

CHAPTER ONE

INTRODUCTION

WITH KEY FINDINGS

Dennis D. Murphy



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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*

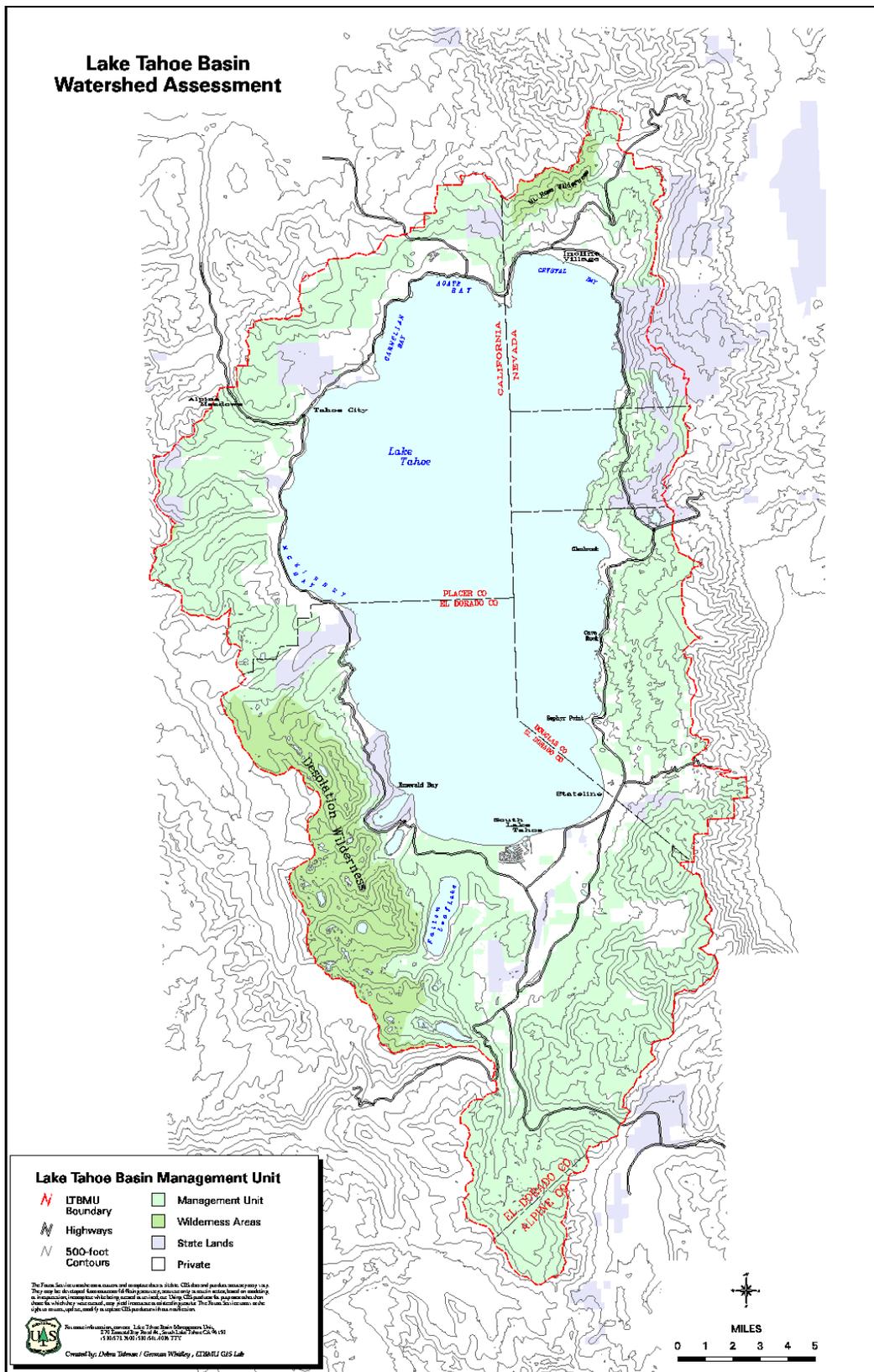


Figure 1-1—The Lake Tahoe basin and watershed boundary.

