efforts such as this would greatly benefit monitoring goals and associated information needs in the basin. An integrated monitoring strategy is an essential component of an adaptive management approach, and its development should be a high priority over the next few years.

The Status of Modeling

The watershed assessment has unearthed and developed important information about the status, dynamics, and interdependencies of resource conditions in the Lake Tahoe basin. Some of the data are new, but much of the assessment analyzes and synthesizes existing information in new ways. Many key findings in this document highlight challenges in designing management actions that achieve multiple resource goals.

Each of the four resource areas assessed for the Lake Tahoe basin (air, water, biotic, and socioeconomic) can be thought of as responding to environmental conditions and human actions. Conceptual models were developed for each resource area, dividing each into "interactive" and "independent" environmental factors. For example, a change in the condition of the air resource within the basin could act as an interactive environmental variable on water resources by significantly altering the rate of atmospheric deposition of nitrogen and phosphorus on the surface of the lake. This in turn, could alter the condition of the water resource within the basin. In addition, the amount and timing of precipitation, an independent environmental variable, can also affect water resource conditions by affecting rates of surface run-off. Each interactive environmental factor can be an output from one resource and an input to one or more of the other resources.

A simple conceptual model for each of the four resources addressed in this assessment identifies the environmental conditions and management actions that can affect resource conditions (see figures 7-4 through 7-7). These conceptual models show several elements: the key factors that affect the con-

dition of resources as inputs to the resource (arrows from factors to the resource); processes that operate within resources and the parameters that describe the condition of that resource; and the outputs of the resource that may be useful measures of resource condition (arrows from the resource to indicator variables). The factors identified as interactive are restricted to those associated with the four key resources addressed in this assessment. These conceptual models can be used to identify influential factors that are common to more than one resource, representing links among air, biotic, water, and socioeconomic conditions within the basin. Emphasis focuses on the links that managers have at least some control over—effects from management activities and interactive environmental factors.

Air Quality Conceptual Model

The air resource is represented by two components in the conceptual model: the regional airshed and the Lake Tahoe airshed (Figure 7-4). The regional airshed describes input of pollutants into the Lake Tahoe basin from the Central Valley of California and the neighboring areas. The Lake Tahoe airshed describes the fate of pollutants generated within or once they arrive to the Lake Tahoe basin. The activities that directly affect the condition of the air resource are automobile and watercraft tailpipe regulations, as well as restrictions on wood stoves within the Lake Tahoe basin. The interactive environmental factors include a variety of factors, but two resource areas have the greatest interaction with the air resource: biotic resources (for example, smoke emissions) and sociocultural conditions (exhaust emissions). However, a potentially overriding environmental factor affecting the air resource is climate, which on a short-term basis can obscure the detection of any changes from either management activities or interaction variables.

Water Quality Conceptual Model

The water resource is represented by two components in the conceptual model: upland watersheds and Lake Tahoe itself (Figure 7-5). Upland watershed processes govern the movement of water and fate of pollutants and nutrients as they move toward the lake. Processes associated with water quality that operate in Lake Tahoe govern the fate of nutrients, pollutants, and sediments in the lake. Management activities that directly affect the condition of the water resource include channel modifications, sediment traps, land use restrictions, and watercraft tailpipe restrictions. The condition of the water resource also can be altered indirectly by a mixture of both on-the-ground management activities and regulatory restrictions. The interactive environmental variables that affect water quality come from each of the three other resource areas (nutrient deposition from the air resource, the urban landscape from the socioeconomic condition, vegetative landscape from the biotic resource), as well as from upland watershed processes to Lake Tahoe (sediment fluxes). A potentially overriding environmental factor affecting the water resource is climate; on a short-term basis, the detection of management-related changes in the condition of water quality could be difficult to detect.

Biological Integrity Conceptual Model

The biological resource is represented by two components in the conceptual model: species/populations and communities/ecosystems (Figure 7-6). The species/population component addresses the distribution abundance of all plant, animal, and fungi species in the Lake Tahoe basin. The communities/ecosystems component addresses the distribution, abundance, and integrity of vegetative and aquatic communities and ecosystems in the basin. Most management actions have at least some influence on biological integrity, with some of the greatest influences in the basin coming from vegetation management, fire management, land development, and recreation. Interactive environmental factors originate from all three of the other resources, but the most influential are water quality and interactive elements within biological systems.

Socioeconomic Condition Conceptual Model

The socioeconomic "resource" is represented by two components in the conceptual model: social well-being and economic performance (Figure 7-7). Social well-being is measurable through a number of sociocultural processes, including population, community resilience to change, adaptability of

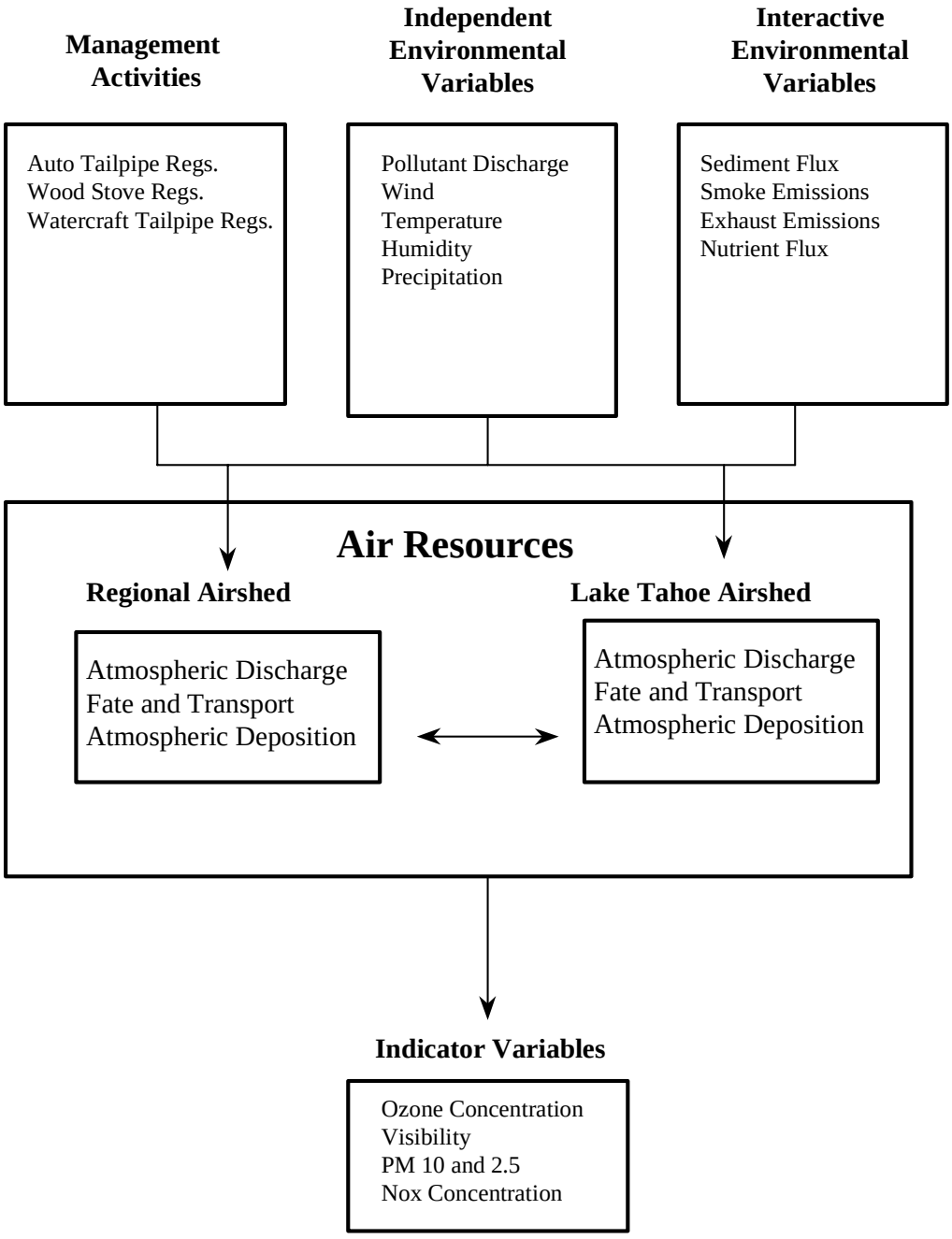


Figure 7-4—Schematic diagram of detailed air resource conceptual model.

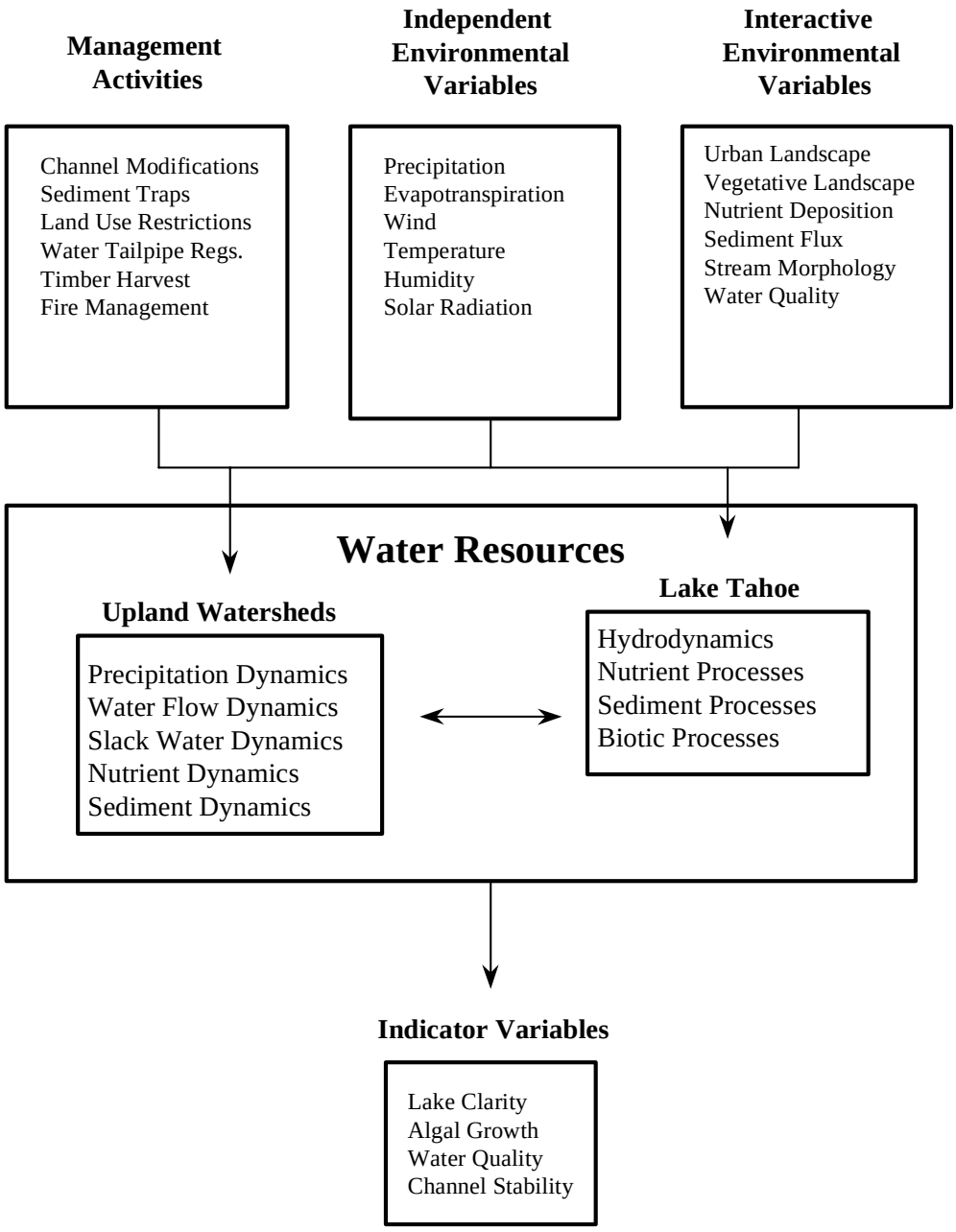


Figure 7-5—Schematic diagram of detailed water resource conceptual model.