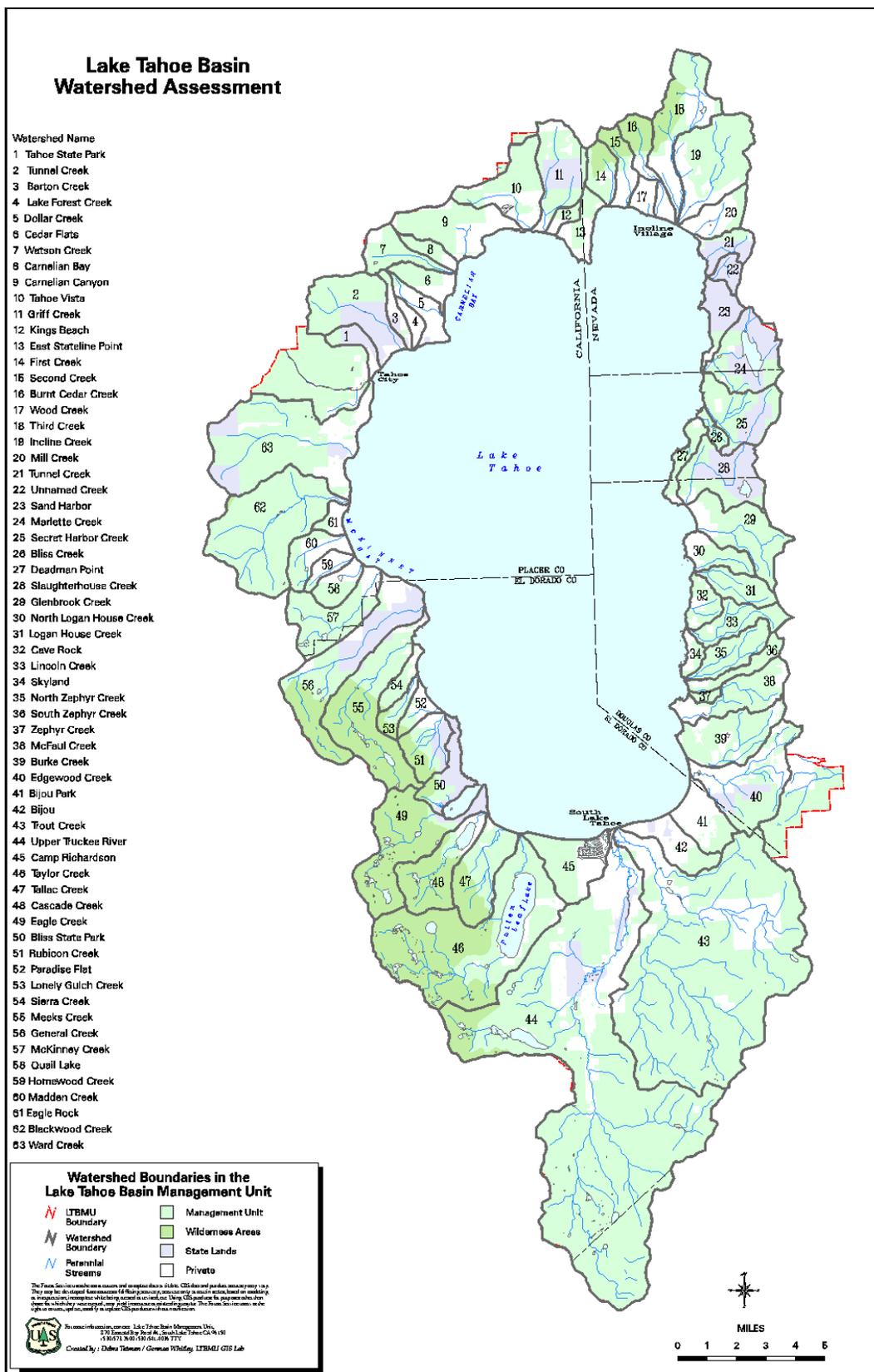


Figure 1-2—Lake Tahoe tributaries.