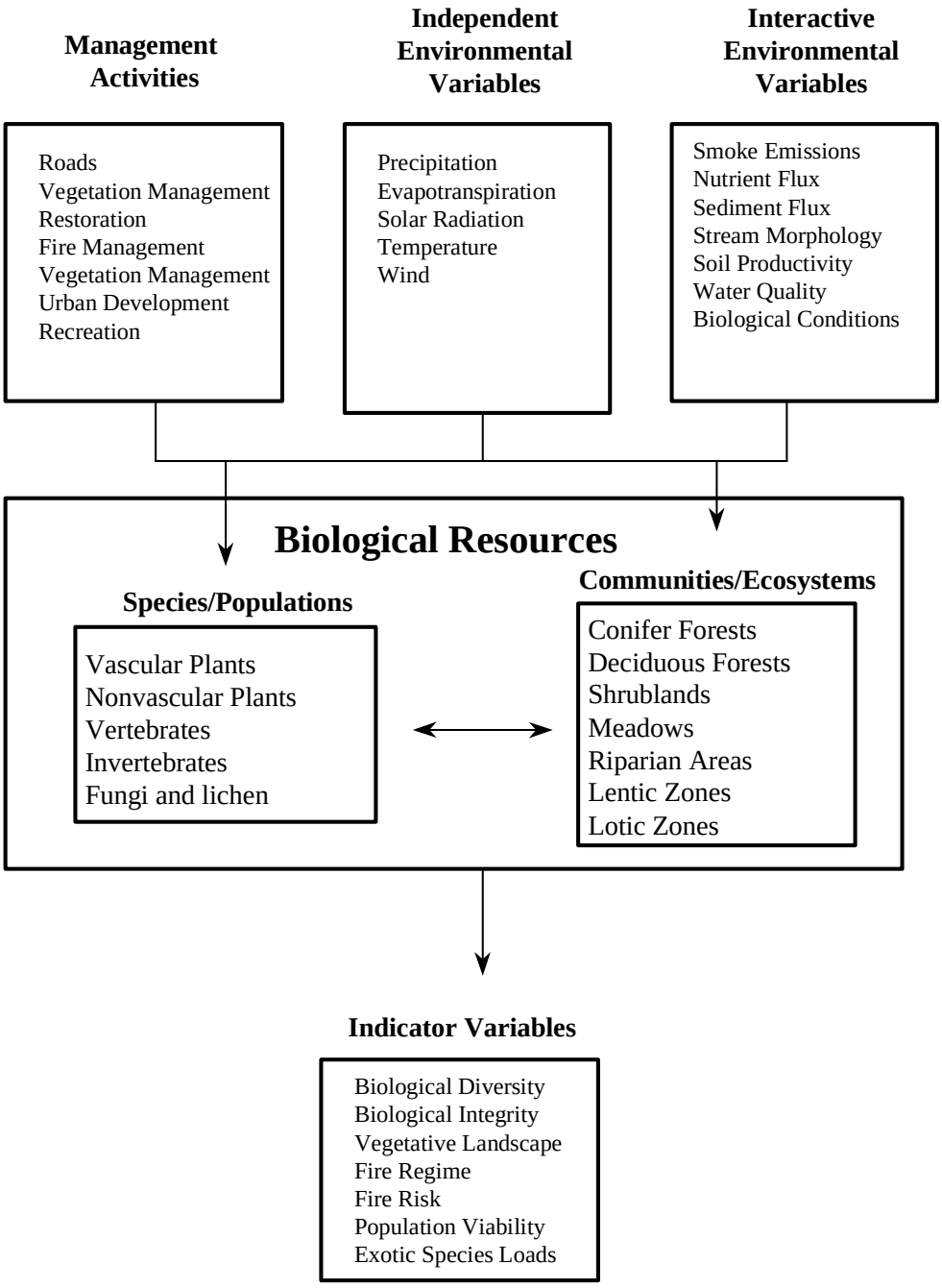


Figure 7-6—Schematic diagram of detailed biotic resource conceptual model.

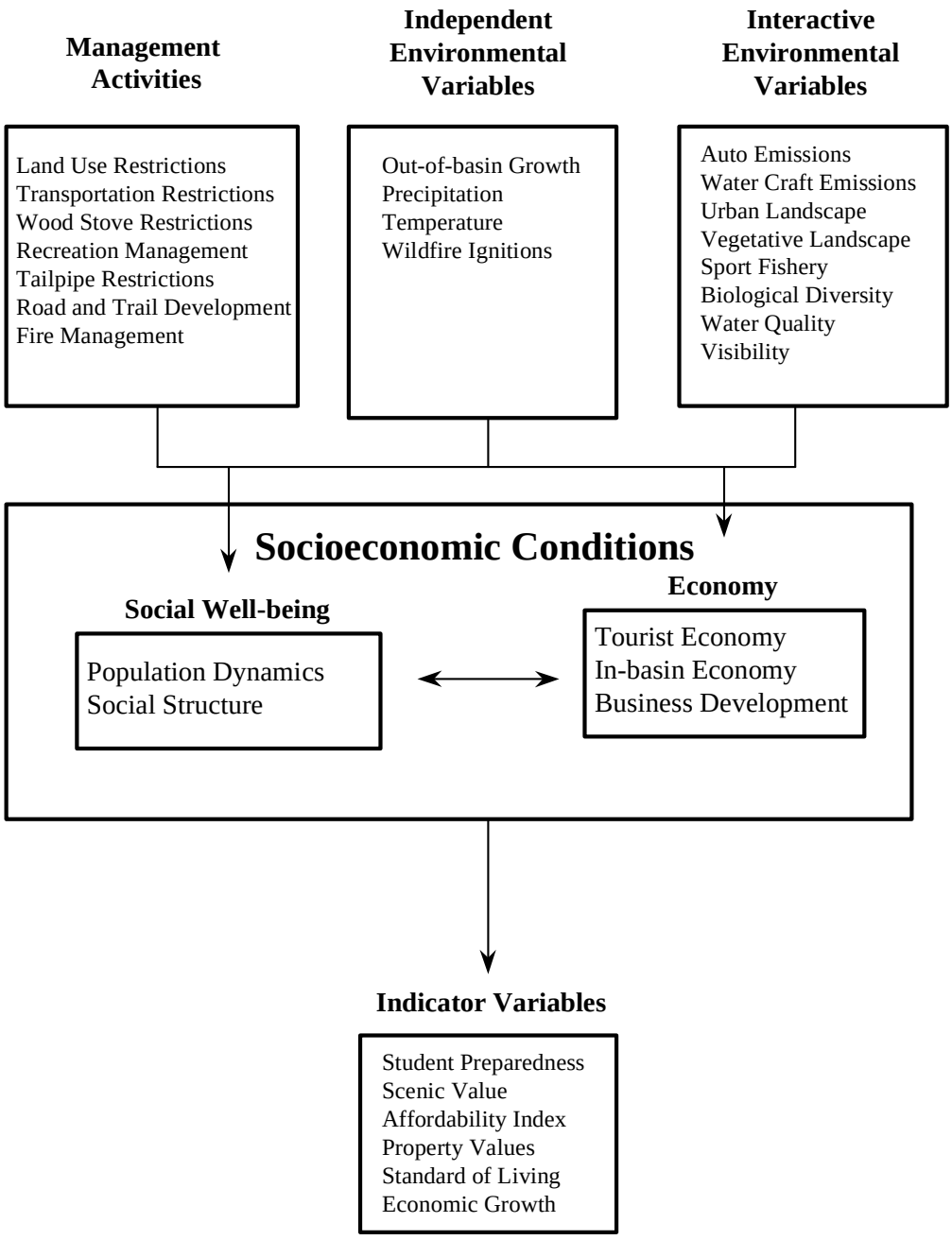


Figure 7-7—Schematic diagram of detailed socioeconomic resource conceptual model.

social structures, etc. The economic component represents the generation and distribution of wealth within the Lake Tahoe basin. Sociocultural processes directly affecting it are recreation and tourism, non-tourist economic activities, natural resource values (market and non-market), and business development. Management activities that directly affect the condition of the socioeconomic resource include land use regulations, transportation infrastructure and investment, tailpipe and wood stove emission controls, recreation management, and road, trail, and public access construction. Socioeconomic conditions are generally more directly affected by regulatory actions and investment than on-the-ground management actions. The interactive environmental variables directly affecting the socioeconomic resource are numerous and come from all three of the other resource areas (visibility and pollution from the air resource, water quantity and quality from the water resource, and fishery production, wildlife populations, and forest health from the biological resource). From this conceptual model, it can be seen that socioeconomic conditions can be affected significantly by conditions in all of the other resources. In addition, socioeconomic conditions could have significant impacts on each of the other resources in the Lake Tahoe basin. Macroenvironmental factors that could affect the socioeconomic system are population growth in California and Nevada and climate.

Summary of Factors Affecting Multiple Resources

A significant number of factors are common to two or more of the Lake Tahoe watershed resources. These factors represent the interactive components of each resource and the greater environment. Understanding these factors, their interactions, and their relative influences can assist managers in designing management activities that maximize the intended effects. Approximately 65 percent of all interactive environmental factors affect two or more resource areas (Table 7-3). More than half of interactive environmental factors serve as output and input factors within the same resource. All but one of the management activities (transportation management) affect multiple resources (Table 7-4). In addition, independent environmental factors also affect multiple resources (Table 7-5). The substantial level of interaction among resource areas indicates strong feedback mechanisms within resource areas and the potential for a chain of events and feedback loops precipitated by the alteration of the condition of one resource. These factors should be key areas of discussion and careful management.

Climatological factors contribute the independent environmental inputs that affect multiple resources, with precipitation and temperature affecting all four resource areas. Understanding the degree to which climatic conditions vary within the Lake Tahoe basin and to which they are likely to vary through time will be a key factor in differentiating among the various contributions of climate and management activities to resource conditions. It is possible that management plans can be effective but still not exhibit improvement in resource conditions if those plans are implemented under adverse climatic conditions. Conversely, it is possible that improved resource conditions could accompany ineffective management activities during periods of beneficial climatic conditions. An example of the confounding effects of climate became apparent when the clarity of Lake Tahoe showed improvement during drought conditions from 1987 through 1993. This improvement may have been due to a weather condition that reduced sediment and nutrient transport to the lake.

Quantitative Models of Key Resource Conditions and Interactions

A number of computerized modeling tools have been developed for a variety of applications, most intended to simulate the processes that affect air, water, biotic, and socioeconomic resources. An extensive list of these tools is presented in Table 7-6, along with a description of each model, the processes they simulate, and references to the literature on the theoretical development of the model. While a catalogue of existing modeling efforts is useful in establishing an adaptive management strategy, evaluating the applicability and utility of those models is critical.

Table 7-3—Interactive environmental factors identified in the conceptual models of air, biotic, water, and socio-economic resources.

	Resource			
Factor	**Air**	**Biotic**	**Water**	**Socioeconomic**
Nutrient flux	O		I/O	
Sediment flux		I	I/O	
Smoke emissions	I	I		I/O
Exhaust emissions	I	I		I/O
Dust	I		O	
Forest health		O		I
Soil productivity		I	O	
Visibility	O			I
Stream morphology		I	I/O	
Water quantity and quality		I	I/O	I
Urban landscape			I	I/O
Vegetative landscape		O	I	I
Fishery production		O		I
Wildlife populations		O		I

Note: I = Input variable, O = Output variable

Table 7-4—Management activities that directly affect multiple resources within the Lake Tahoe basin.

	Resource			
Activity	**Air**	**Biotic**	**Water**	**Socioeconomic**
Tailpipe regulations	X		X	X
Wood stove regulations	X			X
Land use regulations		X	X	X
Road management	X	X	X	X
Fire management	X	X	X	X
Recreation management		X	X	X
Range management		X		X
Vegetation management		X		X
Restoration		X	X	
Development/urban open space		X	X	X
Fisheries management		X		X

Table 7-5—Independent environmental factors that affect multiple resources within the Lake Tahoe basin.

Factor	Resource			
	Air	Biotic	Water	Socioeconomic
Wind	X	X		
Temperature	X	X	X	X
Humidity	X		X	
Precipitation		X	X	X
Evapotranspiration		X	X	
Solar radiation		X	X	

Development of new models and customization of existing models will be necessary as an adaptive management strategy is put in place. Model predictions will have greater accuracy as the models are adapted to site-specific processes. Site-specific models also can be better tailored for integration with other models, eliminating the need to develop interface routines among existing models. Moreover, site-specific models can be adapted more readily to produce information that is more relevant to management issues in the area of application.

Several air, water, biotic, and socioeconomic models are in use or under development in the basin. Although these models have been developed without benefit of an integrated information strategy, they can contribute substantially to a more integrated basin-wide management planning effort when it is developed. Some of the models with the greatest potential to contribute to current and future modeling needs in each of the four resource areas are briefly described below.

Air Resource Models

The only air resource model available for the Lake Tahoe basin is the Lake Tahoe Airshed Model (LTAM), developed by Cliff and Cahill at the University of California, Davis. The model simulates processes within the Lake Tahoe airshed and predicts discharges to the atmosphere, transport and fate of pollutants within the atmosphere, and deposition of nutrients on terrestrial and aquatic surfaces in the Lake Tahoe basin. LTAM can predict in-basin pollutant discharges from traffic sources for the major roadways within the basin, urban pollution sources, and discharges from prescribed forest fires. In addition, out-of-basin pollutant sources from neighboring airsheds can be accounted for in the simulations. The model predicts the atmospheric concentration of gasses (CO, NO_x, NMHC, SO_2) and particles (TSP, PM_{10}, $PM_{2.5}$). A mechanism to predict deposition of atmospheric pollutants onto the surface of Lake Tahoe has been developed, but due to a lack of monitoring information, this mechanism has not been calibrated or validated.

Water Resource Models

A series of models, referred to as the Lake Tahoe Clarity Model, is being developed by the Tahoe Research Group at the University of California, Davis, to predict the condition of water resource elements within the Lake Tahoe basin. The first element is a watershed hydrology and sediment loading model, referred to as the University of California, Davis, Watershed Model (UCDWM). The second element is a water quality model for Lake Tahoe.