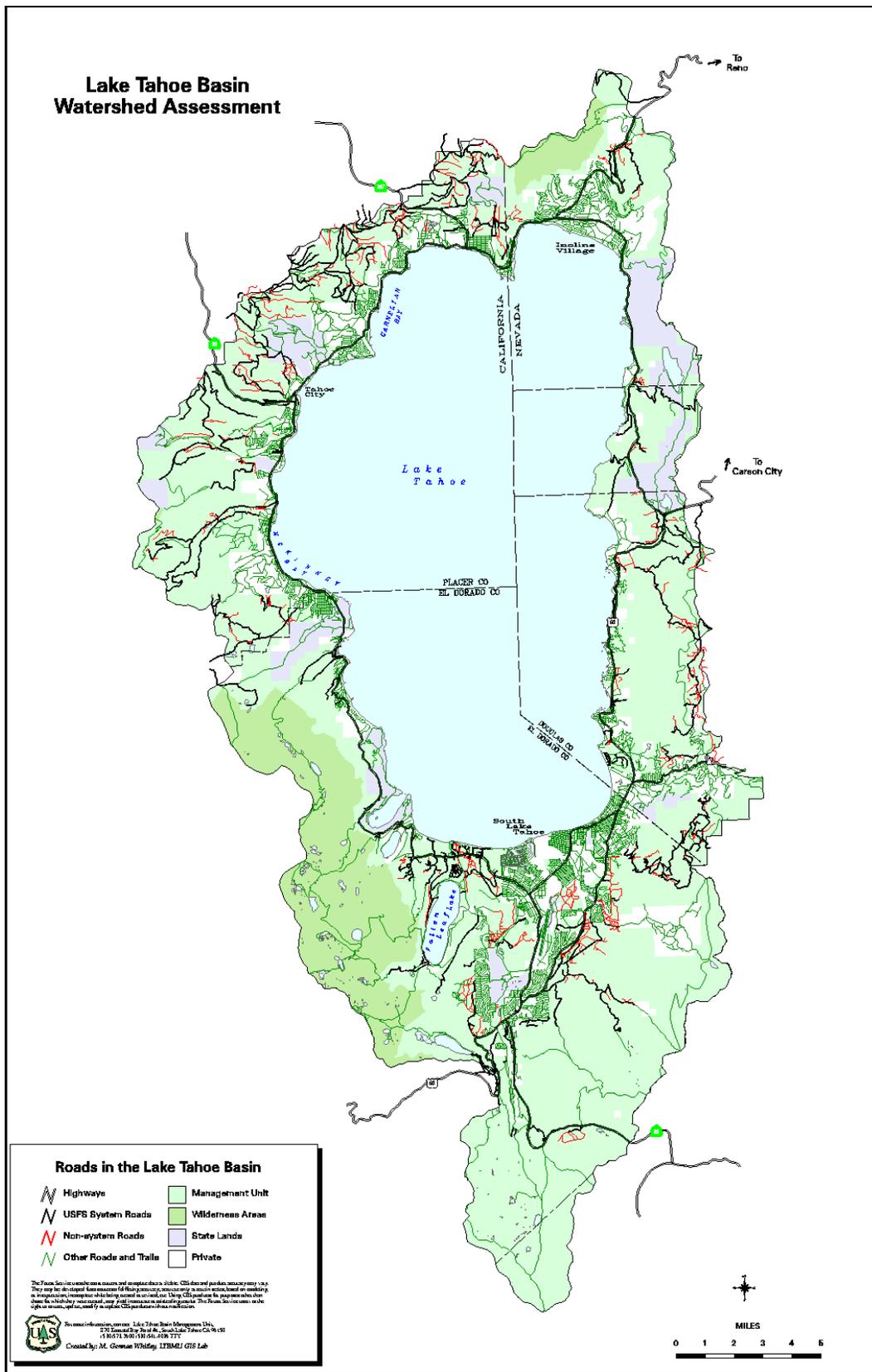


Figure 1-3—Lake Tahoe land ownerships and transportation network.

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 basin-wide 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 informa-

tion 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 eutrophication, 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 eutrophication 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, em-

phasis 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 ($\mu\text{g/L}$) in General Creek to 220 $\mu\text{g/L}$ 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 $\mu\text{g/L}$, consistent with the current California water quality objective of 15 $\mu\text{g/L}$.

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 sug-

gests 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 phosphorus 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 $0.006 (\pm 0.002) \text{ g cm}^{-2} \text{ y}^{-1}$. 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, *Diatomus* 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 Jeffrey 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 to the extent of water and rocky areas. Little or no fuels occur in 23 percent of the terrestrial portion. However, the nar-

row 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 than 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, non-working 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 coalitions

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.