The UCDWM has been used to predict stream behavior in the Ward Creek watershed and will be designed to predict streamflow from rainfall into small to medium basins. The UCDWM is a spatially distributed model that uses maps of physical conditions within a watershed to generate modeling parameters. Models that predict sediment flux and snowpack dynamics are being developed, but they are not sufficiently well developed to link directly to the UCDWM.

The Lake Tahoe water quality model will simulate hydrodynamics in the water quality

Table 7-6—Available models to describe the condition of resources within the Lake Tahoe basin.

Model Name	Processes Simulated	Variables Simulated	Agency or Reference
AGNPS	Water Resource Water Flow, Sediment and Nutrient Dynamics	Water Quantity and Quality Nutrient Flux Sediment Flux	USDA Young et al. 1989
BEAMS	Water Resource Water Flow and Sediment Dynamics	Water Quantity Sediment Flux	USDA Langendon et al. 1998
CALMET CALPUFF CALPOST	Air Resource Atmospheric Discharge Fate and Transport	Visibility	USEPA
CASC2D-SED	Water Resource Water Flow and Slack Water Dynamics	Water Quantity	Johnson et al. 1998
CCHE2D	Water Resource Water Flow and Sediment Dynamics	Water Quantity Sediment Flux	Jia and Wang 1997
CE-QUAL-ICM	Water Resource Water Flow, Sediment and Nutrient Dynamics Nutrient Dynamics	Water Quantity and Quality Nutrient Flux Sediment Flux	USDA Cerco and Cole 1995
CE-QUAL-W2	Water Resource Water Flow, Sediment and Nutrient Dynamics	Water Quantity and Quality Nutrient Flux Sediment Flux	USDA Cole and Buchok 1995
Climatological Dispersion Model	Air Resource Atmospheric Discharge Fate and Transport	Pollutant Concentration	USEPA
COMPLEX1	Air Resource Atmospheric Discharge Fate and Transport	Visibility Pollutant Concentration	USEPA
CREAMS	Water Resource Water Flow, Sediment and Nutrient Dynamics	Water Quantity and Quality Nutrient Flux Sediment Flux	USDA Knisel 1993
DWAVNET	Water Resource Water Flow and Slack Water Dynamics	Water Quantity	Langendon et al. 1996

Table 7-6—*(continued)*

Model Name	Processes Simulated	Variables Simulated	Agency or Reference
Forest-BGC	Biotic Resource Vegetative Communities	Vegetative Landscape	Running and Coughlin 1988
EPIC	Water Resource Precipitation, Water and Sediment Dynamics	Water Quantity	USDA
FRAME	Water Resource Water Flow and Slack Water Dynamics	Water Quantity Sediment Flux	Vieira et al. 1997
GLEAMS	Water Resource Water Flow, Sediment and Nutrient Dynamics	Water Quantity and Quality Nutrient Flux Sediment Flux	USDA Knisel 1980
HEC-HMS	Water Resource Water Flow and Slack Water Dynamics	Water Quantity	US Army COE HEC 1995
HEC-RAS	Water Resource Water Flow and Slack Water Dynamics	Water Quantity	US Army COE HEC 1997
HFAM	Water Resource Water Flow and Slack Water Dynamics	Water Quantity	USGS/EPA Marino and Crawford 1998
HSPF	Water Resource Water Flow and Slack Water Dynamics	Water Quantity	USGS/EPA Bicknell et al. 1997
LAWF	Water and Biotic Resource Water Flow and Slack Water Dynamics, Lentic and Lotic Communities	Vegetative Landscape	Cheng et al. 1998
MOBILE5a	Air Resource Tailpipe Discharge	Pollutant Concentration	USEPA
PLUVUE	Air Resource Fate and Transport	Visibility	USEPA

Table 7-6—*(continued)*

Model Name	Processes Simulated	Variables Simulated	Agency or Reference
PSRM	Water Resource Water Flow Dynamics	Water Quantity	Aron 1996
QUAL2E	Water Resource Water Flow, Sediment and Nutrient Dynamics	Water Quantity and Quality Nutrient Flux Sediment Flux	USEPA
RAM	Air Resource Atmospheric Discharge Fate and Transport	Visibility Pollutant Concentration	USEPA
REMM	Water and Biotic Resources Water Flow, Nutrient and Sediment Dynamics, Riparian communities	Water Quantity Nutrient and Sediment Flux Veg. Landscape	USDA Altier et al. 1998
RPM-IV	Air Resource Atmospheric Discharge Fate and Transport	Pollutant Concentration	USEPA
SHAW	Water Resource Precipitation Dynamics	Water Quantity	Flerchinger and Saxton 1989
SHE	Water Resource Water Flow and Slack Water Dynamics	Water Quantity	Bathurst 1986
SMS	Water Resource Water Flow Dynamics	Water Quantity	US Army COE WES, Holland et al. 1998
SWAT	Water Resource Water Flow, Sediment and Nutrient Dynamics	Water Quantity and Quality Nutrient Flux Sediment Flux	USDA Arnold et al. 1993
SWMM	Water Resource Water Flow, Nutrient and Sediment Dynamics	Nutrient and Sediment Flux Water Quantity and Quality	USEPA
UAM	Air Resource Atmospheric Discharge Fate and Transport	Pollutant Concentration	USEPA

Table 7-6—*(continued)*

Model Name	Processes Simulated	Variables Simulated	Agency or Reference
USLE	Water Resource Sediment Dynamics	Sediment Flux	USDA Wischmeier and Smith 1978
WASP5	Water Resource Lake Hydrodynamics Nutrient and Biotic Processes	Lake Clarity Algal Growth Water Quality	USEPA

using a process-based one-dimensional representation of flow dynamics and temperature profiles within Lake Tahoe. The hydrodynamics model is subsequently used as the basis for determining the transport and fate of nutrients and sediments in the vertical column. An optical model predicts the clarity of the lake based on the vertical distribution of algae and sediment concentrations. The Lake Tahoe water quality model uses data from measurements of nutrients from the atmosphere and watersheds that flow into the lake.

Biological Resource Models

Several models are being developed to simulate biotic resource processes within the Lake Tahoe basin. These include models that predict the risk and consequences of fire on vegetation and the biodiversity in lentic and lotic zones within the basin.

Five fire and fuels models have been applied within the basin. First is a fuels model that was developed by Fites-Kaufman et al. using a rule-based approach to continuously update fuel layers as vegetation conditions change or when vegetation is treated through management. Input information includes vegetation cover, dominant vegetation form (i.e., shrub, grass, or tree), dominant tree species, recent mortality, elevation, recent management treatment (i.e., burning, thinning), and land use classification (i.e., urban, undeveloped). The fuel model outputs can serve as inputs to the other fire models. The second model is FLAMMAP, which produces a spatially explicit, continuous surface of fire behavior characteristics (rate of spread, flame length, heat per unit area, and likelihood of crown fire). Input data include a fuels map and weather set, which are used to display the changes in fire behavior characteristics with different fuel loads or weather conditions. The third model is the Fire Area Simulator (FARSITE) model, which is a spatially explicit fire behavior model. FARSITE can be used to simulate wildland fire growth and behavior under complex conditions of terrain, fuels, and weather. Fire behavior varies with topography, weather input, and fuels encounters as a fire spreads. The outputs of the model include fire extent flame lengths, and heat per unit area across the area burned. Fourth, the results from the FARSITE model can be combined with existing vegetation conditions and analyzed with a First Order Fire Effects Model (FOFEM). FOFEM is a fire effects model that displays fire severity, resultant tree mortality, and changes in vegetation. FOFEM is designed to predict the effects of prescribed fire and wildfire in forests and rangelands. Outputs include quantitative, site-specific predictions of tree mortality, fuel consumption, and smoke. Finally, the Rare Event Risk Assessment Process (RERAP) model dynamically calculates the risk of undesired fire movement and smoke dispersion before a fire-ending event, such as precipitation, can halt its spread. Inputs are historical weather data and FLAMMAP layers. Outputs include probabilities of the fire or smoke event reaching a predefined target, average, or common rate of spread (ROS), and ROS as altered by weather events, such as high winds. RERAP and FARSITE are complementary models.

In addition to fire and fuel models, models of riparian biodiversity are being developed by Manley and Schlesinger for the Lake Tahoe basin. The

models use regression equations to predict indices of biodiversity related to terrestrial characteristics near lentic and lotic habitats. Models have been developed to predict indices of biodiversity for birds, mammals, and vascular plants. Further development and verification of these models is planned.

Socioeconomic Models

A model attempting to simulate the effect of changes in lake clarity on residential property values is being developed by Bernknopf et al. This model portrays relationships between land use restrictions and property values for privately owned lots in the Upper Truckee watershed, which includes much of South Lake Tahoe, California, and Stateline, Nevada, the largest urbanized areas within the Lake Tahoe basin. A regression model has been developed that predicts the property value of a privately owned lot as a function of land development restrictions placed on the lot.

In a related vein, Nechodom et al. are exploring the feasibility of modeling the relationships between public parcels and land and housing values. The effort is preliminary and attempts solely to test the usefulness of using existing assessor parcel data to measure the effects of public land acquisitions in discrete neighborhoods in the basin. Further development of this model would need to determine the additional effects of adjacency of an entire neighborhood to larger public holdings, as well as location-dependent amenity and transportation values, on housing and land prices.

In addition, an economic input/output model constructed at the community-region scale, developed by Robison et al., is presented in Chapter 6 of this assessment. The purpose of this model is to display the potential effects of specific changes in any given industry or economic sector on the rest of the economy. The ultimate use of this model will be to track economic impacts of changes in management policy. However, most immediately, the model is intended to be used to estimate impacts of strategies to derive $252 million over ten years to pay for the local share of the EIP.

Toward the Future

Gaps in our understanding of the ecology of Lake Tahoe are so fundamental that actions based on our current knowledge have a substantial likelihood of missing the overarching target of reversing the current decline in lake clarity. The only practical alternative is a deliberate and aggressive adaptive management program focused on key ecosystem functions, with the explicit goal of restoring lake clarity and forest health. This goal can be accomplished in a manner that respects and supports the mandates, interests, and authorities of all the basin's stakeholders. However, management and research institutions engaged in activities in the Tahoe basin must change how they operate in order to meet this challenge. The need for immediate solutions creates an urgency for action. Collaboration is essential to meeting the information and management needs of the basin for two reasons: the complementary nature of mandates and skills associated with various agencies working in the basin can be leveraged to accomplish more in a shorter period of time, and, correspondingly, a lack of coordination and collaboration could result in duplication of effort, or worse, incompatible approaches that result in no net progress toward restoration goals. Many basin agencies and stakeholders have contributed to creating the current climate of enhanced collaboration in stewarding public resources and for refining sustainable ecological, social, and economic practices in the basin. It is our belief that this valuable collaboration needs to continue and grow into a scientifically informed adaptive management approach to the management and restoration of the Lake Tahoe basin. The remainder of this chapter addresses specific recommendations for the development and structure of an adaptive management strategy. Recommendations for a collaborative institutional structure to help define and guide adaptive management is discussed first, followed by specific recommendations for next steps for each phase of the adaptive management cycle.

Collaborative Structures for Adaptive Management

We recommend the establishment of formal working groups in order to realize a functioning, multi-agency adaptive management process for the Lake Tahoe basin. We recognize that a number of

different structures have the possibility of being equally successful, but for the purposes of discussion, we provide a proposed structure to stimulate discussion and movement toward the establishment of such working groups. Our proposed structure is composed of three main working groups: an Executive Coordinating Committee (ECC), an Adaptive Management Working Group (AMWG), and a Science Advisory Group (SAG) (Figure 7-8). These three primary working groups could be established and sanctioned through the formation of a memorandum of understanding (MOU). The recommended roles and responsibilities of each working group are described below.

The ECC would be chartered to coordinate policy and communication between management agencies and the current Lake Tahoe Federal Advisory Committee (LTFAC). The AMWG would be chartered to streamline communications, to coordinate collaborative implementation of each agency's management plans, and to integrate scientific review from the SAG. Its ultimate objective is to coordinate adaptive management and restoration activities to create a fully integrated and interactive terrestrial and aquatic resources management planning program. The SAG would recommend research, monitoring, and restoration activities and priorities.

A fully developed adaptive management strategy with collaboration as its hallmark needs to be brought on line in the next year in order to successfully meet restoration goals in the Lake Tahoe basin. A five-year plan could focus on the most immediate conservation challenges for an initial period of approximately five years and could prioritize project implementation integrated with research and monitoring, using whatever criteria established by the AMWG. In 2002, a new 20-year regional plan will be developed to guide planning and management actions. Full implementation of the adaptive management strategy should coincide with TRPA's new plan in 2002. Information and experience from a well-developed adaptive management strategy should prove invaluable in establishing the goals of the new regional plan.

Under the authorities and guidelines established by the recently executed MOU among research institutions (signed in June 1999 by University of Nevada, Reno, University of California, Davis, USDA Pacific Southwest Research Station, Desert Research Institute, and USDI Geological Survey), the ECC, AMWG, and SAG should review and make recommendations on research and monitoring activities, particularly those concerning empirical relationships among ecosystem elements and the development of sustainable environmental and social policies. The SAG should provide analytical support to project level planning and be responsible for integration of scales of information appropriate to the project.

The AMWG should convene a task force of information management coordinators and consultants to determine the appropriate protocols for data storage and analysis. An initial charge of the task force should be to conduct an assessment of information needs, data formats, data usage and storage, and hardware and software in use by public agencies. The task force should work with the AMWG and the ECC to develop recommendations for an integrated information management system that is coordinated with other environmental information systems and information clearinghouse efforts in existence throughout the state, such as the Federal Geographic Data Committee (FGDC), EPA, California's data Framework, California Environmental Resources Evaluation System (CERES), and the California Geographic Information Assessment.

The AMWG should be chartered and sanctioned by the ECC to facilitate ongoing policy and management dialogues, informed by the scientific information in this assessment, as well as future research and monitoring activities. The SAG should be required to review and prepare background materials, white papers, and problem analyses to inform the structured dialogues between policy and management. Both the SAG and the AMWG will need to seek outside consultation services when necessary to help distill issues and inform participants in policy and management dialogues. The process should be guided initially by the key findings and research needs identified in Chapter 1 and in this chapter.

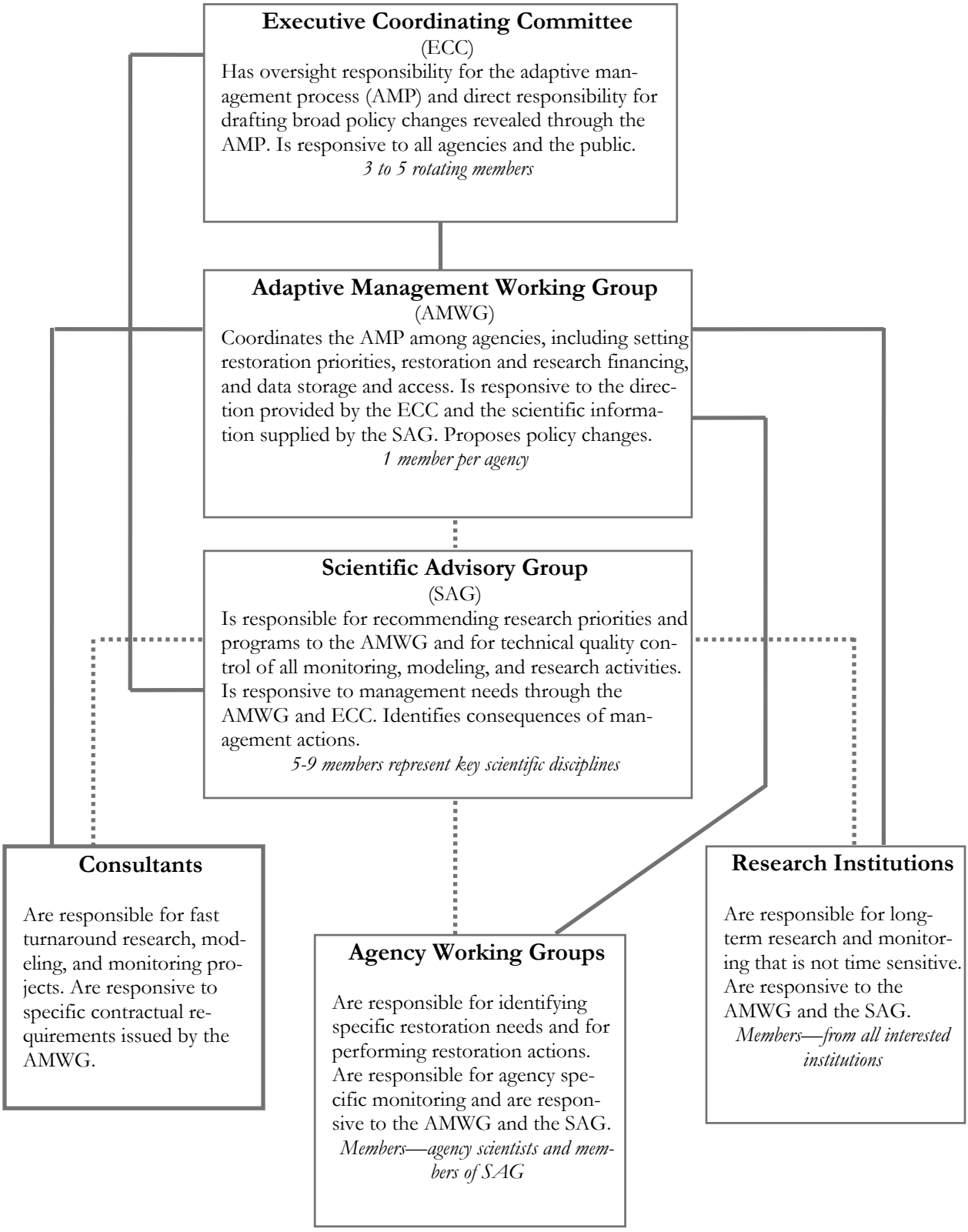


Figure 7-8—Conceptual structure for adaptive management strategic groups in the Lake Tahoe basin. Solid lines = administrative authority, dashed lines = technical exchange.

Next Steps for the Adaptive Management Cycle

Significant effort will be required for institutions to absorb the information provided in the watershed assessment and to integrate that information into policy and management actions. Over the short term, activities, such as those identified in Table 7-5, will provide immediate contributions toward adaptive management; however, the simultaneous development of all phases of the adaptive management cycle is essential. Our portrayal of the adaptive management cycle consists of four phases: information needs identification and prioritization, information acquisition and assessment, evaluation and application to decision-making, and management action. The wealth of information provided in the watershed assessment can be readily applied to effective action that can be taken in regard to each phase of the adaptive management cycle.

The watershed assessment can be used by managers, scientists, and policy-makers for future investments in data acquisition. Charting such a course will involve evaluating not only what is known about the Lake Tahoe basin but also how restoration and management efforts can be informed by additional data. For example, how much better can the relationship between prescribed fire and sediment transport to the lake be described by subwatershed experiments? Would expanding the existing stream monitoring network significantly increase our understanding of how BMPs affect nutrient and sediment loading to Lake Tahoe? What information can be gained by developing models that simulate the response of Lake Tahoe to new regulatory laws? Answers to such questions can provide an important basis for future investments in research, monitoring, and modeling.

The watershed assessment highlights many activities that can be used in prioritizing information acquisition and assessment activities in support of adaptive management. A variety of independent research and modeling efforts are underway in the Lake Tahoe basin, led by numerous academic and research institutions, including the University of California, Davis, University of Nevada, Reno, Desert Research Institute, and USFS Pacific Southwest Research Station. A successful adaptive management strategy will demand greater coordination and collaboration among research institutions and an increased emphasis on projects that address the highest priority information needs. The strategy should identify opportunities for integrated data collection and analysis efforts and structure avenues of funding to emphasize priority topic areas for investigation, favoring projects conducted in a coordinated or collaborative manner.

Funding of projects and studies at Lake Tahoe is currently a piecemeal and ad hoc enterprise. Much of the funding process is unlikely to change, due in large part to institutional arrangements and constraints that otherwise generate healthy competition for limited resources among good project options. However, opportunities for cooperative funding and research can be missed because of differences in mandates and priorities among core institutions. There are few institutional homes for the honest and difficult discussions needed to determine priority basin ecosystem needs—ecologically, economically, and socially—and activities among institutions. Opportunities are fewer yet for setting priorities in an open and transparent dialogue and for providing mutually beneficial incentives to reach the restoration goals set forth in the Regional Plan, the 208 Plan, and the EIP.

A formal process is needed to identify important research questions. Then, the feasibility of answering those questions should be assessed, priorities for allocation of funding must be set, and a competitive process for the funding of proposals must be established. Research and management priorities and goals would greatly benefit from the establishment of a formal peer review process.

Information Acquisition and Assessment

An information acquisition and assessment strategy would greatly benefit management efforts in the Lake Tahoe basin. The objective of such a strategy would be to shorten the time required to fill important information gaps, to test the effectiveness of competing management approaches, and to inform potential changes in policy and management. Each of the other three phases of the adaptive management cycle will require some level of development and function to maximize the effectiveness of an information acquisition and assessment strategy.

Research. A long list of research needs was identified in the watershed assessment. One of the first tasks of the SAG should be to identify the time-sensitivity of these research needs and any interdependence among information needs that requires consideration in the prioritization and scheduling of data acquisition to fill particular critical information gaps. Such an assessment could be used to build a research agenda for the next five years.

Monitoring. A critical element of a successful information acquisition and assessment strategy is the development and implement of a multiresource, basin-wide monitoring plan that would serve as a link between research and management. Monitoring should be designed to answer questions regarding the full range of monitoring questions (implementation, status and trend, and management effectiveness). A mechanism for data analysis, interpretation, and reporting should also be developed. Monitoring results should be used to inform managers and the public about management activities, resource conditions as they compare to desired future conditions, and the results of management and restoration efforts. A process needs to be developed that links monitoring results to the evaluation and reconsideration of management and restoration actions.

Modeling. Modeling efforts must focus primarily on available data and on the immediate needs of restoration planners. This implies that modeling tools should be developed in a collaborative environment that includes scientists and those agency personnel charged with developing and implementing restoration activities within the basin. Collaboration will involve all levels of technical knowledge and modeling capability in conceptual and quantitative formats. For that reason, sophisticated user interfaces will be needed that allow agency personnel a level of comfort with model results and will provide confidence in model simulations. This may entail some reduction in the complexity of model mathematics to improve the understandability and utility of the modeling tools. At the same time, modeling tools must focus on the mechanisms that link the various resource components of the Lake Tahoe basin. The development and use of decision support tools would greatly aid the evaluation and application to decision-making phase of adaptive management in the Lake Tahoe basin, resulting in more scientifically defensible and effective management actions.

Evaluation and Application to Decision-making

The most fundamental problem faced by the policy and management community at Lake Tahoe is the fragmentary and unorganized application of available and technical information; more specifically, the lack of an institutionalized structure to gather, analyze, and disseminate information to support resource management decisions has impeded achievement of ecosystem integrity goals. Adaptive management has been described in this chapter, but the application of its precepts to the Tahoe basin remains to be articulated in a way that invites explicitly defined commitments from the core institutions to redirect resources or to challenge existing priorities.

In addition to highlighting what is known about the ecosystems of the Lake Tahoe basin and what key information is lacking, the watershed assessment also identifies information evaluation and application activities that can immediately serve restoration goals in the basin. The evaluation and application phase of the adaptive management cycle is a sociocultural interpretation of the relevance and meaning of scientific information generated in the information acquisition and evaluation stage. Without this phase, the generation of new information has no purpose. Table 7-6 provides some examples of evaluation and application activities that can be used to integrate information into policy and management. These activities lie not in the realm of science but at the interface between research and management, requiring the input of scientists and managers from different disciplines to decipher the most effective and appropriate responses to new scientific information.

Certain agencies are better staffed to address the stewardship and flow of information in the Lake Tahoe basin. Data are often collected using differing methods, ultimately are subjected to incompatible data storage standards, and commonly require different protocols for quality assurance and control. For example, GIS layers have been developed in disparate formats, impeding ready exchange of spatially explicit information among agencies.

Large quantities of monitoring data have been collected, but much available data remains unanalyzed; hence, management decisions at Lake Tahoe are often made without informed guidance from monitoring.

The pathways followed by resource management information, from data analysis and storage, and then from information transfer to integration into decision-making, must be better understood and refined in order to correct these key deficiencies. Most management and regulatory agencies know the value of effective information management processes. Information management processes should be mandated, funded, developed, and maintained through interagency collaboration and with public involvement and access in a manner that ensures availability of information for restoration purposes.

Under current conditions, management and restoration activities are carried out under the auspices of more than a dozen funding and regulatory processes. The core institutions involved in these funding and regulatory processes are identified in the institutional assessment in Chapter 6 of this document. While there are recent examples of networking and coordination among the core institutions, there is no forum with the explicit goal to incorporate new knowledge into management decision-making and management actions in a timely fashion. Existing examples of successful forums for collaborative fora, such as Chesapeake Bay's collaborative monitoring program, can be used as models for building a collaborative adaptive management scheme at Lake Tahoe. That scheme will at a minimum prioritize research, monitoring, modeling, and restoration projects, will fulfill key scientific information gaps, and will monitor the resource conditions and the effectiveness of restoration activities.

This new way of doing business will require three simple rules of engagement. Participating parties must commit to open, transparent, and scientifically informed processes that set management and policy priorities, that critically evaluate outcomes, and that adapt to new information by changing management strategies when it is clear that current directions are not effective. The parties must encourage robust civil debate, the ultimate purposes of which are to realize the goals in associated policy documents and to protect and restore the ecological and sociocultural assets of the basin. And they must reject institutional competition based on positioning, rather than on ideas and innovation.

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